Revisiting the Role of Architectural Science in Design & Practice

50th International Conference of the Architectural Science Association
7-9 December 2016, Adelaide, Australia

PROCEEDINGS

Edited by:
Jian Zuo
Lyrian Daniel
Veronica Soebarto
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In Design and Practice

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Foreword

The Architectural Science Association (ASA), formerly known as the Australian and New Zealand Architectural Science Association (ANZAScA), is an international organisation, the objective of which is to promote architectural science, theory and practice primarily in relation to teaching and research in institutions of higher education.

The 2016 ASA Conference marks a very important achievement – it is the 50th conference held by the Association. The first meeting took place in 1963 in Adelaide, initiated by the late Professor Henry (Jack) Cowan, Mr Derrick Kendrick and other architectural science academics. This first meeting led to the formation of the Association, enabling them to meet, discuss, and exchange information about their research and teaching regularly. Since then, nearly every year, the Association held an annual meeting and in the past 20 years this modest meeting has grown into much larger annual conference, drawing on not only architectural science academics but also researchers and practitioners outside tertiary educational institutions. The areas of research discussed during these conferences have also broadened as a reflection of the need to integrate architectural science with traditionally ‘outside’ areas of work in order to realise its impact on our built environments. The Association is excited to see that in the past 10 years the ASA Conferences have reflected this change, covering papers across architectural science as well as areas dealing with architectural (science) education, digital design, historic preservation of buildings, and recently, landscape architecture and urban design. The annual conferences also increasingly draw academics, researchers and practitioners from all continents, as well as Australia and New Zealand.

In celebrating the 50th Conference of ASA (ANZAScA) it is timely to ask, ‘Has the Association consistently promoted high quality architectural science, theory, research and practice, in architecture schools?’; ‘Does the work by our architecture graduates reflect the vision and mission of this association?'; and more importantly, ‘Do we now have better built environment, more responsible architecture, and more environmentally sustainable design, than we did 50 years ago?’

The theme of this 50th International Conference of Architectural Science Association (ASA 2016) is therefore:

“Fifty years later: Revisiting the role of architectural science in design and practice”

This publication presents 86 accepted papers presented at the Conference, hosted by the School of Architecture and Built Environment, The University of Adelaide, Adelaide, Australia, 7-9 December 2016. Details of the Conference can be found at: www.architecture.adelaide.edu.au/asa2016.
Each paper in these proceedings has undergone a rigorous peer review process. Following the call for abstracts in March 2016, a total of 170 abstracts were submitted for peer review. Each abstract was blind peer reviewed by two members of the International Scientific Committee, made up of 88 experts from 17 countries, across six continents. Of these, 158 abstracts were accepted for development into a full paper. Following this, 93 full papers were submitted, each of which was again blind peer reviewed by two to three members of the International Scientific Committee. Based on the reviewers’ recommendations, 86 papers were accepted for presentation at the conference, and presented in this publication.

On behalf of the Organising Committee, we would like to sincerely thank all of the people who have contributed to realising this Conference. Thank you to all the authors for working hard on the papers and presentations. We are very grateful to members of the International Scientific Committee for their rigorous reviews, without which we would not have been able to maintain and improve the quality of the papers. We thank our Bronze Sponsors: Sustainability House, Chartered Institute of Architectural Technologies - Australasia Centre, and dsquaredconsulting as well as our supporter, International Building Performance Simulation Association – Australasia Affiliate. We thank those who have worked behind the scenes from the Faculty of the Professions and the School of Architecture and Built Environment at The University of Adelaide, as well as colleagues from School of Art, Architecture and Design, The University of South Australia.

We hope that the papers presented in this publication truly reflect the theme of the Conference and the role that architectural science has played and will continue to play in the betterment of our built environment.

Veronica Soebarto, Jian Zuo, Lyrian Daniel
Adelaide 2016
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Rethinking architectural vocabulary. Comprehensive design resolution via integrated BIM platforms

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Abstract: This paper revisits established practices in architecture related to the instruments of production and addresses their profound influences upon the design outcome. Cartesian geometry has been used as a common reference to represent architectural elements, a view that has been applied into mainstream design software. The enduring ideologies assume the architectural product to be the result of aesthetic-driven operations supporting geometric regularity in defining elements’ shape and relative positioning. These approaches are compared to alternative ones described as form-finding, making extensive use of the computer’s power, often deviating from Cartesian basis, setting the ground for contemporary design research. In these cases, architectural elements are topological compounds undergoing generative operations. Architectural form is seen as an organic output emerging from interactions, shared functions, performed relationships and feedback loops, rather than one’s typically offering full aesthetic control. It is noted that processes related to data inputs, agent management, simulation and recursive testing generally applied to facilitate tectonic resolution via integrated BIM platforms may equally describe those of early design decisions. Such a prospect may set the framing to update existing BIM software, so that the phases of analysis, ideation and conceptualisation are linked with those related to further development, engineering, manufacturing and completion.

Keywords: Dynamic simulation; agent-based; BIM; form-finding.

1. Introduction. Cartesian vs. topological

The vocabulary of architecture includes terms such as slab, column, beam, wall, window, façade, roof, staircase, room and corridor, being some of the discrete elements appointed to resolve form, spatial articulation and structure. Such terms are virtually reflected onto any architectural edifice being analysed to its constituents. In fact, since early Twentieth century modernism, one of the main aspirations of the building industry in reforming its practices has been to fully embrace Cartesian geometry as a reference to rationalise and to resolve design and construction (Le Corbusier, 1923). Such an aim would be achieved by taking full advantage of the new materials and the fabrication techniques, as for example those related to reinforced concrete, steel frame and compound construction. Soon after their first introduction, these innovations were crystallized into architecture’s modern language,
likewise shaping a new attitude about the building seen as a fully industrialized product. Ideally, design in architecture would be conceived, organised, circumscribed and manufactured by a set of controlled, finite and repetitive operations, valued in terms of cost and return on investment (Migayrou, 2002).

Notwithstanding the obvious benefits of Cartesian geometry in setting modern architecture’s vocabulary as one being remarkably efficient in resolving design and construction, in several other instances the related approaches have not always been suitable in describing the plurality of effects produced by more dynamic approaches of formal exploration also seen as ones of less aesthetic control. Setting aside Cartesian references has often led employing ones of organic origin, in support of more seamless comprehension of the parts making the whole. In response to its perceived limitations, geometric regularity and the instruments associated to it have been replaced by topological logic capable of carrying through design’s dynamic nature especially during the early stages of data gathering, also schematic and formal exploration.

This paper first traces historically the above incongruity by also projecting it onto enduring assumptions about design, the instruments and the main references in support of aesthetic-driven processes particularly those associated with Cartesian logic; then, it examines current versions of BIM software with regards to Cartesian definitions of architectural elements, in order to point out that along with the apparent facilitations and efficiencies they have provided in managing a project, meanwhile unquestioned adaptations of Cartesianism have averted from dynamic engaging of influences that would affect form in more challenging, also direct therefore more original tropes. This paper proposes that future BIM software may support extended data inputs since the early stages of the design process, setting a non-Cartesian basis to define architectural form as a topological continuum.

2. The modern paradigm. Cartesian geometry making machines for living

Modern architecture has widely adopted Cartesian geometry as a theme of great validity and respect borrowed from Renaissance. A key figure to modernism’s related endeavours has been Le Corbusier, whose schemes known as Dom-ino and Architecture’s Five Points presented in 1914 and 1925, reinforced a connecting thread between the engineering ideology, the emerging modes of production and construction, the new materials and the new aesthetics. These studies were perhaps ones of the most succinct propositions in representing the modern style as one being true and consistent, mainly due to the fact that it echoed no apparent resemblance with anything else ever built before, despite the fact that it was profoundly linked to geometric rules and tools for making drawings inherited from the Western tradition. Several attempts on similar themes were developed often being more complete and exhaustingly analytical (Mumford, 1999), such as The Minimum Dwelling in 1927 and Ernst Neufert’s seminal book Architect’s Data in 1936. In view of society’s changing principles, modern architecture was identified as a system in which “geometrism” and measure constituted the autonomous and univalent domain of a new dogma (Migayrou, 2002). Elements setting the architectural vocabulary were effectively reduced to pure volumetric prisms. Cartesian geometry was resourced in representing the rational style, in alignment with modernism’s primary objective to describe the architectural edifice and the house being its primary symbol as an assembly of repetitive also geometrically standardised parts making better “machines for living” (Le Corbusier, 1923) (Figure 1).
However, the desire towards extended geometric rationalization would not necessarily act contrary to adjusting the design to individual needs. As Migayrou (2002) comments, the use of standardised elements and identical materials in different constructions would authorise a fortunate architectonic combination of maximum standardization with maximum variety. Such a task could be actualised by a view of the edifice made of same often prefabricated pieces, also by the idea of the open space and mainly the plan that would be adapted to the particularities of each case. Both of these directions have sprung from the presupposition of limitless “geometrising.” By combining repetition with openness, geometric resolution would serve as a way to maximise the economics of design and construction without major compromises on modernism’s socially sensitive principles translated to higher living standards for the masses, manifested in numerous propositions about the modern house. It is therefore important to address Cartesian geometry as a critical and practical means employed in order to reach and to resolve the total set of new often contradictory aims associated with modernism’s founding proclamations.
3. The organic as an alternative scheme

Besides modernism’s preference to Cartesian geometry, there is considerable body of nineteenth century work enabled by the same new-at-that-time technologies in design and production, seeking geometric diversification through dynamic methods of formal exploration. An example may be found in the studies of Eugène Emmanuel Viollet-le-Duc. In explaining his work, Viollet-le-Duc turned to models of physiology also with reference to Gothic architecture, and so he presented the organic relationships and the shared functions of the parts as connected anatomical organs, as opposed to mere results of pure geometric juxtaposition (Vinegar, 1998). Viollet-le-Duc favoured selective techniques of representation that would disclose information about the design only partially and in subjective manners, such as analytical separation and perspective applied in medical and plant anatomy, rather than abstract geometric shapes projected orthogonally onto drawings such as plans, elevations and sections (Vinegar, 1998). For him, graphic representation in physiological models was a critical process rather than one being neutral, specifically with regards to cutting, separating, and exposing of organs for display at the expense of others, even though the results of such actions would still be accepted as scientific evidence. Viollet-le-Duc favoured a dialectical style, both aesthetic and structural, by which to subjugate the forces of nature and those of culture (Bressani, 1989). By inscribing the anatomical metaphor onto architecture, he filtered the viewer’s conception sponsoring more organic interpretation about the total and its parts shaped by their influences, rather than being autonomous. His “anatomical” approach sought ways to transcribe those forces onto form. The geometries emerging from these interactions set adaptive modes of association as opposed to rigid rules about repetition, producing an architectural language that is intrinsically conditioned by processes of topological mutation, resonating operations that are essentially organic (Figure 2).

Figure 2: Eugène Emmanuel Viollet-le-Duc, Concert Hall, 1864.
Similar resolutions were offered alongside modernism’s regulatory scope as alternative pathways to better represent life’s lively patterns not carried out efficiently by geometric shape primitives. To this direction, Hugo Häring preferred organic interpretations that were also compatible with the semantics of modernism such as order, efficiency, economy and performance; however, within the framing he proposed, such terms were unrestricted to modern fixations about form such as functional purity and simplification. In effect, in 1924 Häring envisions the edifice as an organic structure that evolves along with the activities and the people it serves, with design being an approximation of biological processes, as opposed to ones of Cartesian aesthetics. Rather than understanding the building as an optimised solution with reference to a frozen instance in space and time, Häring describes it as a singular event emerging out of the particularities of place, program, material, and culture. The building is not a passive container being indifferent to its content, but an active response to the individuality of various conditions. Architecture sets the standards of the desired conditions with regards to its various meanings being interested in dynamic patterns of change. In 1932, Häring underpins architecture’s further relevance to organic structures, “bred” out of “form arising out of work performance,” looked upon as “man’s second skin,” hence as a body organ. Series of external and internal factors as “functions” that extended that notion’s significance compared to modernism’s dedicated view on functionalism would indicate a degree of fluctuation proposed towards the conception of the building also establishing its dynamic connections with the geo-political site. A great variety of palpable data would actively be involved in producing variable outputs about the total form and its parts reinforcing dynamic integration with the setting, load-sharing and role-distribution. A closer look at architectural studies developed during interwar and the post-war era reveals a recurring appeal towards biological and organic themes, most importantly to the transformative operations due to systemic interactions (Poole & Shvartzberg, 2015). A shift in thinking may be noted, specifically from a focus on form-making to the processes of form-finding, the dynamic constitutive systems and ecologies and also to techniques, building blocks and modules as modes of diversity and evolution (Doxiadis, 1963; Pyla 2002; Mertins, 2009; Aish, 2013) (Figure 3). This shift has caused revisiting the technologies and the phases of production related to the building industry in bio-logistic terms, across scales and across media.

Figure 3: Bio-systemic definitions of architecture and urban settlements (Doxiadis, 1963).
Since modernism, architecture’s main aims have often departed from its designated focus. Topological geometry has been offered as an alternative way to perceive, to calculate, to refine and eventually to construct living entities as integrated compounds of dynamically linked parts. Simple geometric routines may not suffice to describe life’s complex, changing and unexpected experiences, often being without precedent. Although existing typologies generally offer reliable solutions to known problems, they still acknowledge a limited sample of users, being also attached to a specific moment; even more, their function as absolute references to design resolution is virtually incompatible with an equal need for extended flexibility. In effect, dynamic models may be more suitable to simulate the intertwining of activities, their fluctuation in space and time and their potential influences in design in organic terms. Related observations have caused to redefine architectural elements as ones charged by their interaction with contextual factors. In 1984, Paul Virilio, extending the studies he performed together with Claude Parent in the 1960s on the “oblique function” (Parent, 1996), proposed to update the notion of the urban wall, which has given way to an infinity of openings and ruptured enclosures. Its surface-boundary has become an osmotic membrane and a common interface, adapting to facilitate, to impede even to participate in the exchanges between two worlds. Later definitions have proposed the wall as a dynamic element that interacts with the activities of the space it defines, even in real-time. With their built prototype for the project Aegis Hyposurface, the group deCOi (Goulthorpe, Burry & Dunlop, 2001) have set the wall as an elastic structure that holds information about the activities performed around it. Sensors capture the sound and send it to a highly performative control system that recodifies it into dynamic forms. The constructed space has become the result of a nonstop multiplying of effects, affecting – and affected by – their environment, not adequately described by a finite composition. The ongoing research may be seen as the continuation of modernism’s sporadic attempts, this time with the assistance of great computational power. Advanced techniques for modelling and dynamic simulation have been developed and refined testing the dynamic mixtures that occur as the parts interact with the associative agents of design (Garber, 2009). These studies vary significantly in their references and aims, but they all present a common interest in themes such as continuity, mutation, amplified responsiveness and augmented interrelation of “soft” elements making “smooth” totals perceived as aberrations of the norm (Cache, 1995) produced through recursive processes (Lynn, 1993; Spuybroek, 2008) described in relation to evolutionary ones found in biology (Frazer, 1995).

Evolution has become a question of updating a biological structure (Kirschner, 2009) with reference to rules interacting and influenced by external and internal constraints. Simple geometric shapes may only act as malleable starting points, rather than ones design must return to. The emerging models incorporate feedback and employ techniques that are inherently destabilizing. Idealised typologies have given way to topological idioms (Lynn, 1993). Seen as a topological entity, the type acts like a dynamic system acquiring more intelligence as it responds to increasingly complex inputs (Zavoleas, 2016). Moreover, customised manufacturing also under fully digitised therefore reliable procedures invokes questioning the necessity of geometric uniformity for fabrication. Full-scale 3D printing even of whole buildings, combined with research on compound materials and dynamic structures has set the basis for a complete re-evaluation of construction, forcing to rethink whether analysis of an architectural edifice to its parts will soon be relevant, or if these may be conceived, designed and resolved by agent-based simulations as one seamless body (Figure 4). Computers are an asset to such attempts, no longer limited to represent instantaneous ideas, or to carry out age-old tasks, offering instead their potential for dynamic interactivity between data, the designer and the user (Rahim, 2009). Optimization may no longer end when geometric harmony is achieved, but when complexity has reached the highest level of collective sophistication in meeting the design goals.
Rethinking architectural vocabulary. Comprehensive design resolution via integrated BIM platforms

4. Revolutionising BIM

Developing software has focused in meeting the above goals, specifically in supporting extended levels of interaction among data and users involved since the beginning of a project. Traditional methods of design, refinement and delivery have been linear, built upon clear specialisations, mostly isolated phases and autonomous technologies; these have tended to frame the time reserved for design and to restrict the impact of the architect in later decisions (Garber, 2014), potentially having a negative impact on the project’s delivery. An answer to this may be software that promotes participatory modes of production such as BIM, whose idea is to offer extended workflow management with regards to collaboration and information-sharing also across various stakeholders. BIM aims towards integrated project management and to elements connected with real-time databases and shared models, wherein the design team can iterate and test the design prior to on-site execution. It follows that BIM refers to how decisions about design and construction are dynamically connected and affected by various agents; an idea that is only partially carried through by the existing platforms.

In consequence, BIM is challenged by an all-encompassing idea about production, which, apart from tectonic resolution, may also handle information, choices and assessments during all phases of design. Future BIM may contain extended data inputs such as constraints and references about the project and its parts from the beginning of the process, conveying a more organic character to the result. New tools and virtual techniques may hold influences together also with regards to formal exploration. Having dealt with different sorts of input since the early stages, it will be possible to seamlessly unite the components into compounds being linked back to data. This process may be supported by advanced simulation tools translating components and compounds virtually to actual buildings and supervising construction (Garber, 2014). As such, it will be possible to completely merge the phases of creation and management about a project including generative actions, simulation of influences and behaviors among the design agents, calculations related to construction and material and final fabrication via CNC (Computer, Numerically Controlled) operations. Updates similar to those outlined above will set the new workflow supported by shared platforms and across-specialisation information exchange (Zavoleas, 2008). Future design tools will allow extended parametric control of databases also with versatile content, accessed mutually and refined dynamically during the design process, by also taking full advantage of the graphics, the memory and the storage capacity of the computer. The digital file will hold encoded data in the form of inherently built intelligence, having become a witness of a more collaborative approach among various scales, phases and expertise (van Berkel & Bos, 1999). The formed relationships across design, engineering and construction may eventually be crystallized in novel organisations, updated efficiencies and a new course for practice (Lynn & Leach, 2004; Garber, 2014).
Apparently, there is greater potential for optimisation in the earlier stages of the design process, compared to the current standards set by existing BIM software. In fact, design has often employed dynamic simulation software such as Maya Autodesk and Rhinoceros with its plug-ins initially developed for scopes outside architecture to manage advanced parametric entries. The practical difference between these tools and current BIM is that an instance on the screen is described and codified as a topological entity with its inner structure and dynamic properties, as opposed to a Cartesian prism and a set of point coordinates being significantly rigid and so the design is empowered with far greater possibilities for formal manipulation due to increased flexibility. Furthermore, these tools provide with capabilities for simulating effects of forces, fields and other inputs even in real time, in support of design’s early phases in dynamic manners. Related operations have been used in design research to fill the aforementioned gap since the early 1990s, and so it is expected that similar ones will eventually be incorporated into mainstream BIM platforms. As such, BIM will allow for new ways of integration between design theory and research with design practice, which is still underexplored. It will embrace design’s multi-faceted open-ended character, by extending optimisation and customisation with regards to multiple effects, as opposed to latent management capabilities.

5. Conclusion. Holistic design via BIM

So far, this paper has drawn upon earlier adaptations of organic references around the modern era, reinforcing topological definitions about form. The related studies were often overshadowed by modernism’s practice; nevertheless they have heralded more recent approaches that employ dynamic production modes to define form as a continuum. These modes differ radically in their scope, assuming design to be the result of interaction of various agents with form’s dynamic properties, rather than an aesthetic-driven process. It is claimed that such differences portray two different ideologies about design, invested in the tools and their operational performance during the production process.

On the one hand, the traditional one focuses on form’s descriptive properties as the effect of the geometric relationships among the elements and the whole. This approach is supported by the common instruments for drawing such as the ruler, the orthogonal triangle and the T-square. These instruments serve orthogonal layouts, wherein an element and its relative positioning are determined according to Cartesian references, such as straight lines, parallel and perpendicular ones. It is worth noting that the same logic has been transferred from the analogue drawing board to the toolbars and the common operations of the first generation of CAD and BIM software (Figure 5). The main idea is that the elements are created as point-based Cartesian shapes and prisms such as planes, cylinders, cubes and spheres, also that the drawing expresses order in relating them via rectilinear systems (grids, orthogonal snaps); however, this system is limited in handling large point clouds and complex geometries.

On the other hand, design is approached by generative also performative actions since the early phases of production. It is suggested that such a prospect will inform the next generation of CAD and BIM software. In analogy to dynamic simulation and parametric input software currently employed to resolve advanced design tasks, the proposed tools will operate beyond descriptive modes of geometric representation. Form will be addressed as an open system and a dynamic effect, translated to malleable formations as densifications of points whose coordinates are defined and updated via codified expressions and parametric values. Design will be a totality made possible due to the fact that data of all phases will be included and linked together in the digital file. In effect, form will not conform to aesthetic rules based on Cartesian geometry, but instead it will be topological; its intensive properties will reflect the organic relationships of agents about the forces, the fields of action, the assigned
behaviours, the appointed logic, the occurring schemes and the strategies of resolution. Recursive feedback of form-finding will result in non-standard transformations, increasingly complex geometries and variable outputs, in so doing establishing a common thread that connects all stages and decisions related to the production stream.

Figure 5: Analogue instruments used to geometrically regulate the drawing, compared to mainstream CAD tools defining architectural components as Cartesian primitives organised by grid layouts.

While examining architecture’s modes of production, this paper has compared established notions about architectural practice currently represented into mainstream design software. Several analogue and digital approaches of dynamic exploration alternative to those based on descriptive modes and Cartesian references have been revisited, in an attempt to point at the profound influences of the production tools and techniques upon the result. In responding to the perceived limitations of aesthetic-driven operations in supporting design’s dynamic character especially during the early phases associated with creativity in architecture, form is proposed as the outcome of real-time data inputs and agent-based simulations producing topological compounds that are impossible to break apart. In effect, architectural components’ shape and other properties are entirely directed by the shared influences and functions they perform with regards to the design problem whose complexity is invested onto the final form. It is hoped that such an aim presents an alternative direction to update common BIM platforms, so that they represent more holistic views about design.

References


Visual mapping of the Integral Sustainable Design approach

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Abstract: This paper aims to advance the understanding of Integral Sustainable Design (ISD) as an approach for the environmental assessment of buildings. The potential of ISD is the integration of qualitative as well as quantitative perspectives on a subject. ISD offers a bottom up approach to environmental assessment, whereas most common building energy rating schemes follow a top down approach. This paper explores how two and three-dimensional visual mapping can be used to integrate the qualitative and quantitative assessments of buildings. It is suggested that the ISD approach is suitable for the architectural design process even in the early design stage. It also enables the designer to identify and focus on synergies between the design intention and environmental requirements rather than their differences.

Keywords: Integral Sustainable Design, mapping, environmental assessment, environmental design

1. Introduction

There is now widespread recognition that the current generation of efficient or green buildings is insufficient (e.g. Reed, 2007; Hes and du Plessis, 2015). The underlying philosophy of these buildings is that we should conserve as many non-renewable resources as possible, minimize greenhouse gas emissions and if possible minimize impacts on biodiversity, water use etc. As our environmental crises continue to worsen, it has become clear that much more is required from our built environment. An alternative paradigm must therefore be adopted. This new way of thinking has emerged in various forms under different banners, e.g. Positive Development, biophillic or regenerative design. Collectively, these new ways of thinking embrace the concept of regenerative sustainability, which dictates that the built environment must do more than conserve; it must ‘put back’ i.e. restore nature. Only in this way, can the damage done by past behaviour be ameliorated.

New ways/tools of informing and guiding designers have emerged such as REGEN (Svec et al. 2012) and LENSES (undated). The emphasis of these tools is not on ‘box-ticking’, rather it is guiding outcomes through collective decision making, inclusive of all - users, non-users, builders, designers alike.. Non-technical issues such as the feelings of users and locals about a building are included. Broad
environment impacts are also considered, not just those as interpreted in current rating schemes. Good guidance for designers, those with ultimate responsibility for the building design, is critical. Overly complex analysis tools will impede the adoption of regenerative buildings. For example, the two tools cited above require much data and skilled operators. This paper proposes ways of visualizing and guiding designers who adopt another proposed method of designing a new generation of buildings. That method is Integrated Sustainable Design (ISD). The paper begins with an overview of ISD and then describes how the results of using the tool can be mapped and visualized in a three dimensional way.

2. Integral Sustainable Design

ISD is based on Integral Theory, the philosophical approach proposed by the American philosopher, Ken Wilber (2000). It has been further developed by Zimmermann (2005) for application with ecological questions and DeKay (2011) has made it available for the architectural discipline with his book defining the concept of Integral Sustainable Design (ISD). It has been embraced as a useful framework applicable to a wide range of fields, ranging from ecology (du Plessis and Brandon, 2014) to business (Paulson, 2002, cited in Esbjorn-Hargens (2005). DeKay and Bennett (2011) adapted this for the approach of Integral Sustainable Design (ISD) which seeks to overcome the ‘art vs science’, ‘design vs technology’ and ‘analysis vs creativity’ thinking that has dominated the design disciplines for the past decades. Although it acknowledges the intention and worthiness of environmental rating schemes such as LEED, it questions the objective-only approach and gives no credit for experiences of beauty and the relationship people have with nature. ISD suggests that four simultaneous perspectives on a problem can be represented by quadrants each of which takes a different view of the problem. The ‘experiences’ quadrant (upper left) focuses on the individual human experiences, while the ‘behaviours’ quadrant (upper right) looks at the environmental performance. The ‘cultures’ perspective (lower left) focuses on collective interpretation of meaning, symbolism and worldviews on nature, and finally the ‘systems’ quadrant (lower right) investigates the response and interaction with context and systems(Figure 1).
Although developed as a philosophical approach, for architects ISD can act as a reminder of the different perspectives that a sustainable building should address. Commonly environmental issues are approached with top down methods such as building energy rating schemes, which break down a greenhouse gas emission goal and other environmental goals into separate performance criteria and sub criteria that are assessed quantitatively. While this approach has been successful for quantitative assessment parameters, it does not accommodate qualitative criteria very well. In order to overcome this limitation, a bottom up approach to identify parameters and methodologies for holistic assessment of qualitative as well as quantitative parameters is necessary. In contrast to the top down approach, the bottom up approach focuses on the links and synergies between individual parameters rather than their differences and thus offers a different perspective to address the future requirements of the built environment. In contrast to rating schemes, ISD does not prescribe a set of assessment criteria, instead its intention is to identify and establish parameters of importance in the context of a specific project, thus potentially leading to a more-project specific rather than ‘one size fits all’ type of solution.

### 3. Responsibility rather than rating

ISD is an approach to a more comprehensive understanding of sustainable design. It is based on the underlying assumption of Integral Theory that there are always multiple perspectives from which a given question or topic can be investigated. With regards to sustainable buildings, a designer’s view or definition of nature is likely to shape the thinking as well as the resulting design. ISD is based on four quadrants, each introducing a different perspective, and four levels of understanding for each quadrant. ISD suggests different definitions of nature for each of the four levels. On the traditional level the understanding of nature is based on the concept of nature being ‘managed’. On the modern level, the understanding is to ‘use’ nature, e.g. in terms of resources. Postmodern thinking is centred around the idea of ‘saving’ nature, whereas the integral viewpoint suggests that nature and culture are united (DeKay 2011). Designing from one viewpoint or another is likely to lead to different proposals of what sustainable architecture would look like. And vice versa, a design is likely to communicate the underlying viewpoint on nature that the designer had. Each viewpoint predefines certain choices as more or less ethical and shifts particular design approaches or technologies in or out of focus (Table 1). For example, on a traditional level, the building manages nature or natural forces as experienced by the senses. On a modern level building is a response to an intellectual understanding of how natural resources can be used efficiently for the benefit of the building. On a postmodern level nature is understood as a complex ecosystem, with the building attempting minimum interference. At an integral level, the building becomes an integral and responsive part of a living ecological system.

<table>
<thead>
<tr>
<th>Level</th>
<th>Experiences (UL)</th>
<th>Cultures (LL)</th>
<th>Behaviours (UR)</th>
<th>Systems (LR)</th>
</tr>
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<tbody>
<tr>
<td>Traditional</td>
<td>Sensory mediation</td>
<td>Nature managed</td>
<td>Embedded practices</td>
<td>Tacit systems</td>
</tr>
<tr>
<td>Modern</td>
<td>Intellectual mediation</td>
<td>Nature used</td>
<td>Building science</td>
<td>Logical systems</td>
</tr>
<tr>
<td>Postmodern</td>
<td>Contextual mediation</td>
<td>Nature saved</td>
<td>Cyclic analogues</td>
<td>Complex systems</td>
</tr>
<tr>
<td>Integral</td>
<td>Self mediation</td>
<td>Nature united</td>
<td>Responsive structures</td>
<td>Living systems</td>
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</table>
This illustrates a fundamental difference between the framework of ISD and common building energy rating schemes. A rating scheme is defined by a set of assessment criteria which through the nature of these criteria communicate the underlying perspective on nature. The approach of ISD is the exact opposite, in that the framework first raises awareness that there is the possibility of different perspectives on nature, and then rather than prescribing a set of criteria, it raises the awareness of designers to make responsible choices depending on the individual challenges they are facing. Where a rating scheme, by offering criteria to be “ticked off”, to a certain degree takes responsibility off the designer, ISD does the opposite by emphasizing the designer’s responsibility. This responsibility proposed by ISD can be empowering for a designer as the pool of potential choices and methodologies is not limited to those on a list of criteria. At the same time it can be challenging, as responsible choices require broad knowledge and are likely to be very project specific.

In this sense however, ISD is very well matched to an architectural design process. A design process starts with a brief and a site, and then it is the responsibility of the architect to synthesize various requirements into a design proposal. This involves defining what is important for a particular project and to deal with conflicting requirements. There is no universally prescribed way how to design a building and it is largely a result of the design intentions of the architect, which explains the diversity of proposals in architectural competitions. Similar to that ISD can be interpreted in a way where a ‘sustainable’ building can have many different faces, depending on the perspective and the choices made by the designer.

4. ISD as a mapping tool – a case study

4.1. Mapping to analyse a building (2D)

Figure 2 illustrates an attempt to visually map the findings from a case study ISD analysis of the Deakin University Waterfront Campus Building in Geelong, Victoria, Australia across the four quadrants of IT. The analysis has been performed as part of a previous pilot project (Roetzel et al 2015), and due to the small scale of the study it was focused on parameters that were readily available rather than being a result of comprehensive research. The intention of the mapping was to highlight interconnections between parameters and therefore only parameters with at least one link to another parameter have been included.

As can be seen in Figure 2, the 2D map shows more parameters in the right hand side quadrants (UR performance and LR context). This can be interpreted in two ways. Firstly it is possible that the researchers paid more attention to the right hand side quadrants, and secondly it can indicate that the design of the building has a stronger emphasize on the right, rather than the left hand side quadrants. The arrows in the map show how parameters within and across quadrants influence each other, and it can be assumed that the parameters with mostly outgoing arrows are causes whereas the parameters with mostly incoming arrows are effects or responses. In the case of the Waterfront Campus building, the most influential parameter (four connections) is the geographic location in Geelong. The location

- impacts on individual travel modes to the campus due to limited public transport in Geelong as opposed to Melbourne
- provides beautiful views across Corio Bay
- predefines brown coal as a primary energy source in the state of Victoria, Australia
- determines the temperate climate zone
The reuse of an old woolstore for a university building is the second most influential parameter as derived from this map. It:

- makes for a well-known building, as it has been around for a long time and is connected to the city’s past importance in wool trading
- predefined survey responses of people in Geelong saying that the building does not look like a university
- reduces the embodied energy of the campus building due to adaptive reuse rather than new construction

The views across Corio Bay influence two other parameters, visual comfort of occupants enjoying the view and the windows facing the views (and the northern sun) have an indirect influence on thermal comfort.

The parameter most influenced by others, i.e. the one with the largest number of incoming arrows is greenhouse gas emissions. This is due to the high amount of individual car travel and the predominant primary energy source with a rather high emission conversion factor being brown coal in Victoria.

While further testing with different buildings and a larger number of parameters would be helpful, it can be concluded that the parameters which have the largest number of outgoing as well as incoming arrows in the map are parameters that require particular attention of the designer, as they may provide...
the strongest potential for responsible choices. E.g. in the state with the worst CO2 conversion factor for electricity in Australia, measures that lower CO2 emissions will be relatively more influential than in other states.

4.2. Mapping to compare different buildings (3D)

ISD is commonly visualised in a two-dimensional diagram as illustrated in Figure 3. However DeKay discusses the four quadrants (experiences, behaviours, cultures and systems) in the context of the four levels, traditional, modern, postmodern and integral. These levels can be thought of as an additional third dimension in the visualisation of ISD.

![Figure 3: Two-dimensional visualisation of ISD](image)

An attempt to visualise ISD in three dimensions is illustrated in Figure 4. The limitation of this visualisation however is, that the image depicts the transitions between levels as clear boundaries, which does not accurately reflect the ISD approach. The levels are roughly sequential in the sense that on a global scale post modernism got broad attention after modernism. However ISD argues, that each new level did not make the previous one superfluous, rather it added an additional perspective, and that all the four levels are available and valid today depending on the specific challenge a designer is facing. The attempt to draw boundaries with one line clearly defining in and out is therefore limiting, but pursued in Figure 4 for the sake of visual simplification.

The advantage of this three dimensional representation is that it is a simplified way of mapping the intentions or focus area of a project as illustrated in Figure 5. For example, a community centre (A) might have a strong emphasize on the lower left quadrant (cultures), a project that blurs the boundaries between built form and landscape (B) might have a strong emphasize on the lower right quadrant, a hammam (C) could be expected to have a focus on individual experiences, whereas a building housing a nuclear reactor (D) would be strongly represented in the UR quadrant. This very simplistic method of visualisation enables a quick comparison between projects.
A question that arises in this context is whether it is feasible or desirable for all quadrants to be at equal levels for all types of projects. Figure 5 is based on the assumption that by their very nature, different building types might have a bias in one or another quadrant. The purpose of a hammam, for example, is to provide individuals with a sensory experience of or protection from natural forces (upper left quadrant, traditional level) and without doing that it would defeat its purpose. On the other hand, the building housing a nuclear reactor could lead to a disaster if the performance of the envelope in containing radiation and preventing pollution of the surrounding natural environment was not the absolute priority (upper right quadrant). This is not to say that the other quadrants are not also significant for these buildings, but the nature of the project seems to suggest an order of priority among the quadrants. This is in opposition to Buchanan’s (2012) interpretation of Integral Theory applied to architecture, suggesting an even balance between quadrants as a design goal. His discussion however is focused on less extreme building types such as houses and public buildings where an even balance might be more realistic.
For a designer this simplified way of visualising the quadrants and levels can be useful in two ways. At the start of the design process it can help to establish:

- what are the project’s desired relationships with nature as viewed from the perspective of the four quadrants
- at what level of design response would be appropriate

At later stages of the design process the intentions defined at the start can serve as a benchmark for the assessment of the success of the project. The quadrants and levels can also act as a reminder for perspectives that might offer potentials for improvement when further explored.

4.3. The difficulty to with quadrant boundaries

One major finding from our previous research on this topic is the interconnectedness of the four quadrants. As pointed out in the lessons learnt from a case study project (Roetzel et al 2015) for many aspects of a building it is not straightforward to associate them with one quadrant or another as from an integral perspectives several quadrants would be related. E.g. a photovoltaic system will contribute to the energy performance of the building, a parameter commonly associated with the upper right quadrant. However the output is also determined by the climatic context, which is a parameter related to the lower right quadrant. In several cases it was difficult to draw clear boundaries between quadrants. This implies a challenge when visualising the framework of ISD. On the other hand the parameters which are “difficult to file into one single quadrant” are the ones with the most interconnections with parameters in other quadrants. As identified in the 2D mapping exercise above (building analysis) it is these parameters however, which seem to have the largest potential for synergies, which means they may be key parameters in environmentally responsible decision making.

It could be hypothesized that a building’s success in environmental terms could be established by the degree of interconnections between quadrants, and the difficulty to relate particular aspects of a building to only one quadrant.

5. Conclusions

Integral Sustainable Design as described by DeKay is a theoretical approach to environmentally responsible architecture. This paper reflects on an initial pilot study conducted by the authors, aiming to explore how this theoretical approach can be made available to architectural practice. Many lessons still remain to be learnt concerning the potentials and limitations of ISD as an assessment approach. This paper reflects the current understanding by the authors as part of an ongoing research process.

Lessons learnt so far:

- ISD highlights the importance of integrating qualitative as well as quantitative perspectives. As such it is more closely aligned with the discipline of architecture at the intersection of art and science, compared to quantitative-only rating schemes.
- ISD has potential for better integration with the architectural design process compared to common building energy rating schemes. Rating schemes often require rather detailed information for an assessment to be performed, and are therefore assessed in later stages of a design process when this information is available. ISD does not predefine a particular level of detail of analysis and can therefore be useful already in early design stages.
- when used as a mapping tool, ISD can act as a reminder for a holistic design approach acknowledging multiple perspectives on a project and the responsibilities that are associated with each perspective. It can also help to identify synergies between different perspectives, i.e. where the architectural design intentions go hand in hand with environmental responsibility.

Lessons still to be learned:
- further research is needed to establish how ISD can be applied at different scales of a project. The investigated pilot project focused on a room or building scale, but the potential for ISD to be used at a larger scale (urban, regional) would be worth further exploration.
- further research is required to investigate the case study project not only from the perspective of the four quadrants but also considering the four levels.
- further research into the synergies between the approach of ISD and the architectural design process can advance the understanding how ISD can be made useful for architectural practice and what potentials and challenges are.

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References


Architecture, physical activity and a capability evaluative framework: satisfaction is not enough

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Abstract: Despite recognition that building design can contribute to human health by facilitating increased incidental physical activity, knowledge of how building design can enable this is underdeveloped. Further, there is evidence that design features introduced to support routine physical activity and improve occupant satisfaction may not necessarily lead to increases in actual physical activity. Evaluative frameworks encompassing a range of individual, organisational and built environment factors that contribute to shaping occupant behaviour may provide insight into how buildings can support greater levels of routine physical activity. This paper argues that capability theory can inform our understandings of the dynamic interrelationship between building design and building use. In this paper we describe our approach to developing a framework for capabilities-based evaluation of buildings and building occupant physical activity. Based on a capability perspective we consider the intersection of building ‘domains’ and ‘functionings’ that influence occupant physical activity; and question how such evaluations could account for a range of occupants. The research is of relevance to those engaged in the production of architectural environments and evaluation tools that support physical activity—inclusive of building designers, procurers, managers and occupants.

Keywords: Building evaluation; mobility; audits; capability approach.

1. Introduction

There is growing recognition that building design has the potential to contribute to human health through facilitating increases in incidental physical activity. The health risks of physical inactivity are well understood, and have even been described as a health hazard similar to that of smoking and obesity (Lee et al 2012). However, research on this issue from a built environment perspective lags behind that from medical, public health, sports and exercise sciences—especially for indoor environments (Marmot & Ucci 2015; Zimring et al 2005). We know ‘behaviour settings’ and their influence on physical activity and sedentary choices have been articulated (Sparling et al 2000) and that both the social and physical contexts of places have an influence over people’s health behaviours (Baum et al 2009; King et al 2002). Yet only recently has the impact of individual, interpersonal, organizational and physical environment aspects on physical activity and sedentary behaviour begun to gain attention in architectural research.
Architecture has the opportunity to provide better health and wellbeing outcomes for building occupants by increasing opportunities for routine physical activity within buildings. Indeed many architecture and health researchers are working in this space.

Effective evaluation of buildings for how they support physical activity is one area than can contribute knowledge about what constitutes healthy building environments. In the field of building performance evaluation research Leaman, Stevenson and Bordass (2009) argue for the need to move beyond evaluating buildings for only efficiency and productivity. In addition, they call for evaluation that captures a range of other qualities that may be difficult to fit into quantitative measures. In particular, we have a thin understanding of the interrelationship of individual, organisational and built environment factors that contribute to shaping building occupants’ behaviour. Further, there is evidence that existing evaluative frameworks that measure occupant satisfaction with the perceived health of their environment may not necessarily be associated with increased actual physical activity (Creagh et al 2016). There is scope to consider one aspect of building occupant wellbeing as the capability to move around freely. In this context an evaluative framework that encompasses the range of individual, organisational and built environment factors that influence building occupants’ physical activity or sedentary behaviour would provide a meaningful starting point for architectural designers and researchers. In this paper we present a critical literature review which identifies the need to better understand occupant capabilities to engage with physical activity within a building.

2. Mobility audits in urban planning and population health

Built environment audits are tools that systematically evaluate places and settings against their level of supportiveness for particular activities. Audits can provide a means to capture a measure of satisfaction with a place, or capture an inventory of built environment elements or behaviour. Built environment audits have increasingly been used in design-based disciplines, urban planning, transport planning and urban design, as well as by public health researchers, to evaluate places such as streets (Pikora et al. 2003), parks (Kaczynski et al. 2012), urban trails (Reynolds et al. 2007) and for communities (McGuirt et al. 2011).

Evaluations from audits have informed knowledge about built environment elements associated with physical activity with a view to inform an evidence base related to healthy built environments. Audits have also increasingly been used as advocacy tools, to measure places against recognised best practice and advocate for change. However, compared to the use of audits in urban planning research, the current state of the art in auditing buildings for physical activity is limited. This is despite recognition of negative health implications for the sedentary nature of workplaces and increasing interest in the role of buildings in providing opportunity for regular physical activity.

The theoretical basis of auditing the built environment presented by Ferdinand Lewis provides some insight into how audits could be used to evaluate buildings for physical activity. Lewis (2012a; 2012b) drew on the work of moral philosophers such as Mills, Rawls and Sen, to develop a theoretical model of built environment audits based on how audits value ‘resources’ in the built environment, and how they position individuals’ capacity to access these resources to improve their wellbeing.

Three audit types are identified by Lewis based on differing relationship between individuals and built environment resources. The first audit type is the utilitarian audit. This audit is informed by auditors’ responses to the built environment and contains measures that prioritise psychological end-states such as ‘the sense of safety’, ‘pleasurability’ or ‘comfort’. Evaluation is based on the averaging of a group of individuals’ ‘satisfaction’ with the built environment. This audit of satisfaction assigns an
absolute proportion of the built environment resource to individuals, assuming that all individuals hold an equal proportion of the resource being audited. What is not taken into account in the audit’s evaluation, is the varying capacities of building users to convert resources to improve their wellbeing. A further criticism is that an individual may not be aware of the possible extent of wellbeing and therefore adjust their perception of their own level of satisfaction to sub-optimal conditions, a concept termed adapted preferences (Qizilbash 2006).

The second audit type is the general resources audit. This audit evaluates the built environment resources available to individuals. Lewis refers to this type of audit as an audit of opportunity. This audit evaluates the means individuals have to convert built environment resources into wellbeing rather than end psychological states. General resources include the physical infrastructure and spatial characteristics of built environments that allow individuals to convert resources into wellbeing, such as increased physical activity. However, a weakness of the general resource audit is that it does not evaluate whether individuals do convert resources into wellbeing. Building accredited for sustainability and health standards, such as Green Star ratings, can provide the means supportive of higher rates of physical activity by usable and attractive staircases and well-designed building layout, but this may not necessarily translate into actual increases in physical activity when compared to standard buildings (Creagh et al 2016).

The third audit Lewis identifies in his general theory of audits is the capability audit. The concept of human capability first emerged in the field of development studies by Amartya Sen and later advanced by Martha Nussbaum (Philips 2006). The concept has however been applied widely in more design based disciplines, for example in transport planning (Beyazit 2011), disability studies (Riddle 2014) and product design (Ooseterlaken and Hoven 2012). Capability is a normative concept reflecting both what people can do and what or who people can be. These various ‘doings’ or ‘beings’ are referred to as a capability set and are effectively the range of positive freedoms available to individuals to carry out a range of ‘functionings,’ or day-to-day activities that support wellbeing. Evaluations based on a capability approach focus on conversion factors that create barriers or facilitate the expansion of capability sets.

In the context of the built environment, a capability audit would not only evaluate the presence of built environment resources, but also individuals’ agency to convert resources into wellbeing. Capability audits according to Lewis audit both opportunity and agency encompassing both means and ends and addressing the weaknesses of the first two audits (Lewis 2012, 296). Lewis illustrates an example of a capability audit as the Design for Health audit. Design for Health evaluates as well as built environment factors, social capital and institutional factors which may constrain the agency of different population groups to convert built environment resources into health behaviour. Whilst the strength of Lewis’ work is in presenting a theoretically robust model of audits, he falls short of providing any principles for audit developers seeking to take a capability approach to auditing. A key challenge is to understand how the concept of human capability for physical activity is translated into a building design context. To do so we first review the literature on barriers and facilitators to physical activity in buildings.

3. Research Approach

The literature includes a number of frameworks that seek to provide ways to categorise the influence of the built environment on people’s physical activity. At the broadest scale social-ecological models understand an individual’s environment as nested fields of influence: individual, social, organizational, community, policy (see for example Plotnikoff et al 2003). Although this model provides one of the foundations of this paper it does not offer sufficient focus on building design. Taking an explicitly built
environment focus Zimring et al (2005, 187) considers physical environment factors at “four nested levels of spatial scale: (1) urban design, (2) site selection and design, (3) building design, and (4) building element design.” Zimring et al highlight the usefulness of this model in its correspondence to the “general temporal flow of a design project”. We sought a capability approach to a framework that focused on the occupant/user experience of a building, rather than the designer. Hollands et al (2013) identify Ambience, Functional Design, Labelling, Presentation, Sizing, Availability, Proximity, Priming, and Prompting as factors in an environment of choice. A key difference in the approach taken in this paper, compared to Hollands et al is to separate domains and functionings and to develop a framework which illustrates their intersection.

An initial search of the literature produced a list of original research papers published within the last 15 years that had investigated the relationship between an aspect of the interior building environment and different direct and indirect indicators physical activity levels. Indicators included workplace stair use, sitting time at office, overall physical activity levels, and total energy expenditure. The literature base was expanded further through a snowball method, where further relevant papers were identified from the reference list of key papers.

The literature was initially summarized and categorized based on several key fields: methodology (e.g. cross-sectional, pre-post, longitudinal), method of investigation (e.g. direct observation, remote monitoring, questionnaire survey), indicator of physical activity (e.g. stair use, sitting time) variable under investigation (e.g. stairwell design/location, building layout, elevator availability), and building functioning. Variables under investigation were then clustered into building domains informed by the authors’ experience in architectural design (Table 1). Building functionings were derived from the five physical environmental factors likely to influence stair use identified by Nicholls (2007): Appeal, Comfort, Convenience, Legibility and Safety. The application of these functionings was broadened to include ‘Social/Organisational Program’ within the category of convenience (e.g. workplace exercise programs and equipment), as well as ‘Health Prompts’ within the category of legibility (e.g. point of decision motivational signs). Papers were classified under multiple categories as appropriate. The building domains and functioning categories are described further in the following section.

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Cross-sectional</th>
<th>Pre-post tests</th>
<th>Longitudinal</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>6</td>
<td>3</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Methods</th>
<th>Direct Observation</th>
<th>Activity Monitoring</th>
<th>Questionnaire/Survey</th>
<th>Automatic Counting</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>7</td>
<td>8</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indicator of PA</th>
<th>Stair Use</th>
<th>Sitting Time at Office</th>
<th>Total Physical Activity</th>
<th>Energy Expenditure</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building Functionings</th>
<th>Appeal (Quality)</th>
<th>Convenience (inc programs)</th>
<th>Comfort</th>
<th>Legibility (inc prompts)</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>8 (+2)</td>
<td>6</td>
<td>5 (+9)</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building Domains</th>
<th>Building Culture</th>
<th>Vertical Circulation</th>
<th>Horizontal Circulation</th>
<th>Interior Places</th>
<th>Outside</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>12</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
The strength of evidence was based on number and type of studies. Substantial evidence included at least one systematic review or two pre-post test studies; emerging evidence included at least one pre-post test study or two cross-sectional studies; and weak evidence had little or no published research (Table 2). Weakness or ‘gaps’ in the literature were notable in regard to building culture, horizontal circulation and, more surprisingly, in the consideration of the interface between building interior and outside (Table 2).

Table 2: Strength of Evidence. This table describes the strength of the available literature on possible conversion factors for people’s active movement within buildings. S=substantial, E=emerging, W=weak.

<table>
<thead>
<tr>
<th>Building Domains</th>
<th>Visible Active Movement</th>
<th>Convenient Active Movement</th>
<th>Quality Space for Active Movement</th>
<th>Safe Active Movement</th>
<th>Comfortable Active Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culture</td>
<td>W</td>
<td>E</td>
<td>W</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>Vertical Circulation</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Horizontal Circulation</td>
<td>E</td>
<td>S</td>
<td>W</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>Interior Places</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>Outside</td>
<td>E</td>
<td>E</td>
<td>W</td>
<td>W</td>
<td>W</td>
</tr>
</tbody>
</table>

4. An evaluative framework for buildings and occupants

As outlined in the previous section, two organising schema emerged in the analysis process. The first, on the left hand vertical axis (figure 1) are areas or ‘building domains.’ The second, on the top horizontal axis (figure 1) are ‘building functionings’—qualities identified across the literature that represent the ideal states of people’s physical activity within buildings. Together the two organising schema combine in a modular format through which to understand conversion factors for people’s capability for movement in buildings. In the following paragraphs we will describe each of the building domains and building functionings that make up the framework.

Figure 1: The Framework: Example showing potential to weight functionings, and divide or add domains. (Image: Authors’ Own)
Building Culture: The ‘Building Culture’ domain recognises the importance of peoples’ actions (and especially the people with power) within a place to shape it physically and socially (Jancey et al 2015). Many evaluations of physical activity in buildings, and urban environments more broadly, struggle to engage with culture as a key domain. Recognising the importance of the social aspect of an environment is part of a social-ecological understanding that moves beyond placing individuals as solely responsible for their own health behaviours. Recognising the significance of building culture and also challenges the dominant architectural mode of place analysis which focuses on the built form as the dominant driver of any behaviour.

Vertical and Horizontal Circulation: The most dominant cluster of literature regarding people’s physical activity in buildings is around the use and design of ‘Vertical Circulation.’ There is in particular a focus on stair use prompts and various approaches to programing elevators (see for example Soler et al 2010; Nicoll & Zimring 2009). In comparison, there is less literature on the relationship between ‘Horizontal Circulation’ and occupants’ physical activity. In architectural practice there is a deep interest in the typologies of buildings and how these different arrangements of areas and circulation influence people’s experience of space.

Interior Places: Mapping studies of people’s movement in buildings emphasises the importance of trips to in-office destinations in accumulating incidental physical activity and breaks in sedentary behaviour (Rassia 2008; Creagh et al in print). These destinations in an office context include printers, tea room/kitchen, meeting rooms, break-out spaces/landings and toilets. Quantity, access, variety, comfort, privacy, layout and kit (equipment) are likely factors influential on the utilisation of destinations within a building (Oseland et al 2011). We have used the term ‘Interior Places’ to emphasise both the quantitative and qualitative aspects of destinations within the building. For example, in an office context, some interior places such as toilets, and arguably print stations will be used by occupants irrespective of their placement and condition (Rassia 2008). Others, areas such as meeting rooms, break out-space, kitchenettes, will be used relative to their user-perceived appropriateness for the function (Oseland et al 2011).

Outside: West Australian studies have identified street/footpath as the places where the majority of people’s physically active time is spent (Rosenberg et al 2010). As such, the environment outside the building (and our perception of that environment from inside the building) is an important driver of active movement. The framework focuses on the interface between the inside and outside of the building: that is, what can be seen from inside the building; the experience of moving between the inside and the outside; and the facilities and environment of the outside immediately surrounding the building.

Building Functionings: The ‘building functionings’ on the horizontal axis (table 2) are derived from the work of Nicoll (2007) on stair case design in academic buildings. Nicoll identifies five use factors: Convenience, Legibility, Appeal, Comfort, and Safety. We have shifted the language slightly to consider use and design. Legibility, a term that refers to the way building elements are ‘read’ by occupants, is here an idea within ‘Visible Active Movement’. We have used ‘Quality of Space for Active Movement’ to emphasise that Nicoll’s ‘Appeal’ is a result of design decisions that value the quality of the building environment. For the remaining three drivers the key words and emphasis remain: ‘Convenient Active Movement’, is how straight-forward it is to move around the building; ‘Safe Active Movement’ is how safe it feels to move around the physical and social environment and ‘Comfortable Active Movement’ is occupant comfort while moving around the building. Occupant comfort and building performance is a key area of research in architectural science which has historically placed emphasis on the building
services’ ability (through lighting, heating, cooling, airflow) to achieve people’s comfort while sitting and working.

5. Implications and considerations for adapting a capability audit for buildings and occupant physical activity

The Active Building Framework that we outline here is proposed with reference to a capability approach to built environment auditing as described by Lewis (2012). A capability approach has the potential to overcome weaknesses of existing audit approaches used to evaluate buildings and internal environments. In its current form, the framework is a guide for the development of a building physical activity audit tool (a copy of the current draft is available on request from the authors). An audit tool informed by the framework could work through each of the intersections of domains and functionings identifying areas of strength and weakness of the building’s performance in terms of supporting capability for active movement (figure 2). An audit developed in this way could potentially measure the interactions between people’s movement and the building environment and to propose and evaluate changes. Using such a tool in an overall evaluation may help to identify areas in need of particular attention and that the organisation/individual has the capacity to improve. In some cases it may be more convenient to consider each building domain at a time, an example of this would be when conducting a review of an existing building: for instance looking at vertical circulation, then at horizontal etc. In other cases it may be more useful to consider a building functioning in its entirety. This might be particularly useful in the design process. Looking at a sketch design of a building we might ask “How convenient would it be for occupants to move actively in this building?” in which case working through the ‘Convenient Active Movement’ section would present a series of provoking questions (or design problems) to engage with. In this way, the framework is user experience focused. It invites the designer to think through the building as an experience rather than a design—it invites reflection on the quality of the journey rather than the elegance/efficiency of the plan.

Figure 2: Sample page from Active Building Framework in development. (Image: Authors Own. Graphic Design: Mark Robertson)
The modular format of the audit framework also enables a capability evaluation. The adaptive structure of the framework emphasises the intersection of building domains and functionings. Weightings can be distributed across a range of distinct modules—each representing various capabilities embedded within specific building contexts. Through articulating a diverse range of capabilities relevant to physical activity in buildings the framework can potentially intersect with group and individual experiences of the world in different ways. The importance of understanding the varied context of buildings and how they shape the experience of a range of building users has been highlighted in literature from usability and adaptive performance perspectives (Lindahl, Hansen and Alexander 2013).

An adaptive framework approach rather than a prescriptive linear format is reflective of the indeterminate nature of capability as noted by some scholars (Philips 2006, 92). Although capability scholars like Nussbaum have provided a set of standard human capabilities, Sen on the other hand did not specify capabilities, instead suggesting that social evaluations should emerge from particular contexts (Philips 2006). The modular format of proposed framework accommodates the context specific nature of capabilities. For example someone using the framework to evaluate a residential apartment block may want to divide the ‘interior places’ category to consider apartments separately from shared places within the building (such as a laundry, entertaining room or gym) but apply the functionings with a shift in emphasis to each of these sub domains.

An adaptive framework for audit evaluations creates space for deliberation from audit designers and building users on content and process. Weighting of domains and capabilities allows different audit evaluations or intervention scenarios to be tested and compared. By offering multiple evaluation scenarios, the scope of audit knowledge is broadened and there is the possibility to accommodate a diverse range of building users. The modular design of the framework enables collective evaluation which can be responsive to the particular use and context of a building by incorporating further domains and adapting methodologies to particular domains. As Brown and Cole (2009) note there is a difference in the way that standards and regulations assume building occupants will act and their actual behaviour. Their research shows that building occupants’ awareness and knowledge is a key factor in shaping building occupants behaviour. Brown and Cole highlight the potential conversion factors according to a capability perspective such as occupants’ tacit knowledge, the building context and cultural factors.

This framework will be useful for those engaged in building management, design and research, including post-occupancy reviews, health promotion interventions, fit-outs, and architectural design development—wherever occupant physical activity is valued. Feedback on the format, focus and potential applications of the framework are needed to progress beyond this first iteration. In the coming months we will be facilitating a consultation process with experts in building management, design, evaluation; and community health promotion to better understand how this framework might be best shaped to inform practice. Green Star and LEED are particularly influential building evaluation systems, which are themselves constantly evolving. An ideal eventual outcome of this research would be to have this framework inform the industry standard evaluation tools such as Green Star and LEED. A recent example of the evolution is the introduction of the Green Star Communities category to the evaluation suite, which includes evaluation of ‘healthy active living’ and walkability within the criteria.

6. Conclusion

In this paper we present our work to date in developing an Active Buildings Framework as a tool to help systemise information and knowledge about people’s movement in buildings. The framework presented here opens a promising line of enquiry. It is a start point from which to critique building design or to
develop an audit from a capability perspective. The planned next steps in the research are to engage with built environment and health promotion professionals to gain feedback on the usability, scope, and potential for application of the framework.

The value of this modular Active Buildings Framework is that it can be used to guide critical enquiry and reflection on the way in which buildings support or present barriers to people’s physical activity. When evaluated, this framework will have the strengths of the audit: the potential to frame strong arguments in advocacy and to suggest improvements to the built environment. By learning from capability theory this framework recognises the importance of the intersection of contextual and individual specificity to understanding people’s movement within buildings.

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References


Perspectives of sustainability elements in selected South Australian primary schools

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Abstract: In Australia, there has been an expectation that infrastructure associated with sustainability will be used for teaching. In mixed methods post-occupancy evaluations undertaken on selected case study primary schools in metropolitan Adelaide, South Australia, staff and students were surveyed about their perspectives of their built environment. The survey was designed so that participants were given the opportunity to express their general views on school infrastructure, and then they were asked specific questions about the sustainability infrastructure and activities present in their school. All schools were observed to have similar sustainability infrastructure, yet staff and students tended not report this in the general questions. In the questions specific to sustainability, students did report knowledge of this infrastructure, as did staff; however, staff did not indicate that infrastructure was a pedagogical tool despite sustainability being a cross curriculum priority. This lack of inclusion in pedagogy suggests that sustainability teaching requires more than passive infrastructure presence. While important, caution should be exercised when asserting that this infrastructure acts as a teaching tool.

Keywords: School sustainability; post-occupancy evaluation; School buildings.

1. Introduction

Australian Government policy has promoted use of school sustainability infrastructure in curricula. The National Solar Schools Program, which commenced in 2008 proposing environment and education benefits, ended in 2013 with the assertion that the $217 million allotted to 60% of Australian schools ‘...helped to educate students about renewable energy and energy efficiency, and that everyday actions can prevent the production of millions of tonnes of carbon pollution’ (Department of Industry, 2016).

Advice from the Australian Government shortly after this during economic stimulus, identified that school buildings could ‘...be utilised so that they provide teaching tools or outputs (e.g., energy efficient light fittings, passive solar design)’ as a way of ‘advancing sustainability’ through building design decisions (Australian Government, c2009). This is contemporary with the South Australian Government’s ecologically sustainable development protocol requiring infrastructure to have demonstration capability for inclusion in curricula (DECS Asset Services, 2009). These guidelines presume that buildings and
sustainability infrastructure are pedagogical tools, suggesting justification beyond a cost-benefit analysis.

In schools, sustainability can cover a range of implementations and resources. First, guidelines provide normative design principles drawn from the Green Building Council of Australia’s Green Star ratings categories (DECS Asset Services, 2009). These instructions for designers intend to embed sustainability in the built environment fabric through resource use and waste reduction. This design-oriented guideline positions occupants as passive in their built environment, which provides a silent contribution to sustainability. As a capital investment, this contribution is best reviewed using quantity surveying and life cycle costing techniques, and is beyond the scope of this paper. Second, sustainability is considered integral to the curriculum. While Australian education for sustainability is complex in both curriculum and implementation (de Leo, 2012), at the time of the field work, primary school education included sustainability in the national curriculum as an embedded ‘cross curriculum priority’ and ‘organising idea’ (ACARA, 2011). In parallel to this, the ‘Australian Sustainable Schools Initiative’ (AuSSI) was also in operation, as one component of the South Australian implementation of Education for Sustainability (EFS) (DECS, 2007). Neither of these include school buildings. Third, school infrastructure is seen as a teaching tool. Policy bodies in other countries (DfES, 2006) have promoted school buildings as teaching tools about sustainability for over 10 years. Qualitative studies tend to confirm that this infrastructure can be successful as teaching infrastructure (Higgs and McMillan, 2006; Hes, 2012), but it is noted that these were undertaken in the context of supported sustainability teaching programmes.

Given the continuous political discussions about Australian school funding, it is prudent to review aspects of the effect of installation of this school infrastructure class. This research reports a component of a larger post-occupancy study of selected case study primary schools (Pearce, 2016). The fieldwork was undertaken during the 2012 school year (three years after the economic stimulus) and evaluates qualitative and quantitative evidence for recall about the inclusion of this infrastructure in school curriculum and culture. It was expected logically that, if the evidence-base driving these policy assumptions was reliable, then strong perspectives about this infrastructure would be present.

2. Methods and case studies

The post-occupancy study used a mixed methods approach to compare occupant use and perspectives with observed building fabric and services. This approach, although informed by contemporary building sustainability POE investigation methods (e.g., Bordass et al., 2001; Baird et al., 2012), was grounded in social science mixed methods discussions (Teddlie and Tashakkori, 2009). To maximize learning from case studies (Flyvbjerg, 2006, p. 230), schools were approached if they had been recognised with an architectural award, implying that their building quality was ‘extreme’, or as ‘maximum variation cases’ due to age as indicated by heritage listings. Four case studies schools, coded as Yellow, White, Orange and Red, participated on the condition that they were not identified publically (Table 1). All had occupied their buildings for more than five years and represented a mature occupation rather than the initial occupancy phase. Through negotiation, participant classrooms were selected to include older primary school students and enable student surveys. Out of the four schools, twenty teaching spaces (classrooms and library/resource spaces) were observed for use and environment. Across the schools, 147 student participants, aged 10-13, were recruited from eight classrooms. Staff were recruited from all areas of the participating schools (N=44).

The study considered the possibility that, unlike architects, sustainability may not be at the forefront of school users’ minds, so any direct questions may inadvertently be leading questions. People draw on
‘chronically accessible information’ rather than context specific ‘temporarily accessible information’ (Schwarz et al., 2008, p. 28-29). To mitigate against memory priming, the survey posed general open questions first, followed by sustainability-specific questions. Open response questions were post-coded using thematic analysis, i.e., without an a priori code strategy (Liamputtong and Ezzy, 2005, p. 265). Results presented here show summary code categories. These graphs represented collated and normalised thematic detail codes across schools. The five-point scale and multiple-choice questions presented use descriptive and inferential statistics.

Table 1: Summary of case study schools (at 2012)

<table>
<thead>
<tr>
<th>School / Year opened</th>
<th>Approx. floor area</th>
<th>Enrolment Area/student</th>
<th>Building construction description</th>
<th>Award or heritage/AuSSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow / 1877</td>
<td>1415 m²</td>
<td>178 7.9 m²</td>
<td>Buildings include stone buildings over 100 years old, block veneer and permanent lightweight.</td>
<td>Architectural award &amp; heritage</td>
</tr>
<tr>
<td>White / 2003</td>
<td>4580 m²</td>
<td>613 7.5 m²</td>
<td>Greenfield school &lt; 10 years old. Brick veneer/lightweight construction with passive energy saving devices and centralised HVAC control and BMS. Some lightweight transportables.</td>
<td>Architectural award</td>
</tr>
<tr>
<td>Orange / 1998</td>
<td>4300 m²</td>
<td>597 7.2 m²</td>
<td>Greenfield site. Construction 60/40 solid mass and lightweight transportables. Permanent buildings include passive energy saving devices (vents).</td>
<td>Architectural award</td>
</tr>
<tr>
<td>Red / 1877</td>
<td>3130 m²</td>
<td>324 9.7 m²</td>
<td>All buildings except 2 (lightweight &amp; masonry veneer) &gt; 50 years. Old buildings solid stone/brick construction. Significant interior renovations.</td>
<td>State &amp; local heritage</td>
</tr>
</tbody>
</table>

3. Findings

This section commences by summarising the observed sustainable design elements. The contextual perspective of students and staff is then presented, followed by perspectives of school sustainability.

3.1. Observed ESD design features

All schools were audited against the DECS guidelines for ecologically sustainable design (DECS Asset Services, 2009). Selected findings are reported in Table 2 (appendix). All were found to comply with the guidelines for daylight, energy efficiency and use restriction, water conservation and renewable energy in either in their original built form (White School and Orange School), or after retrofits to the original fabric (Red School and Yellow School). All buildings were observed to have the possibility of mixed-mode use, i.e., all had both operable windows and HVAC systems; however, the operable windows were not used. Site biodiversity was increased through either food production or ecosystem in schools. Given this, it was concluded that the schools had incorporated guidelines into built environment design and use.

3.2. Contextual perspectives

3.2.1. School uniqueness

In an open question to provide context, staff and students were asked to state what was special or unique about their school. Nearly 80% of students and 100% of staff responded. Both physical facilities and non-physical school aspects made schools unique to participants (Figure 1). Students responded
that buildings, building elements (specific components such as stack ventilation) and grounds made the school unique, but also identified the aspects of school culture, history and teaching / learning made the school special. Staff focussed more on building elements, grounds and visual appearance.

![Figure 1: School uniqueness – open question category code frequencies](image)

The detail codes generated through grounded theory coding of the text responses (student responses N=44, staff N=36 separate codes) were not uniformly distributed across case study schools, but were consistent with local conditions. Students and staff reported accurate size perspectives of schools (White and Orange School were large and Red School was small). Orange students noted that there was a variety of buildings (permanent and transportable buildings with visually distinct materiality). Building shape was reported by White School students and staff, which was consistent with the observed skillion roofline and stack ventilation.

Specific responses about sustainability aspects were coded only twice for both students (‘zero carbon’ and ‘focus’), and staff (‘sustainable development’). Other detail codes that could be associated with design for sustainability include building elements. These were coded at a low rate for both students (N=7, materials, ventilation, skylights) and staff (N=7, ventilation, skylights, automatic HVAC/windows).

The response to this open and unstructured question suggested that the uniqueness or specialness of a school was more complex than staff and student perspectives of their facilities alone. Where infrastructure uniqueness was reported, it was consistent with what was observed at the school, thus, suggesting that staff and students actually did notice their built environment, particularly large-scale form. The student participants showed that they hold definite opinions about their school’s uniqueness, be it either lacking distinguishing features, or having a wide range of physical and cultural features, which suggested that they had capacity to articulate on their built environment.

### 3.2.2. Buildings and grounds contribution to teaching and learning

Staff were asked about their views on how buildings and grounds contribute to teaching and learning (Figure 2). Staff responded with an 89% response rate. Participants did not report any sustainability elements as contributing to teaching and learning. Rather, staff tended to report specific architectural design and the holistic learning environment as being the most important aspects of the built environment that contributed to teaching and learning.
3.3 Sustainability perspectives

3.3.1. Sustainability overall and energy and water saving

Participants were given a variety of options to express their expectations and observations of school sustainability. Staff and students were asked to quantitatively rate their school as sustainable on a five point scale (response rate students 91%, staff 80%). Students responded with a perception slightly above neutral ($M=3.27$), whereas staff had a neutral perception of school sustainability ($M=3.06$), with no significant difference detected between cohorts (two tail $Z$-test, $\alpha=0.01$).

Both groups were tested for differences between schools. Student perspectives differed (one-way ANOVA $F(3,130)=3.43, p=0.019$) such that students from Yellow School scaled their school as being less sustainable ($M=2.84$) than the perspectives of Orange School ($M=3.49$) and Red School ($M=3.48$) students had about their schools, without any difference to White School students ($M=3.16$). In contrast, staff responses did not differ across schools ($F(3,31)=1.78, p=0.17$). Given that Orange ($M=3.55$) and White ($M=2.87$) Schools had specific building elements that were intended to indicate sustainability, such as stack ventilation, it was expected that sustainability might have scored higher with these schools. Though not significant, it is noted that the Orange School staff response mean was higher than other schools (Red Staff, $M=2.67$; Yellow Staff, $M=3.00$).

Stepwise multiple linear regression on all variables found predictive variables for the perspective of school sustainability. The staff regression could not be mathematically resolved. Student perspectives were predicted moderately ($R^2=0.26$) by perspectives of buildings being well maintained ($\beta=0.22, p=0.033$), perspectives of energy saving ($\beta=0.28, p=0.004$), and the perspective that light helps with learning ($\beta=0.23, p=0.022$), ($F(3,92)=10.96, p<0.0005$). This was consistent with the installation of timers or automatic HVAC control, suggesting that these do contribute to sustainability perspectives.

Students and staff were asked to quantitatively rate their buildings for ease of saving energy and saving water. Student responses were just above neutral on a five point scale for both making energy saving easy ($M = 3.29$) and water saving easy ($M=3.30$). Staff responded with less than neutral ratings for energy saving ($M=2.56$) and water saving ($M=2.74$). For both variables, mean testing resulted in significant differences between student and staff cohorts (two tail $Z$-test, $\alpha=0.01$).

One-way ANOVA on student and staff responses found that no schools differed significantly in their perspectives of buildings saving energy for student responses ($F(3,114)=1.70, p=0.171$) or saving water
for both students and staff (students, \(F(3,112)=1.87, p=0.139\); staff, \(F(3,35)=0.547, p=0.653\)). Staff response of energy saving were found to differ significantly across schools (\(F(3,37)=3.74, p=0.019\)); however, after post hoc adjustment for unequal sample size, no significant differences were found.

To explore nuances, participants were asked about their expectations and observations of school sustainability in open questions. Response rates about expectations were moderate (students 54%, staff 66%), but more attempted the question about observed sustainability (students 66%, staff 90%), suggesting that expectation of sustainability had a low awareness or importance in both cohorts. The category code frequencies for expectations (dashed) and observations (solid) are presented in Figure 3.

Students responded with expectations about building elements, daily management, energy use and reduction (photovoltaics, other energy saving devices), recycling, and described observed sustainability as building elements, energy, buildings, grounds, and recycling. They also described observed student activities as being present far more than expected, and daily management as being present far less than expected. Staff had more expectations about, energy, water and recycling, and observed more sustainability aspects in building elements than expected. Comparing the different cohorts, students expected and observed sustainability aspects in their grounds, whereas staff focussed more on building elements and design, suggesting an influence from different territories of occupation.

![Figure 3: Expected and observed school sustainability – open question category code frequency](image)

### 3.3.2. Observed use of components by students

Students’ observation of staff use of selected components was collected using a multiple-choice question (Figure 4). Responses were consistent with observed case study building elements. For example, students observed heating and cooling used in schools with wall controls (Yellow, Red and Orange). Both Orange and White case study schools have air vents in the walls, but only Orange School students tended to observe them being used, possibly because the White School air vents are centrally controlled and subtly located under storage joinery so are not obviously visible to students. Figure 4 also shows that most ‘other’ responses came from White School students, who reported seeing that their teachers had no control over the HVAC and opened doors to improve ventilation. This is consistent with observations and the complexity of viewed instructions for the centrally controlled HVAC (observed to be five A4 pages). All of this suggests that students are observing and recalling how teachers are modifying and adapting the room environmentally using ad hoc methods.
3.3.3. Sustainability discussed in class

A multiple-choice question was posed to capture recall about class discussions (Figure 5) based on items identified with 'ecologically sustainable design' (DECS Asset Services, 2009). Overall, when prompted, students and staff largely agreed with each other about what was discussed. Differences between schools were consistent with school configurations, such as the distinctive solid mass building materials in Orange School. White School staff and students reported air conditioning and windows at a higher proportion than other schools. This is consistent with the poor control of these elements reported elsewhere (Figure 4). The two demonstration components (DECS Asset Services, 2009), rainwater tanks and photovoltaic panels, were reported at low rates (0-5% and 4-8%, respectively).

The open section of student responses showed that students identified grounds and garden facilities as being discussed in lessons, which was also consistent with the observation that, regardless of school size, all schools had some form of garden. This suggests that when compared to, say, photovoltaic panels, the act of participating in gardening may increase student awareness and may offer more value to learning than items not maintained by students.

4. Discussion

In questions where participants were not specifically asked about aspects of sustainability, few volunteered this as, say, something that makes their school unique or special (2-3%, Figure 1), or what is
considered to help with teaching and learning (Figure 2). Thus, the presence of sustainability elements is not at the forefront of recall about the school or the role of buildings in teaching and learning. This lack of sustainability building components in the school narrative, as compared to gardens, can be explained in three ways. First, the inclusion of these components as part of the curriculum may be so integrated that they become ubiquitous and are a completely normative part of the environment, rather like desks.

The second explanation offered is that additional specialist teaching resources are required to integrate these technical elements into teaching and learning, yet there was little evidence collected that this staff resource was available. In South Australia, it was recommended that a ‘key staff member’ be available for the on-going operation of ESD and reporting (DECS Asset Services, 2009), which has also been reported as necessary in other programs such as AuSSI (Lewis et al., 2009). Thus, lack of integrative resourcing may reduce awareness. Third, this inquiry did find that students tended to report activities such as gardening rather than the existence of infrastructure. This is consistent with other reported preferences for biodiversity over other sustainability themes (Lewis et al., 2009).

Turning to the sustainability questions, since all schools had built environment design, fabric, and systems, that were intended to contribute to sustainability and sustainability teaching, when asked directly, it was expected that users would rank their schools highly in perspectives of sustainability. This did not occur. Given the selection of extreme case studies, this alone implies falsification of the premise and the case studies are more likely classed as critical (Flyvbjerg, 2006, p. 230).

Expectations of sustainability and reporting of sustainability elements present differed between cohorts. Staff were aware of the more (possibly intellectually) complex concepts of energy use, water, and building elements. These were consistent with the component-driven approach as proposed by the facilities standards (DECS Asset Services, 2009) but did not include the 'organising ideas' of social and environmental sustainability as proposed by the Australian Curriculum (ACARA, 2011). In contrast, student responses tended more towards participatory action rather than fabric-integrated solutions, suggesting sustainability means different things to different groups.

It has been proposed that school buildings act as teaching tools (Newton et al., 2009), but also that behaviour modelling is more effective in teaching sustainability (Higgs and McMillan, 2006). The quality of interaction with the fabric also suggests a complex socio-technical interaction. There was no evidence that White School’s BMS was used as a teaching tool. Rather, staff were observed to have problems adjusting the BMS to achieve comfort using mixed-mode system. Given this, the system could be categorised as ‘risky, with performance penalties’ (Bordass et al., 2001, p. 148). Where control is automated, such as in White School, modelling knowledge is lost, or replace with ad hoc ventilation solutions such as opening a door, which results in a negative modelling behaviour. On the positive side, gardens and biodiversity seem to be far more interesting to students, suggesting capital expenditure in this area is supported. Given that sustainability elements were only recalled when participants were directly asked, future evaluations should not assume that recall to specific questions about buildings is equivalent to prominence in attitude. Without establishing the relative importance of building elements to a participant in the context of their built environment, there risks claims based on false positives.

5. Conclusion

Sustainability elements in the built environment have high social expectations placed on them. In the late 2000s, as part of capital expenditure programs in Australia, education infrastructure policy expected sustainability infrastructure to contribute to teaching and learning. As part of a wider post-occupancy study, the mixed methods research presented demonstrated that staff and students have some
perspectives about these components of their learning environment, but it is not prominent in their overall recall of their school suggesting a lower priority than that of design professionals. Some sustainability elements were reported as being used by teachers, thus initiating learning by modelling behaviour. While, this modelling was demonstrated to be both correct and ad hoc operation, and might comply with the notion of a demonstration appliance, it did not contribute to the narrative of school identity or teaching and learning, and ad hoc operation may detract from sustainability objectives. This is not necessarily a failure of policy, since the intention of this expenditure was also to future proof for climate change. Rather, the evidence presented here suggests that the justification of the expenditure for teaching and learning is not strongly supported; however, funding school buildings to be quietly robust in the context of climate change and sustainability has merit and is likely to be stronger evidence-based policy.

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References


**Appendix: Observed built environment summary of case study schools**

Table 2: Observed available sustainable components (DECS Asset Services, 2009) in case study schools.

<table>
<thead>
<tr>
<th>Components</th>
<th>School infrastructure &gt; 30 years old</th>
<th>School infrastructure &lt; 30 years old</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural vent</td>
<td>Op. windows (unused)</td>
<td>Op. windows (unused)</td>
</tr>
<tr>
<td>Glazing ht</td>
<td>&gt; 1200</td>
<td>&gt; 1000 high; Skylights</td>
</tr>
<tr>
<td>Sill height</td>
<td>1200</td>
<td>800, 1100</td>
</tr>
<tr>
<td>Daylight control</td>
<td>No shade devices</td>
<td>Shade devices:</td>
</tr>
<tr>
<td></td>
<td>Retrofitted interior blinds</td>
<td>Retrofitted film-perm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Blinds-Transportables</td>
</tr>
<tr>
<td>Insulation - roof</td>
<td>Likely&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Library - No</td>
</tr>
<tr>
<td>Insul. - ceiling</td>
<td>Unknown</td>
<td>Library</td>
</tr>
<tr>
<td>Insulation - walls</td>
<td>No, except one classroom</td>
<td>No - permanent blds</td>
</tr>
<tr>
<td>Mass-walls/floor resources</td>
<td>Yes / Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Reduce const. resources</td>
<td>Possible - use of local mass wall material</td>
<td>Possible - use of local mass wall material</td>
</tr>
<tr>
<td>Energy eff. components</td>
<td>T5 lamps</td>
<td>T5 lamps</td>
</tr>
<tr>
<td>Energy limiting</td>
<td>Heat exchanger&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Heat exchanger&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Renew. energy</td>
<td>Photovoltaics</td>
<td>Photovoltaics</td>
</tr>
<tr>
<td>Water, saving, harvest, reuse</td>
<td>Rainwater tanks - toilet flush</td>
<td>Rainwater tank</td>
</tr>
<tr>
<td>Site biodiversity</td>
<td>Food production garden</td>
<td>Eco-system, Food</td>
</tr>
</tbody>
</table>

<sup>a</sup> No roof access due to WHS issues. Judgement based on reading local conditions using professional architect knowledge.
Counselling Maori: Relationships to space and implications for design

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Abstract: Mental health services in New Zealand have undergone changes since the 1980s with regard to how Maori values and Maori ways of thinking can be integrated into the assessment and delivery of care for mental health consumers. Key to this change is the understanding of Maori psychological frameworks and how this can relate to improved consumer experience and outcomes. Maori psychological frameworks are defined as a set of values, ways of doing things and understandings, which shape these individuals’ interaction with the world. As explored in this paper, Maori psychological frameworks also encompass influential spatial dimensions, including how built features and building design informs behaviours, influences emotions and relates closely to the delivery of mental health services. Delivery of mental health services on a marae, a traditional community building/meeting house, is practiced in New Zealand, however is not always possible due to service delivery limitations. Using the marae as a platform for analysis, this paper explores Maori psychological frameworks in relation to therapy and counselling, and the built environment. Using architectural science principles with regards to examining the way buildings are used and how well they physically fit their function, this paper explores Maori understanding of built environments to enable a better design of the spaces for therapy and counselling.

Keywords: Mental health; therapy; Maori; built environment.

1. Introduction

“I find it helpful to assume at the start of our counselling encounter that I have to earn the trust of the client. The alternative seems to me to expect the client to trust me by virtue of implied status and expertise. It doesn’t matter how many years of experience I...

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1 The term ‘consumer’ is used within this paper refering to the individuals who are clients of mental health service delivery. This term is favoured in contemporary literature and practice within mental health care.

2 Maori psychological frameworks are defined within this paper as key themes or notions which are present in how Maori populations relate to, behave in and understand their environments. This definition is consistent with psychologist Mason Durie’s definition (Durie, 1999).
have, or letters after my name – if I assume I’m owed respect then I have already forfeited the right to it” (Grimmer, 2007, p. 19).

Maōri are the indigenous population of New Zealand. As noted in the 2006 national census, 565,329 New Zealanders identified themselves as Maōri (14% of the population) and 643,977 claimed descent from a Maōri (Statistics New Zealand, 2007). It is also estimated that by 2051, the Maōri population will increase to around one million, and that 33% of all children in New Zealand will be Maōri (Statistics New Zealand, 2007). Early anthropologists and ethnographers such as Elsdon Best (1856-1931), Edward Tregear (1846-1931) and Percy Smith (1840-1922) sought to understand and document the Maōri world view. This was followed by further pivotal research by Te Rangihiroa Peter Buck (1962) and Apirana Ngata (1972) which helped to shape the contemporary researcher’s understanding of Maōri psychological frameworks. Social anthropologists have examined various aspects of Maōri psychological frameworks, including culture change and identity (Fitzgerald, 1970), marriage (Harre, 1966) and culture change in relation to urban environments (Metge, 1964; Hohapa, 1974; Kawharu, 1975).

Changes in the delivery of mental health care have reflected a growing understanding that specific focus needs to be given to Maōri approaches to therapy. In recognitions of this, a cultural treatment unit was established in consultation with Maōri elders and patient families at the Tokonui Psychiatric Hospital (Rankin, 1986). In fact, there are increasing numbers of Maōri centred programmes (McCarthy, 1993), and use of Maōri cultural services within the delivery of mainstream mental health care (Durie and Kingi, 1995). Key to this transformation is the notion that a cultural understanding must underpin relationships and encounters in therapeutic settings (Durie, 2007). Within a mental health sphere, psychiatrist, psychologist and Professor of Maōri Studies, Mason Durie has promoted Maōri perspectives of health which questions Western delivery of mental health services and he outlines a pressing need to meet the requirements of an increasingly diverse clientele. He describes four dimensions of health that are critical to the delivery of health services to Maōri, as distinct from delivery to other populations (Durie, 1985). These include a consideration of taha hinengaro explaining Maōri ways of thinking and behaving, particularly in relation to environments, and a spiritual dimension, taha wairua, recognising the importance of culture to identity. Key to the successful delivery of care for Maōri consumers is the notion that mental health services should not direct efforts just to the psyche, as with other populations or common practice, but physical, social and spiritual dimensions as well (Durie, 2011). This transforming delivery of the way services are offered in conjunction with developing understanding of Maōri psychological frameworks in relation to therapy highlights how these services should be delivered differently for Maōri consumers and how these particular consumers will approach and relate to therapeutic processes in different ways.

Contemporary psychology research aims to promote a field of research that is sensitive to indigenous people, culturally relevant, and is not imposed or imported from elsewhere, in order to achieve good health outcomes (Nikora, 2007). This acknowledges the unique psychological frameworks distinctive to Maōri, and utilises this to more appropriately shape mental health research and deliver mental health services. This paper seeks to translate this methodology to research for the built environment, using Maōri perspectives to inform design of the built environment to increase functionality and suitability of built therapy spaces.

Research exists linking good design practice in the built environment to mental wellbeing. Evaluations of specific design interventions have shown that good design of clinical and treatment environments leads to better clinical outcomes and less stress for the users; both patients and staff (Berry et al., 2004; Ulrich et al., 2004; Marberry, 2006; Ulrich, 2006). When considering environments
for therapy and counselling specifically, research which links this therapy practice with the built environment has been undertaken, illustrating how its design can affect therapeutic delivery and suggesting that the incorporation of spatial and built elements should form a part of therapeutic techniques (Sivadon, 1970). The counselling environment is regarded within clinical literature as having an effect on a consumer’s sense of wellbeing (Gross et al., 1998; Ulrich et al., 2008). Consumers’ experience of such spaces can have a highly emotional dimension (Pressly and Heesacker, 2001) which is suggestive that environment design should be investigated as a potential means to influence therapeutic efficacy. Further, individuals have differing abilities to censor or suppress their environments (Dijkstra et al., 2008) and a stressed patient has reduced capacity to exclude environmental distractions (Samuelson and Lindauer, 1976; Dijkstra et al., 2008), suggesting the environment of a counselling room may have more impact for these individuals who often arrive in a distressed state. This paper develops the existing area of research, focusing specifically on indigenous understandings of space, and how this can influence the extent to which the design of therapy and counselling spaces fit their function.

Fieldwork undertaken by the author in 2015 involved a series of focused interviews with five respondent groups: consumers of mental health services, practicing therapists/counsellors, carers of a loved one with a mental illness, architects/designers who practice in the field of designing for mental health and design experts/researchers who work and research in the field of design for mental health. This fieldwork was undertaken in order to understand consumer experience of built environments delivering therapy. The collected data was analysed through a thematic network (Attride-Stirling, 2001) and was re-interpreted to draw conclusions on spatial perception, and implications for the design of built environments to best support the function of therapy. Open ended questions were asked in order to facilitate participants expressing their views on the issues being investigated (Creswell, 2003). The interviews lasted from forty minutes to ninety minutes depending on interviewee’s responses to interview questions. This exploratory qualitative analysis (Attride-Stirling, 2001) was undertaken with the data from the five respondent groups noted above.

In the following section of this paper, the marae will be used as a platform to discuss Maōri psychological frameworks, implications for therapeutic practice, and relationships to space and the built environment. Through this analysis, an understanding can be developed regarding the significance of the built environment to improved consumer experience and outcomes for indigenous Maōri populations.

2. Marae

In modern New Zealand, marae are Maōri ceremonial meeting spaces. The space usually consists of a large open area (the marae ātea) with a meeting house which is often decorated with carving and weaving. It is also common to have additional shelters opposite each other across the marae ātea for hosts and visitors to sit whilst “the ‘rituals of encounter’ are carried out”(Addis et al., 2011). Marae have become a focal point of Maōri community activity in modern New Zealand (Salmond, 1975). Marae can be utilised as a platform for understanding and exploring Maōri psychology as the encounters which occur on a marae have key cognitive and behavioural implications. The marae experience is so critical to the understanding of Maōri psychological frameworks, that it is a condition of full membership of the New Zealand Association of Counsellors that applicants have experienced an overnight stay on a marae (New Zealand Association of Counsellors, 2007). Durie outlines a set of elements of marae encounters, which he notes have key significance and meaning to Maōri understandings. Further, by linking these encounters with broad conceptual zones, “distinctive psychological and behavioural attributes and
values can be identified” (Durie, 1999). Through the encounters rehearsed on marae, it is possible to understand the distinctive Maōri ways of thinking, behaving and regarding the world, which has implications for therapeutic practice and spatial design. Four key themes emerged from fieldwork undertaken by the author, including elements concerning the domains of space and boundaries; mind and earth; time; metaphorical domains; and safety. These are elaborated below. Each element is explained, and then using relevant literature and findings from the fieldwork data analysis, its relevance to counselling and counselling environments is discussed.

2.1. Space and boundaries

Anthropologist Anne Salmond has explored the complex patterns of juxtapositions in spatial arrangements of marae, which emphasises the significance of boundaries in Maōri philosophy and thinking (Salmond, 1978). The providing of space in a counselling context allows for the possibility of retreat, should the encounter become upsetting or dangerous. Space is also closely related to boundary concepts. “Distinctions between tapu and noa, between tangata whenua and manuhiri, between right and left, between first and last, between clean and unclean, food and water, act as constraints to the building of unqualified relationships and the exercise of acceptable behaviour” (Durie, 1999, p. 361). Significant to the counselling context is that closeness in a physical sense does not equate to a loss of personal boundaries or the abandonment of caution (Durie, 1999, p. 361), which is suggestive of a flexibility of spatial layout and territories to allow the negotiation of boundaries within the therapeutic relationship.

“Observing boundaries should be fundamental to the process of counselling for the protection of both parties. The boundary between counsellor and client is necessary for a good outcome and creates a measure of safety, especially for clients who might otherwise mistake friendliness for encroachment. Professional boundaries, intergenerational boundaries, gender boundaries and boundaries between the living and the dead enter into the counselling processes and deserve respect. Efforts to overcome diffidence by being overly ready to embrace or diminish boundaries may well lead to withdrawal and retreat into silence” (Durie, 2007, p. 7).

Orderliness is also related to marae encounters and Maōri psychology. “Order is apparent not only in physical arrangements but also in the sequence of proceedings, the progression of thoughts, and the way in which time is allocated” (Durie, 2007, p. 7). Orderliness is often correlated with rigidity of thinking, however in this context this is not the case. Patterns of behaviour and thinking allow for creativity to unfold within, and further, such orderliness reduces opportunities for misinterpretation (Mahuta, 1974). Within a counselling context, this is suggestive of flexible layouts, but a consistency of spatial sequencing around a counselling session.

2.2. Mind and earth

Within Maōri psychology, connection to land in a particular area is significant. This is recognised in the tradition of burying a new-born child’s placenta in that earth; the word for land, whenua, is the same as the word meaning placenta (Williams, 1967). The bonding between an individual and the land is considered paramount for the development of identity and sense of self (Durie and Kingi, 1995). Marae encounters provide this link between mind and earth, and are crucial for development of identity. From a therapeutic perspective, interaction with marae as part of therapy “is getting people to go back to
Counselling Maōri: Relationships to space and implications for design

their roots, and so what holds them, and so sometimes that disconnection from what their roots are causes some of the problems they are dealing with as well, it is a sense of belonging” (Therapist, 2015, Personal communication). Further, “the space becomes a talking point for unpacking things, the space becomes like their home, their safe place” (Therapist, 2015, Personal communication).

Within a counselling context this relates closely to territories of space. As one counsellor reflects, “I try to apply in my mind the roles of tangata whenua and manuhiri to myself and the client. Almost always the client is coming into ‘my’ space” (Grimmer, 2007, p. 20). In this situation, protocols and spatial dynamics are thrust upon the consumer, which may be unfamiliar or frightening. Thus, “I need to work actively to avoid reproducing a colonial encounter in the counselling room by ‘colonising’ the space” (Grimmer, 2007, p. 20). This is suggestive both of flexible layouts, and also increased comprehensibility of the room, which can be achieved by such measures as clear spatial boundaries, materiality delineating use, and textures assisting textural perspective (Liddicoat, 2015).

2.3. Time

On a marae, the domain of time is allocated to how long is needed for a task or discussion, speaking until satisfied that a message has been conveyed, rather than by the clock. This also relates closely to the sequencing of events, which will occur in a particular order, in the amount of time is needed to establish legitimate representation of people and opportunities to address their concerns (Durie, 1999). Thus, ordering and sequencing is emphasised in the built environment, and “the implications for counsellors is that we make available the time that is needed” (Grimmer, 2007, p. 21).

2.4. Metaphorical domains

Metaphorical domains relate closely to patterns of thought. “Maōri generally shun directness, preferring a type of communication that alludes to but does not necessarily focus on a detailed point... psychological energy moves outwards, it is centrifugal rather than centripetal” (Durie, 2007, p. 6). Within a counselling context, one therapist reflects: “the cognitive-behavioural approach that I use is largely concerned with eliciting thoughts, feelings, physical symptoms and behaviour in order to find effective interventions in each domain. This approach is largely contradictory to a Maōri way of thinking about experience” (Therapist, 2015, Personal communication). In fieldwork conducted by the author, the counselling experience was better comprehended when presented as a linear journey within the built environment. This involved a careful consideration of the spaces preceding and proceeding the counselling workspace, a consistency of spatial journey, a linear circulation from entry, through counselling workspace, to exit, and circulation which keeps consumers who are entering from interacting with consumers who are leaving.

2.5. Safety

A system of tapu and noa exists on a marae which distinguishes between spaces/events that are off limits or to be regarded with caution and those which are freely accessible (Metge, 1976). This underpins much marae activity and conduct (Dansey, 1971). Safety relates closely to a counselling session also, and where Maōri clients are receiving therapy not on a marae, they may feel less safe, less able to connect to their roots, and less open to discussion (Therapist, 2015, Personal communication). Psychologist Durie advises that “[Maōri] clients need space before they can have confidence in a counsellor. Cramped office conditions or physical closeness before the terms of the relationship have
been established may lead to aborted engagement. Underlying the comfort of distance is the knowledge that retreat is possible if the encounter is unpleasant or unsafe” (Durie, 2007, p. 6). This implies particular design initiatives in the built environment, such as allowing enough personal space, offering visual retreat and respite through windows/views, and offering visual and physical access to exit.

2.6. Design Initiatives

In New Zealand it is common practice to offer therapy on a marae for Maōri consumers. However, this is not always possible due to budgetary constraints, therapist availability, and services offered by a particular practice (Therapist, 2015, Personal communication). Further research is suggested into potential design initiatives to assist architects in relation to the design of counselling workspaces/practices, to make these environments more conducive to the delivery of mental health care for indigenous Maōri populations. These suggestions must address the articulation of the built environment to relate to Maōri consumers’ spatial perceptions in a supportive way, and thus enable the spatial function of delivering mental health services to be encouraged.

3. Conclusions and future research directions

Using Maōri psychological frameworks as a starting platform, this paper aimed to understand how these indigenous people use their buildings, relate to space, and how counselling and therapy spaces fit their function when delivering mental health services for these consumers. The types of thinking and behaving as evidenced in encounters with a marae are not confined only to the marae environment, and reveal much about Maōri psychological frameworks. A lack of spoken response may not be disengagement, but in fact an uncertainty about the boundaries of the therapist and consumer relationship; unspecific phrases may be interpreted as avoidance rather than a deeper search for multiple and greater meanings. The themes outlined in this paper reveal aspects of Maōri thinking and experience in relation to marae, therapy, and space and environments. A consideration of possible design initiatives is encouraged by this paper which may be useful to integrate Maōri psychological codes and processes into the delivery of mental health care within conventional counselling workspace settings.

Beginning with an understanding of how indigenous societies relate to their built environment, and how a failure to appreciate these nuances could negatively impact the nature of mental health care in the context of New Zealand, this study encourages a review of perceptions of how spaces function (based largely on European sensibilities). This review of how indigenous societies use and perceive their built environments has impacts for those seeking to understand human-space relations in multi-ethnic societies, particularly in environments for special care, education and mental health.

Further research is suggested into the design initiatives with indigenous populations to add detail and expand on the possible tools for architects to use to design the most supportive spaces for counselling and delivery of mental health care for indigenous populations. This paper thus recommends the integration of consumer consultation in future research to understand unique indigenous consumer spatial perceptions, careful post occupancy evaluations and control studies in order to best understand the efficacy of particular design initiatives.
Counselling Maori: Relationships to space and implications for design

References


Property branding in Ghana: a reflection on colour, architecture and spatial agency

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Abstract: Property branding or the practice of painting people’s properties with corporate colours is an emergent phenomenon in Ghana, with significant implications for community identity and socio-spatial relationships in both rural and urban areas. It is often considered outside the domain of mainstream architectural practice; however, an expansive approach could provide better and more meaningful outcomes for the built environment. This should not be based on architectural objects but on the methods of empowerment and the change that it can engender. Therefore, this study underscores the utility of spatial agency in placemaking for positive social and spatial outcomes.

Keywords: Identity; society; legitimacy; environment.

1. Introduction

Colour is an essential element of the visual world that impacts the interactions between humans and their immediate environment. It is a sensory perception that informs the interpretation of our environmental experiences and psychological mood (Meerwein et al. 2007). Colour serves as a powerful visual property, and a medium of communication without which our built environment will be experienced as a mundane achromatic environment with little or no vitality and aesthetic appeal. Several studies have shown the importance of colour in consumer-product-preference, socio-cultural identity, architectural psychology, and in regulating the visual perception of a given space (Aslam 2006; Crozier 1996; Elliot & Maier 2014). Mahnke (1996), underscores the influence of colour on the mood and physiological wellbeing of people in their given environment. For example, colours such as red, yellow, and blue are noted to be associated with aggression, brightness, and relaxation respectively (Meerwein et al. 2007). Nonetheless, studies in the psychology of colour has yet to fully explain the
emotional and physiological impact of different colours on people due to subjective human response to colour.

In the area of architectural science and urban design, colour has been identified to influence one’s thermal perception in different environments (Auliciems 1981; Fenko et al. 2010); and an individual’s or community’s sense of place (Stedman 2003). These observations are underpinned by studies in neuropsychology which underline how the human brain reacts to sensory information (such as colour) from the external environment (Mahnke 1996; Tanaka et al. 2001). Therefore, the choice of colour for a given environment has the potential of evoking diverse emotional and/or physiological reactions from people, besides the socio-cultural symbolism it may embody. Property branding or the practice of painting commercial and private properties (i.e. buildings, fence walls, stalls etc.) with corporate colours, has emerged as a pervasive phenomenon in most rural and urban areas in Ghana. It is increasingly redefining the outlook of the built environment, thereby, giving the rural and urban space a commercial image. Nevertheless, what this practice means for the character and the community identity of the built environment, and how it influences the socio-spatial relationships of the rural and urban architecture have received little attention in both academic and policy discourses. So far, no studies have been found in this area. Therefore, this paper explores the underlying drivers of property branding, how it impacts people’s perceptual judgement of their environment, and the extent of social acceptance of this practice. The study pays particular attention to branded houses, how it influences people’s sense of home; and the role architects (in particular) and other related disciplines can play, in collaboration with government and society, to reframe property branding for positive social and spatial outcomes.

Figure 1: Various locations within Ghana with properties branded in corporate colour (Source: Ghanaweb)
2. Emergence and implications of property branding in Ghana.

Although the genesis of property branding in Ghana remains uncertain, this practice gained momentum in the early 1990s. The Structural Adjustment Program introduced in Ghana in 1983 allowed for greater hospitality towards foreign organizations through trade liberalization and privatization of state-owned enterprises. These policies fuelled the influx of multinational companies in the country. Eventually, the quest for market share and cheaper means of advertisement in a porously regulated environment, created room for the branding of properties at relatively cheaper cost but wider coverage. As illustrated in figure 2 below, property branding started with the painting of stalls and container shops located along major roads in some parts of Ghana. This exercise was extended to the painting of fence walls, and subsequently to private and commercial buildings located at vantage points in both rural and urban areas. Taking advantage of public ambivalence towards this practice, one corporate entity issued a statement that “if you remain still for too long, we will brand you” (Dowuona 2009). This assertion portrays the aggression and impunity with which some companies are turning the image of most urban and rural settings in Ghana into corporate brands with little or no regard for place-identity. For an individual who is unfamiliar with Ghana, the intricacies of the built environment from cultural aspects of daily life, climate, and materials are masked by the prevalence of property branding.

Figure 2: Trend of property branding in Ghana (Authors’ construct)
Property branding plays a particular role in identity and ownership that other means of advertisement such as billboards, radio and TV commercials do not. It impacts how we conceive, interpret, and identify with space. As Merleau-Ponty (1962) points out, our understanding and interpretation of the world are inextricable from the space we live in. Conventionally, one’s home is where you live, how you live, and how you are identified. Home is that term of identification of the self that connotes one’s attachment to various things, e.g.: homepage, hometown, and homeland etc. In an interview, Swiss architect Peter Zumthor notes: “I like to travel the world but it’s important for me that I’m anchored here. To come from a place, I think, is a very basic human thing” (Brislin 2012, p. 9). This assertion underlines the notion that home might be a primal and innate need for one to locate him or herself in the world regardless of the form it actually takes. While the image and significance of one’s home and what constitutes a home is not universal among groups, demographics, and culture, it is readily identified as the possession most often associated with personal (and family) identity, security and well-being (Marcus 1995). Therefore, society and individuals tend to associate people with their home regardless of that individual’s own sensibility and attachment to their home.

People personalize their homes with their favourite colours and ornamentations so that their houses reflect and communicate their affinity, and personal and/or social values. Invariably, social and spatial components of the human environment are mutually dependent so that your physical place is organized within layers of social relationships. If the assertion by Zumthor is anything to go by, then the role of place, home, and identity are all functional as basic human need; and they are architectural in their connection to the intricate ways in which home is shaped both socially and materially. To be “homeless,” is universally viewed as a serious concern: it is not simply to go without adequate “shelter” but the sense of displacement, disorientation, and loss of identity that comes with it. Therefore, the implication of property branding for our visual perception, environmental experience, and a sense of place and identity cannot be overemphasized. Indeed, human beings, and for that matter our built environment, have an urge for identity (Leach 2006); therefore, any attempt to mire this identity is inimical to one’s sensibility. Against this background, this study draws on exploratory inquiry to: understand the drivers of property branding; examine how it impacts people’s perception of space; assess the extent of social acceptance; and identify the roles government, society, and professionals etc., can play to collectively reimagine and define the character of the built environment.

3. Methods

This study was mainly an exploratory research given the limited data and/or interest in property branding in both academic and policy discourses in Ghana. Semi-structured interviews were conducted with key stakeholders in three major cities in Ghana namely: Kumasi, Accra, and Sunyani. Participants of the interviews included: (1) the marketing departments of corporate organizations engaged in property branding; (2) house/property owners and tenants of branded houses; (3) architects- both in academia and practice; (4) urban designers and researchers; (5) policy makers and local government; (6) students; and (7) the general public. A total of 30 interviews were conducted. Due consideration was given to all ethical requirements with regards to data collection and reporting. The interviews were complemented by a random survey of people on the streets of Kumasi to seek their opinion on the practice of property branding in their neighbourhoods. The wide range of respondents engaged in the study allowed for an evaluation of diverse opinions and interpretations of property branding, and how it affects the visual quality and local identity of the built environment. The findings of the study have been organized into three thematic areas: (1) drivers and motivation for property branding; (2) legitimacy of property branding; and (3) spatial agency.
4. Results and discussion

4.1. Drivers and motivation for property branding.

The stakeholders identified in this study have been categorized into three main groups i.e.: (1) those who are directly involved in property branding i.e. corporate entities and property owners; (2) policy makers and regulators; and (3) the general public (both ordinary people and professionals). Each stakeholder group had different interests and perceptions about property branding and how it affects them and their immediate environment. The first stakeholder group, identified above, were largely the marketing departments of corporate organizations on one hand, and property owners on the other. An analysis of the underlying motivation of property branding for companies such as Vodafone, Glo, MTN, Airtel, and Expresso, reveals that the primary incentive of property branding is cheap advertisement. On average, property branding saves companies more than 50 percent of their advertisement costs compared with other traditional means of advertisement such as billboards, and radio or television advertisement.

On the other hand, depending on their negotiation prowess, property owners were paid little or no money to have their properties branded. Some property owners viewed this exercise as killing two birds with one stone. In the first place, they got their, hitherto, poor-looking properties painted as well as some financial gains from the companies; although their rights to determining the colour of their buildings were usurped. Furthermore, the policy making bodies and regulatory institutions, engaged in the study, such as the Kumasi Metropolitan Assembly, acknowledged property branding as a legitimate means of advertisement in their metropolis. It provided income for the local government through advertisement fees which were determined based on the location of the branded property (proximity to major roads or the central business district), ownership (public or private), and the total surface area of the property being branded. Most local authorities had no regulations to guide how the branding was carried out; and the fees charged were far less expensive than, for example, those charged for mounting or renting a billboard. Hence, the ubiquity of branded properties in both urban and rural areas in most parts of Ghana.

In addition, the perceptions of the general public about property branding were sought since the buildings are in the public domain. In this regard, particular attention was paid to the views of ordinary people and those of professionals in the built environment. In a random survey we conducted among the general public on the streets, more than 60 percent of the people had a negative view of property branding. Among those who viewed it negatively, 86 percent of them did not like the colours used, and were also discontented with the poor quality of painting. Besides, the opinions held by the professional group (e.g., architects, developers, engineers, urban researchers etc.) suggested a strong disapproval of the idea of property branding. Majority of them emphasized that property branding is a “nuisance”, “disgusting”, and “a bit vulgar”. It was viewed as undermining modern civilization, inimical to local identity and the socio-cultural values it may embody, and an “obliteration of the image of the built environment”. Ironically, although some members of the public were forgiving of the concept of property branding, they rejected the idea of having their houses branded; portraying the NIMBY syndrome. These observations raise questions about the legitimacy of property branding, and the value people attach to their immediate environment beyond the four walls of their homes.
4.2. Legitimacy of property branding.

Borrás and Edler (2014), identify legitimacy as the extent of social acceptance of change, a niche regime, or new institutional rules or practices. The success (or failure) of any emerging socio-technical system, largely hinges on the socially shared legitimacy of that system. This is buttressed by the notion that social acceptance of an innovation or an emergent phenomenon engenders a sense of normative obligation and/or voluntary adherence that help save local authorities the resources required to enforce compliance (Scharpf 2009). Referring to the work of David Easton (Easton 1965), Borrás and Edler (2014) point out that legitimacy can be conceptualized by two main criteria: (1) social engagement and support of the process by which public decisions are taken- “input legitimacy”; and (2) the extent of public acceptance of the outcomes of such decisions- “output legitimacy”. Following this abstraction, a legitimate action or phenomenon can be conceived as one that engages stakeholders in its conceptualization, and produces outcomes which are consistent with stakeholder expectations.

The process of property branding remains questionable considering its input legitimacy. Although some companies negotiate with property owners and local government before branding any property, a larger part of society who are affected by such practices are backgrounded. Interviews with tenants of some branded compound houses revealed that tenants are not consulted in the negotiation process; and for the most part, the property owners who do the negotiations do not live in the houses themselves. Hence, tenants are forced to live with the brand of a company they may not identify with. Several tenants complained of losing a sense of home and, therefore, objected to such practices. Beyond local residents’ expectations, there is also no professional input in the way properties are branded. Companies do not engage architects or planners etc. in the choice, design or branding of properties due to their obsession with cost cutting ambitions. In fact, there are no regulations that bind them to do so. Consequently, they resort to cheap labour which eventually leads to poor output and public disapprobation (output legitimacy). In the light of the viral nature of property branding and the negative perceptions associated with it, it is important to identify alternative approaches that can be applied to reframe property branding for positive social and spatial outcomes.

4.3. Spatial agency: an alternative approach to property branding?

In their book, Spatial Agency; Other Ways of Doing Architecture, Awan et al. (2013) provide the concept in which architecture is deployed in more ways to empower others and their agency for spatial production. “Spatial agency expands the definition as to what might constitute a site of action, seeing it as something that is in the widest sense of the word, physical, social, metaphorical, phenomenal, and rarely limited by externally determined instructions and conventions” (Awan et al. 2013, p. 55). Engaging the expansive spatial forces of the political, ecological, virtual and other diverse networks is both necessary and challenging. The critical aspect of spatial agency is that the “consequences of architecture are of much more significance than the objects of architecture” (Awan et al. 2013, p. 33). In this way, we hope to consider property branding in the context of fostering change in the sensibilities, methods, and responsibilities of architects, urban planners and related disciplines, in collaboration with government and society in general.

Interviews conducted with architects, planners, educators and other professional allies as part of our investigation reveal a political and cultural climate that constrain design activism. Kultermann and Maass (1969), point out similar sentiments that architecture, social and political conditions are inseparable, but their interaction in practice are not encouraging. In this respect, Brislin (2012, p. 9), proposes an architecture, “that valorises the human spirit through its focus on place, the senses and
memory”. There are Ghanaian architects who have dedicated themselves to creating such meaningful work; however, the viral nature of property branding seems to present a new challenge and, perhaps, opportunity for re-imagining architectural agency. In the concept of spatial agency, the term “architecture” is removed, in part, for its tendency to equate architecture and the building in order to create an opportunity in which architects and non-architects can work together to define the form and function of a given space. In this regard, architecture could be understood as dynamic, accommodating, evolving, social, political and experiential among many other domains with which it intersects.

In the absence of strict government regulations to streamline the process of property branding, it is important to identify a more efficient approach to its application that may have positive outcomes on the environment and society in general. One of such approaches identified in the study is the engagement of property users in how a property is branded. So far, this decision rests with the branding companies with little or no inputs from the users. This engagement is seen as a way of promoting a sense of ownership and agency among users. Another important factor is the engagement of professionals, for example, architects in the design and execution process of property branding. Some architects opined that to make property branding meaningful to society, it will be useful to incorporate traditional symbols (also known as Adinkra symbols), that reflect the values of property owners and society in general, into the branding of those properties. These symbols may also serve as educational tools for young people in society. There are more than 70 Adinkra symbols in Ghana, each embodying different meaning and traditional significance. Figure 3 below, is an illustration of how property branding could incorporate Adinkra symbols to add some traditional value to it. The symbol shown in Fig. 3 is referred to as “Nkyinkyim” which means “initiative, dynamism, and versatility”.

Figure 3: Adinkra symbol, ‘Nkyinkyim’ on a Vodafone branded house (Authors’ construct)
5. Conclusion

Alastair Fuad-Luke’s book, *Design Activism*, is subtitled “a beautiful strangeness for a sustainable world” (Fuad-Luke 2013). While Fuad-Luke relies on a rather banal sounding definition of design, that is, merely the effort to improve any current situation, it unfolds into all aspects of our lives. Fuad-Luke’s subtitle gives us the essence of good design. Design creates something unexpected, unfamiliar, unknowable and, when done well, it creates opportunities and solutions for the most challenging, complex issues we face. It is not merely problem-solving, but reaches deeper to define the problem itself. Design encompasses all aspects of our lives and connects us all through our shared desires to live richly and improve the situation in which we find ourselves. In this paper we have tried to address the problem of property branding in the context of a complex, intertwined set of issues and to suggest that the problem that needs to be solved can be addressed through design’s capacity for spatial agency.

This paper is part of an initial process in which we are seeking inroads for actual change; despite the scale of the challenge and the complexity of property branding. We hope to engage others to consider our assertion that property branding is a critical and persistent issue of what is architecture in Ghana, and that it could be addressed within a framework of spatial agency. Property branding could be viewed as a negative and identity corrupting action that could produce a course of action which could result in undesirable social and spatial outcomes. However, it could also be recognized that identity is not static but its co-produced through socio-spatial engagement drawing on all areas of influence (Pellow 2002). Therefore, alternative means could be sought to engage key stakeholders in the process of property branding to ensure its output legitimacy. This engagement should take into account the views of property users, and the implications of property branding for community identity. That said, it is important to understand factors that may, potentially, present barriers to stakeholder engagement and participation in property branding; and how these barriers could be eliminated.

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Beyond the counselling workspace: Spaces of significance in the treatment of self harm

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Abstract: This paper explores the significance of environments outside the counselling workspace¹ in the treatment of self harm². Spaces considered include a de-escalation space post counselling, an urge room in inpatient care, and a natural mind-space, adjacent to the counselling workspace and accessed only visually. The transition of spaces and planning of the spatial journey around a counselling session are also discussed. Using literature of therapeutic practice, each of these spaces are analysed to show the reasons behind their significance to individuals in treatment for self harm. Utilising the architectural science principles of examining the way buildings are used and how well they physically fit their function, this paper explores the design of the built environments delivering mental health services, and the impacts of design practice on the therapeutic efficacy and the function of these spaces. By understanding how individuals who self harm may experience a space, better design of these environments delivering mental health services may be enabled. This paper suggests a series of design initiatives for each of the spaces outlined, and suggests further research into how to evaluate and integrate these into built environments. Implications for clinical practice are discussed, to explore the relationship between the physical space and the function for which they are designed.

Keywords: Self harm; therapy; built environment; interior design.

1. Introduction

There is a considerable body of literature affirming links between mental wellbeing and good design practice. Evaluations of specific design interventions have shown that good design of clinical and treatment environments leads to better clinical outcomes and less stress for the users; both patients

¹ Within this paper, the counselling workspace is defined as the space where a therapeutic/counselling session occurs. This is typically an interview room/office type space, and is inclusive of physical items such as a table, chairs, bookshelves and similar; physical aspects such as ceiling height, colour, lighting levels and similar; and other aspects such as control, personalisation, territories, interpersonal distances and similar, all forming what Stanley Law describes as 'the therapeutic situation'. [Law, S., G (1948) The therapeutic situation, in S. G. Law (ed.), Therapy through interview, McGraw Hill, New York, 12-21.]

² Within this paper, self harm is conceived of as the physical harming of the body without suicidal intent. This involves a physical wounding of the body tissues. More broad definitions of what may constitute self harm, such as eating disorders, tobacco smoking, alcohol abuse, or some forms of tattooing, and correlated but clinically separate conditions, such as depression, are not considered part of this research.
and staff (Ulrich et al., 2004; Marberry, 2006). When considering environments for therapy and
counselling specifically, research exists which links this therapy practice with the built environment,
illustrating how its design can affect therapeutic delivery and suggesting that the incorporation of spatial
and built elements should form a part of therapeutic techniques (Sivadon, 1970). The counselling
environment is regarded within clinical literature as having an effect on a consumer’s sense of
wellbeing (Gross et al., 1998; Ulrich et al., 2008). Consumers’ experience of such spaces can have a
highly emotional dimension (Pressly and Heesacker, 2001) which is suggestive that environment design
should be investigated as a potential means to influence therapeutic efficacy. Further, individuals have
differing abilities to censor or suppress their environments (Dijkstra et al., 2008) and a stressed patient
has reduced capacity to exclude environmental distractions (Samuelson and Lindauer, 1976), suggesting
the environment of a counselling room may have more impact for these individuals who often arrive in a
distressed state. Research exists linking the design of counselling workspaces to communication and
patient self-disclosure. This highlights the potential significance of the physical design of built
environments which are delivering mental health services.

2. Methodology

The above discussion serves to emphasise the importance of spatial encounters within counselling and
therapeutic practice, as defined in the literature. As outlined in this paper, the author has conducted
interviews with consumers in treatment for self harm to further understand and analyse the linkages
between space and therapy. Many counselling theorists and practitioners assert that there is a link
between counselling environment design and therapeutic outcomes (Pressly and Heesacker, 2001).
However there is also an acknowledged lack of research in this area (Pressly and Heesacker, 2001),
further, many existing studies which examine the impact of the designed environment on counselling
practice have focused on the public areas, such as common rooms in in-patient psychiatric facilities,
rather than more private spaces, such as counselling rooms (Corey et al., 1984). A number of studies
have only focused on therapist perspectives of the issue rather than interviewing patients/consumers
(Pearson and Wilson, 2012). This is suggestive that consumer perceptions also need to be included in
the research, and that a multi-source data collection methodology is ideal, where the counsellors,
patients, and other related parties such as patient carers, are sought to provide feedback to inform the
research. The design of built environments delivering mental health services affects each of these
groups (Pressly and Heesacker, 2001).

Fieldwork undertaken by the author involved a series of focused interviews with consumers,
therapists/counsellors, carers, architects/designers and design experts/researchers, in order to
understand consumer experience of built environments delivering therapy. This data was analysed
through a thematic network (Attride-Stirling, 2001) and the data re-interpreted to draw conclusions on
spatial perception, and implications for the design of built environments to best support the function of
therapy. Open ended questions were asked in order to facilitate participants expressing their views on
the issues being investigated (Creswell, 2003). The interviews lasted from forty minutes to ninety
minutes depending on interviewee’s responses to interview questions. This exploratory qualitative
analysis (Attride-Stirling, 2001) was undertaken with the five respondent groups noted above, including:
12 consumers of mental health services, 12 practicing therapists/counsellors, 3 carers of loved ones with

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3 The term consumer is used within this paper referring to the individuals who are clients of mental health service delivery. The terms patients and consumers
are used interchangeably.
a mental illness, 4 architects/designers who practice in the field of designing built environments for mental health; and 5 design experts/researchers who work and research in the field of design for mental health. For in depth interviews, as were undertaken, the number of interview respondents were deemed significant enough to draw substantial conclusions (Attride-Stirling, 2001).

Through this fieldwork undertaken by the author, three further environments in addition to the counselling workspace were found to be significant, which are the subject of this paper. These spaces include a de-escalation space post counselling, an urge room in inpatient care, and a natural mind-space, adjacent to the counselling workspace and accessed only visually, such as through a window to an outside courtyard. The transition of spaces and planning of the spatial journey around a counselling session was also found to be significant. Each of these spaces is discussed below, as they were reflected upon by interview participants. Each space is also presented with reference to clinical literature to better enable an understanding of why these specific spatial environments and their particular design is significant. Following this, therapeutic implications of spatial design are discussed, outlining how the physical built environment affects therapeutic delivery. Finally, a series of design initiatives are suggested in relation to each of these spaces, to better enable the activity of therapy and support this function.

2.1. De-escalation space

A space to occupy post- counselling as part of a journey of de-escalation was found to be significant to individuals who self harm, in fieldwork undertaken by the author. After the intensity of a counselling session, for individuals who self harm the transition to the outside world afterward was found to be very difficult:

“The therapy sessions are often really intense, I don’t know about other people but my sessions might go for two hours, and I’d be totally numb afterwards and have to go straight out into the world, when I feel so vulnerable and it was so frightening, sometimes I’d just get so anxious about it, I’d be self harming in my car on the way home” (Consumer, 2015, Personal communication).

Having a space to occupy alone post counselling was raised by several consumers as being of potential benefit to them:

“If you could sit on your own and self soothe and rebalance yourself before you leave; otherwise I just dissociate and I think how did I get here! I must have gotten in my car and driven home but I’ve dissociated, which I do really easily after a session, and I have no idea how I’ve gotten home, and that’s dangerous! Somewhere in private before you go, it’d stop you dissociating, and mediate between the really intense heavy session, and going home” (Consumer, 2015, Personal communication).

Consumers who were interviewed mentioned feeling very vulnerable after their counselling session and needed a space to occupy quietly and privately to rebalance themselves and move from the intensity of the counselling session to the noise and pressure of the ‘outside world’. Some mentioned that within the counselling workspace they felt shut off from the world and needed a private space to sit in and maybe have a cry and prepare themselves for moving back into the world they had felt shut off from moments before. One consumer noted that even knowing that a private room was available for
this de-escalation would help: “you may not go into the room, but knowing it is there [would bring comfort]” (Consumer, 2015, Personal communication).

A practicing therapist also reflects and supports the idea of a de-escalation space for consumers after a counselling session:

“Emerging straight into the world is confronting; I would liken it to getting up in the morning, and you have been in another state like sleep, and you need to adjust and bring yourself back to the world outside and bringing yourself back to whatever that might need to be. So, I think you are at a different rate, whether it be consciousness, or reengaging back into where you were previously, I think that can take time, and it can also take an awareness of how you can bring yourself back to that space” (Therapist, 2015, Personal communication).

One practicing therapist also discusses the notion of a de-escalation space for consumers to occupy post counselling, revolving around bodily movement:

“Possibly beyond that [counselling space] a space for someone to take a short walk, like a small hallway, for someone who the way they gather themselves... [is to] take a short walk back and forth... the physicality of walking is calming... it does offer the opportunity for your mind to go to find the answer. The rhythmic nature is also important” (Therapist, 2015, Personal communication).

This is suggestive that the transition between a counselling session and the world beyond is difficult and needs to be supported by environment and design, such as through a de-escalation space.

It seems the suggestion of a de-escalation space post counselling is strongly related to dissociation; this dissociation is prominent in individuals who self harm and the de-escalation space would be beneficial to help manage this, aiding reconnection with the self and re-integration with the ‘outside world’. Self injury is synonymous with stronger dissociative traits (Zlotnik et al., 1999), particularly during an episode of self harm (Low et al., 2000). Further, dissociation means that the experience is not remembered, which is confronting. This perhaps indicates why such a space is significant in individuals who self harm.

2.2. Urge room

The notion of an urge room in inpatient care was brought up in interviews with individuals who self harm. This is essentially a space where they might go when confronted with the urge to self harm, and this space would help to quell these desires through its design. This is described thus:

“Bright coloured pods, a confined space, where I could go would help - I blast the senses to occupy myself, to bring me back to the present. A sensory stimulus pod! That can rock! To soothe yourself. I mean, that’s why I watch a movie really loud [when I have the urge to self harm], or play my music real loud, to bring me back and stop distress. Rocking - it's relaxing, and it’s disabling, it’s rhythmic and brings you back to your body” (Consumer, 2015, Personal communication).

High sensory stimulation is paramount in this room to quell dissociative traits and enable the individual to remain present. Music is also noted as useful in this endeavour: “[Music] would be great for soothing, to be more present, it’s a good distraction and coping strategy. Music is good for escapism, it can transport you” (consumer, 2015, Personal communication).
Within clinical literature it is noted that individuals who practice self harm are commonly also afflicted by symptoms known as ‘high sensation seeking’ (Leibenluft et al., 1987). There is a close relationship between the practice of self harm and the sensations of the body (Huband and Tantam, 2009); the harming procedures serve to elicit sensory response as an emotional release, or aim to reconnect with the body, when anxiety or emotional distress has served to disengage the individual’s perceptions of their body, its boundaries and their environment (Juzwin, 2004). The high need for sensation is also attributed to maintaining arousal states in self harming individuals (Jones, 1982), essentially used to feel “something...more tangible” (Huband and Tantam, 2009) and provide important evidence that one is still alive. High sensation seeking is directly related to both mental wellbeing/function and the individual’s wider environment. There is an inference in existing research that high sensation seeking individuals have very particular perceptions to and needs from their environments (Hebb, 1958). Some require very strong stimuli in order to experience optimally strong emotions and support appropriate mental functioning (Zaleski, 1983). Experiences of high stimulation and arousal may help the individual to bypass the urge to self injure (Bresin et al., 2013). This is suggestive that an urge room would be useful in aiding individuals to quell dissociation and urges to self harm.

2.3. Natural mind-space

A view through a window to a natural landscape adjacent to the counselling workspaces was found to be very significant for individuals who self harm, in fieldwork undertaken by the author.

“Having that view out to a landscape, it’s been important through my whole stages of treatment, yeah the whole way, but I didn’t realise until I didn’t have that safe view from a window, and I think that is probably part of the reason I didn’t continue in some ways, because as I said it was so confrontational, I had nowhere to look, I felt totally judged and I just didn’t feel safe” (Consumer, 2015, Personal communication).

It seems that this landscape is not important to occupy physically, and that visual access provides the sense of escapism or mental respite which is desired:

“I would look out the window and even in the counselling I would need a window to feel safe, to “Oh, there’s a world out there!” You know? There’s a world out there and I might not feel safe in the physical area I am in, but it’s OK. It gives me a psychological connection to a bigger space, to a world outside what I am dealing with” (Consumer, 2015, Personal communication).

This window, alongside escapism, also promotes a sense of control, which is commonly lacking in individuals who self harm (Briggs et al., 2008):

“I’d like a big window where I could focus on everything. Otherwise [if the window is too small] it’s like you are just looking through a tunnel, you are not seeing what both sides are, what the big picture is, if I had a bigger window, I could see a bigger picture... It’s more relaxing, it allows me to be free, it allows me my freedom and my control, not anyone else’s” (Consumer, 2015, Personal communication).

The counselling space itself can be a smaller space, whilst still providing this visual access to a landscape space:
“I prefer smaller, smaller around me, but visual access to something larger, like a landscape, ideally” (Consumer, 2015, Personal communication).

However, it seems that a large expansive view to an unframed landscape, with no boundaries, is not preferable:

“I think if it’s too big, yeah I don’t think I’d feel safe, I don’t know why. No, if it’s too big I don’t think I’d feel safe” (Consumer, 2015, Personal communication).

The notion of a framed landscape as providing greater sense of freedom and comfort simultaneously is echoed by several consumers, who discuss how connection to nature in a contained way allows them to maintain a sense of protection and control through the borders or framing of the natural space.

Self harm is also associated with notions of control, which may explain why an unbounded landscape is threatening, as it may be more difficult to ‘come back from’, and this is confronting to individuals who already feel a lack of sense of control. Clinical literature and accounts of self harm describe how self injury is often a means by which an individual aims to reassert a sense of control and to quell anxiety. A perceived lack of control as occurs in self harm is closely linked with increased anxiety, and further “chronic self-injurers are often significantly less able to cope with emotional stress” (Huband and Tantam, 2009). The purpose of self harm is to reduce anxiety. The accounts of self harm also allude to notions of control when discussing boundary. These individuals seek experiences of high sensation in order to root themselves in a sense of stability (Levitt et al., 2004), in order to feel and explore the extent of their body (Huband and Tantam, 2009), and to feel in control (Briggs et al., 2008).

Practicing therapists also acknowledge that “landscapes and views to nature allows you [the consumer] a sense of escapism” (Therapist, 2015, Personal communication) and yet “a vast expanse is going to allow you to go too far, and might be threatening” (Therapist, 2015, Personal communication). Access to nature provides tranquillity and “it did have that enclosed space to it, and that offered me a lot of comfort” (Consumer, 2015, Personal communication). Thus, “the closed space does make sense to be able to bring someone back” (Therapist, 2015, Personal communication). It is noted by another practicing therapist how a sense of boundedness might also afford a psychological kind of privacy, which is important to therapeutic processes:

“The containment [around a natural space] demarcates that this is a sacred kind of space, and it respects people’s privacy, so what we are talking about here is just between us, and I think if it was just in the middle of a field it might feel unsafe... [it is important to have containment] when a client is talking about things that might make them feel vulnerable or exposed. Having an uncontained landscape would just exacerbate that feeling of vulnerability, I think it really could” (Therapist, 2015, Personal communication).

It also seems that the window offering views to nature should be on the ground floor or lower levels of a building for therapeutic reasons. As one practicing therapist explains, “being in a high building and having a view out might not be so grounding” (Therapist, 2015, Personal communication) which can be problematic therapeutically. Another therapist echoes this notion, explaining how high elevation in a built environment can be destabilising, and this can interrupt the therapeutic processes of the counselling session.

Theoretical research in this area explains that nature containing elements and content will reduce stress (Ulrich, 1999). Studies in healthcare environments generate strong evidence of the stress-reducing benefits of real or simulated views of nature or natural elements, and this manifests in positive
emotional, psychological and physiological changes (Hartig et al., 1995). This relates to how visual access to nature may allow individuals who self harm a sense of safety, as nature helps to reduce stress and anxiety and thus promotes a sense of comfort. Literature discusses user control in relation to territories and boundaries; as Goffman explains, we utilise boundary markers to distinguish territories and exert a sense of control (Goffman, 1971). This perhaps explains why a bounded landscape, accessed visually and occupied only by the mind, is calming, whereas an unbounded landscape is threatening.

2.4. Spatial journey

The notion of a linear spatial journey was also raised as being significant by individuals in treatment for self harm. As one explains: “It’s kind of yucky to walk out the same way you came in if you are distressed. There should be a distressed door [an exit to use when feeling distressed after a counselling session], where you can’t be seen, and can leave that’s different to the entry. Yeah a linear journey, I like that idea” (Consumer, 2015, Personal communication). It seems there is a metaphor of progress made spatially, and to back track and repeat earlier steps is not conducive to or representative of therapeutic development, and reminds the consumers of how they felt prior to the session, which to the consumers feels as though they are not making positive progress. A practicing therapist reflects on this:

“So you step out of the counselling space and if it is somewhere where you have just been, it doesn’t totally make sense [to reverse your journey] and I can see why someone could feel like it is a little bit of a backtrack, and you are just back where you started... if a certain behaviour environment represents something to someone, we need to listen to that and understand that it is really beneficial” (Therapist, 2015, Personal communication).

Another practicing therapist reflects on the metaphorical journey of a counselling session:

“Perhaps they [the consumers] are somewhat mentally preparing for a session and what to mention to their counsellors and it might be the space that triggers a lot of that thinking, and perhaps then having a space that you could then leave through would associate more with letting go of the session, and creating that mental boundary or that mental break between what just happened in the session and resuming your day to day daily life” (Therapist, 2015, Personal communication).

The importance of metaphors, such as the physical journey around counselling, may be of particular significance to individuals who self harm. To express emotional or physical pain to another, individuals who self harm “often rely upon metaphor. Self-mutilation is generally an unspoken expression of an internal and intangible experience” (Hitchcock Scott, 1999). Here self harm is a significant metaphor. Perhaps this is an indication of why the metaphor of a journey through physical space is of particular significance to individuals who self harm, who are already operating with strong use of metaphors, and find much comfort and calm in this.

3. Therapeutic implications of spatial design

Each of the spaces discussed above suggest a relationship between the physical design of the built environment delivering mental health services, and the therapy taking place. A de-escalation space may better enable a consumer to re-engage post counselling, reduce stress and anxiety, and minimise dissociation, which in turn promotes re-connection with the self. An urge room, by offering high sensory stimulation, may quell dissociative traits and urges to self injure, allowing the consumer to
remain present and more readily engage in therapy. A natural mind-space reduces stress and anxiety, offers escapism and a sense of control, which aligns with key aims of therapeutic treatments. A journey manifested spatially reinforces notions of progress and development, which supports empowerment in the consumer. These therapeutic implications of spatial design highlight the significance of the physical environment in supporting delivery of mental health services.

4. Design initiatives

Following the initial literature review, and the analysis of interviews conducted by the author, potential design initiatives suggested to architects were developed in relation to the design of counselling practices, relative to the three spaces beyond the counselling workspace outlined in this paper (see Table 1). Further research is suggested into these suggested initiatives, through a careful post occupancy evaluation and control studies, to better understand their applicability and therapeutic effects.

Table 1: Design initiatives

<table>
<thead>
<tr>
<th>De-Escalation Space:</th>
<th>Therapeutic effects discussed</th>
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<tbody>
<tr>
<td>Layout to permit movement (walking/pacing) as well as sitting</td>
<td>De-stress;</td>
</tr>
<tr>
<td>Visual and audial privacy must be afforded (consider lines of sight, access, soundproofing)</td>
<td>Reduce dissociation, remain present;</td>
</tr>
<tr>
<td>Rich material palate promoting sensory stimulation</td>
<td>Progress metaphor.</td>
</tr>
<tr>
<td>Connection to nature ideal (artificial means include artwork posters with nature content, sound recordings of nature; other means include pot-plants, views to nature/courtyard, sand trays/rock garden to engage with)</td>
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<tr>
<td>Exit must not link back to the point of entry; circulation must be a linear journey</td>
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<tr>
<th>Urge Room:</th>
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<tbody>
<tr>
<td>Rich material palate promoting sensory stimulation</td>
</tr>
<tr>
<td>Ability to play music – user controlled</td>
</tr>
<tr>
<td>Bright colour in interior furnishings and wall colouring</td>
</tr>
<tr>
<td>Small interior dimensions – the space needs to feel tight in order to quell anxiety (do not use high ceilings, spacious interior)</td>
</tr>
<tr>
<td>Tactile wall treatments beneficial</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Reduce dissociation, remain present; Foster sense of agency.</td>
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</tbody>
</table>

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<tr>
<th>Natural Mind-Space:</th>
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<tbody>
<tr>
<td>View to nature is privileged – natural space must be directly adjacent to the counselling workspace</td>
</tr>
<tr>
<td>Nature area is framed or bordered (such as an enclosed courtyard, an open area with a surrounding hedge, tree-lined (evergreen) to block further sight, consider clear spatial boundaries)</td>
</tr>
<tr>
<td>Nature area cannot be accessed (the area must be enclosed an private to allow it to be occupied by the mind – ensure entry points are not seen from the counselling workspace)</td>
</tr>
<tr>
<td>Large windows to allow access to this nature area from the interior of the counselling workspace</td>
</tr>
<tr>
<td>Counselling workspace is on the ground floor or lower levels of the building</td>
</tr>
<tr>
<td>Visual access to ground and sky is permitted at all times (consider lines of sight and window positioning)</td>
</tr>
<tr>
<td>Interior area of counselling workspace may be smaller if nature area is larger</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Escapism; Provide safety and privacy; De-stress; Remain present/ grounded.</td>
</tr>
</tbody>
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<tr>
<th>Spatial Journey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear circulation from entry, though counselling workspace, to exit</td>
</tr>
<tr>
<td>De-stress;</td>
</tr>
</tbody>
</table>
Consider use of spaces before and after the counselling workspace, such as reception/entry and de-escalation space. Consider use of a ‘distress door’ or exit which separate to the entry. Consider privacy around the exit from the counselling workspace (lines of sight from reception/entry, audial privacy). Consider circulation which keeps consumers entering and consumers leaving from interacting and maintains privacy.

Progress metaphor; Increase privacy/safety.

5. Conclusion

Self injury is acknowledged by the literature as a growing health concern (Klonsky and Glenn, 2008). In addition, self injury is correlated with many types of psychopathology, and personality disorders, including the borderline, dependent, schizotypal and avoidant personality disorders (Klonsky et al., 2003). This paper has addressed therapeutic interventions for individuals in treatment for self harm through the vehicle of the design of the built environment. This paper found the importance of a de-escalation space post counselling, to quell dissociative traits; an urge room to keep individuals grounded in the present and help quell urges to self injure; the inclusion of a natural mind-space adjacent to the counselling workspace; and the journey of counselling manifest in physical space is significant for remaining present and quelling dissociative traits. The findings suggest a need for these proposed spaces, but further research is needed to prove the need and efficacy of the suggested design initiatives.

This reinforces the importance of the physical environment in relation to therapeutic outcomes, and a consideration of how buildings are used and how well they physically fit their function of delivering mental health services. Further research is recommended into how the spaces discussed in this paper may be manifest and integrated into the development of care. The findings in this paper emphasize the importance of consumer consultation, to best understand the perception of these spaces by individuals in treatment for self harm. Finally, consideration should be given to further research into the specificity of how to design and integrate these spaces, through careful post occupancy evaluation and control studies, to enable the built environment to best support therapeutic delivery and mental wellbeing.

References


Counselling workspace design and therapeutic practice

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Abstract: This paper investigates the relationship between the design of the counselling workspace and therapeutic practice for individuals who self harm. Architectural science encompasses how a built environment physically fits its function; in this paper the subject of investigation is how the design of the counselling workspace affects its function, the delivery of mental health services and therapy. Firstly, the counselling workspace design is discussed across three key themes which were significant points of overlap between architecture and clinical literature during the literature review undertaken. These themes include: self disclosure; territories, self image and autonomy; and body language in therapy. Secondly, the research methods relevant to understanding the significance of counselling workspace design in therapy are discussed. Thirdly, following fieldwork research undertaken by the author, a table of design initiatives is presented. This is suitable for architects and designers working in the design of counselling workspaces, and is also expanded to the wider field of designing for mental health and designing for inpatient and/or hospital care.

Keywords: Therapy; built environment; self harm; interior design.

1. Introduction

“When circumstances necessitate a change in offices, in the case of a patient who has been visiting for some little time, it takes the patient and therapist part or all of an interview to settle down in the new environment. This would seem to indicate that in a therapeutic situation an emotional overtone develops that is unique and defies description” (Law, 1948).

Within this paper, the counselling workspace is defined as the space where a therapeutic/counselling session occurs. This is typically an interview room/office type space, and is inclusive of physical items, such as a table, chairs, bookshelves and similar; physical aspects such as ceiling height, colour, lighting levels and similar; and other aspects such as control, personalisation, territories, interpersonal distances and similar, all forming what Stanley Law describes as ‘the therapeutic situation’ (Law, 1948). These
spaces are common across a wide range of treatment service providers where mental health clients may be treated, such as hospitals, private clinics, and community service providers. Each consumer¹ will encounter such a space and will also likely encounter this environment for an extended period of time or over a number of visits, thus are the subject of initial examination within this paper as they are both widely utilised and regularly attended.

2. Counselling workspace design: Literature review

Whilst treatment of mental health conditions occurs in a range of settings, including specific mental health agencies, hospitals, community service centres, schools and private practices, each has a certain room in common: a counselling workspace, which will be encountered by the consumer. This particular space has been reported as a factor that can influence the relationship between therapist and consumer, as well as therapeutic outcomes (Iwai et al., 1983).

The counselling environment is regarded within clinical literature as having an effect on a consumer’s sense of wellbeing (Gross et al., 1998; Ulrich et al., 2008). Consumers’ experience of such spaces can have a highly emotional dimension (Pressly and Heesacker, 2001) which is suggestive that environment design should be investigated as a potential means to influence therapeutic efficacy. Further, individuals have differing abilities to censor or suppress their environments (Dijkstra et al., 2008) and a stressed patient has reduced capacity to exclude environmental distractions (Samuelson and Lindauer, 1976), suggesting the environment of a counselling workspace may have more impact for these individuals whom often arrive in a distressed state. Research also suggests that layout has strong psychological dimensions for consumers in therapy, and may form a pathway to addressing issues of the self (Liddicoat, 2015). This is suggestive that the counselling workspace may be influential in consumer anxiety levels and therapeutic efficacy.

Linking the design of counselling workspaces to communication and consumer self-disclosure is another major area of research. Self-disclosure, communicating personal information about oneself to another individual (Strassberg et al., 1978), can be confronting to a consumer (McLeod and Machin, 1998) and is less likely when the consumer is in an anxious or worried state (Ignatius and Kokkonen, 2007). However, this self-disclosure is important for the physician or counsellor to plan suitable treatment (Cegala et al., 2004). Studies demonstrate that non-verbal cues in communication account for more variance in the message than verbal cues in communication, sometimes as high as a ratio of 1:20 (Argyle et al., 1971). The interplay of verbal and non-verbal cues is of significance in a counselling context (Gladstein, 1974) and non-verbal variables have been analysed with reference to communication in counselling settings, including distance, body position and body motion (Dinges and Oetting, 1974). These non-verbal communication aspects may be affected by the design of the spatial environment (Sommer, 1974). Non-verbal communication is also of particular significance for individuals who self harm, who find conventional language means of communication as not meeting their needs, and who use their bodies as communication to others via self harming (Horrocks and House, 2010). The following paragraphs discuss how aspects of the counselling workspace, as identified in the existing literature, have an effect on consumer self-disclosure.

Research shows a wider distribution of light leads to perceptions of greater spaciousness (Martyniuk et al., 1973), greater amounts of floor space are judged to be larger (Benedikt and Burnham, 1985), as

¹ The term ‘consumer’ is used within this paper to describe the individual who is the user of mental health services. This term is favoured within contemporary literature and mental health practice.
are rectangular rooms over square (Sadalla and Oxley, 1976). Building upon the notion that a larger room may generate feelings of freedom and spaciousness (Meyers-Levy and Zhu, 2007), Okken et al reported through their own investigation that an increase in room size positively influenced consumer comfort and self-disclosure, and that these consumers also preferred a smaller interpersonal distance when the room was large. It is also suggested that limited space within a room may induce crowding perceptions which can decrease communicative behaviours (Sundstrom, 1975). Research examines the effect of personal space and distance variables on human behavior (Argyle and Dean, 1965), and this notion within counselling settings (Stone and Morden, 1976). Studies by Lecomte, Hall and others are suggestive that distances between 30"/76.2cm and 50"/127cm between consumer and therapist produce highest self-disclosure, which is closer than social distance (defined by Hall as 80"/203.2cm) and also “not the culturally expected conditions for counselling interactions” (Hall, 1963; Lecomte et al., 1981). Meagher and Marsh suggest that affordance in an environment, that is, the opportunities for behaviour it affords, will increase feelings of spaciousness (Meagher and Marsh, 2011). Atmosphere is also implicated in self-disclosure in counselling workspaces: “Is the atmosphere conducive to thinking and reflection? Is the encouragement of conversation and discussion desirable?” (Smith and Watkins, 2010). Spaces consisting of resistant surfaces and bright lighting are suggested as increasing consumers' feelings of non-control over their environments (Sommer, 1974). This is suggestive that atmosphere, spatial layouts, and the notion of spaciousness are influential in consumer self-disclosure, and in turn therapeutic outcomes.

3. Counselling workspace design: Research methods/approaches

Many counselling theorists and practitioners assert that there is a link between counselling environment design and therapeutic outcomes (Pressly and Heesacker, 2001). However there is also an acknowledged lack of research in this area (Pressly and Heesacker, 2001), with many existing studies which examine the impact of the designed environment on counselling practice have focused on the public areas, such as common rooms in in-patient psychiatric facilities, rather than counselling rooms (Corey et al., 1984). Further, many studies only focus on therapist perspectives of the issue rather than interviewing patients/consumers (Pearson and Wilson, 2012). This is suggestive that a multi-source data collection methodology is ideal, where both the counsellors, consumers, and other related parties such as patient carers, may partake in data collection. Fieldwork undertaken by the author involved a series of focused one-to-one interviews with consumers, therapists/counsellors, carers, architects/designers and design experts/researchers, in order to understand consumer experience of built environments delivering therapy. This data was analysed through a thematic network (Attride-Stirling, 2001) and the data re-interpreted to draw conclusions on spatial perception, and implications for the design of built environments to best support the function of therapy. Open ended questions were asked in order to facilitate participants expressing their views on the issues being investigated (Creswell, 2003). The interviews lasted from forty minutes to ninety minutes depending on interviewee’s responses to interview questions. This exploratory qualitative analysis (Attride-Stirling, 2001) was undertaken with the five respondent groups noted above, including: 12 consumers of mental health services, 12 practicing therapists/counsellors, 3 carers of loved ones with a mental illness, 4 architects/designers who practice in the field of designing built environments for mental health; and 5 design experts/researchers who work and research in the field of design for mental health. For in depth interviews, as were undertaken, the number of interview respondents were deemed significant enough to draw substantial conclusions (Miles and Huberman, 1994). The interview respondents were from
Australia, New Zealand, England and Iran, and were undertaken in 2015. Cases of existing built environments delivering mental health services were also analysed in order to provide another lens for observing human experience and understanding the effect of counselling room environmental features. Ten cases were analysed, two in New Zealand and eight in Australia. Analysis of the cases was framed within a cases analysis tool developed by the author which focused on the translation of the factors arising from the interviews into the language of designing spaces. This data set as a whole was analysed through a thematic network (Attride-Stirling, 2001) and the data re-interpreted to draw conclusions on spatial perception, and implications for the design of built environments to best support the function of therapy.

4. **Counselling workspace design: Design initiatives**

Following fieldwork undertaken by the author, a table of design initiatives is outlined below for architects/designers working in the field of designing for mental health service delivery. These initiatives presented extend beyond aspects of the design of the counselling workspace, to include wider areas, such as waiting areas and inpatient bedrooms, which also impact the delivery of mental health services and efficacy of treatment being offered. As arose from the fieldwork data analysis, the physical fit of a building to its function, in this case the delivery of mental health services, is not limited to only the counselling workspace design, and as such, design initiatives for other spaces within delivery facilities are tabled to best consider how to design spaces to support the function of delivering mental health services. These design initiatives are presented below, in order of scale from large to small, including: Facility Wide Design Initiatives; Waiting Area; Counselling Workspace Interior Layout; Counselling Workspace Furniture and Fitting Selection; and Inpatient Bedrooms. Each design initiative is also noted as either related to function and manageability, or to therapeutic processes and psychological outcomes, or to both.

Each table was derived by firstly gathering suggestions arising from the fieldwork data collection undertaken, verifying or elaborating these through a comparison to existing literature within architectural discourse and clinical/social work fields, and examining these through the thematic network analysis to best understand their significance, relations to therapeutic outcomes, and intended architectural articulation as voiced by interview participants. These were then arranged into sets, through a consideration of scale and/or location within a healthcare facility, which gave rise to each table presented below. The tabled design initiatives are suggestions arising from the study undertaken, but further research is needed in order to understand the mechanism of how these architectural initiatives influence mental wellbeing, and their efficacy, through further qualitative data gathering, careful post occupancy evaluations and control studies.

Facility wide design initiatives (see Table 1) were predominantly concerned with wayfinding strategies, both to increase functionality/usability of spaces and to reduce stress experienced by the users. In relation to functionality, this related to issues of surveillance and lines of sight, and having a linear journey through the facility as experienced by the user undergoing counselling. This was seen by consumers as a metaphor for therapeutic progress, and afforded a greater sense of empowerment. Reducing stress is achieved through the inclusion of greenery and green spaces, such as courtyards, and layering of spaces in terms of their privacy for greater spatial and behavioral comprehension and articulation of territories.
Table 1: Facility wide design initiatives

<table>
<thead>
<tr>
<th>Facility Wide Design Initiatives</th>
<th>Functionality/Manageability</th>
<th>Therapeutic/ Psychological</th>
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<tbody>
<tr>
<td>Abundant use of nature and greenery, including visual access to natural elements as well as physical presence in the interior spaces. Artificial presence, such as through photographs of landscapes, is also seen as beneficial, but should be included in addition to physical presence of nature, not instead of. Include spacious and airy atria and entry spaces. A low ceiling in these areas is considered quite detrimental. Include facilities for patients to develop skills such as kitchens, for control and empowerment. Overall layout should have no dead ends in circulation. Have multiple spaces able to be accessed from circulation paths, not a circulation route which ends in one space, which feels enclosing. Interaction between inside and outside created by several different buildings on a campus which is well landscaped is considered ideal. Have discrete entry points to protect privacy. Access to the practice is part of the journey, and so must be private and secluded and feel separate from the outside world. Consider a layering of thresholds at the entry point. Include niches off corridors for informal discussions. Spaces have visual connection to other spaces and do not feel fully enclosed. Provide controllable, dimmable lighting to promote a sense of calm. Do not have internal rooms. Layouts that are not ‘octopus’ like in plan. Layouts which resemble a figure 8 with courtyards at the centres and a staff station at the central connection point allow visibility and surveillance for staff and access to courtyards for all. Include a gradation of spaces in terms of their privacy from entry to occupied spaces to allow people to adjust. Privacy gradients ensure that a consumer never leaves a counselling room/private space and goes directly into a large communal space. Use spaces such as a seating area in between. What can also be useful is a threshold area within a door with a lowered bulkhead and differing floor treatment; this denotes a more private spatial boundary. Do not physically separate consumers from staff, particularly in reception areas, such as having a fish-bowl type reception desk. Include internal gardens where possible. Minimise exposed concrete in gardens/courtyards. Have a linear journey from waiting area, to counselling workspace, to exit. Include a de-escalation space post-counselling, for self-soothing and rebalancing. This is to be private, include a space for walking/pacing, some natural elements (such as a potted plant, natural photograph or view to a courtyard), comfortable seating, and sensory modulation materials. Minimise use of lifts after a counselling session (not an ideal exit strategy). In communal spaces, such as waiting areas, make them more open plan and differentiate walking areas by lowering the ceiling or changing the floor finish or lighting. If one is going to walk through a large space, the design needs to differentiate the spaces for walking in and the spaces for being static in.</td>
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Waiting area design initiatives (see Table 2) were predominantly concerned with physical and psychological privacy. This was a primary concern for consumers, and affected their mental states prior to counselling and the extent to which they were able to engage in the therapy sessions. Physical privacy related to aspects such as managing lines of sight in the environment and audial privacy. Psychological privacy related to how safe or unsafe a user felt, by being exposed, and the notion that by being confronted with another consumer, or overhearing them, they felt overwhelmed with the magnitude of their own thoughts and feelings as well as those of others sharing the space and intruding in their own psychological space.

Table 2: Waiting area design initiatives

<table>
<thead>
<tr>
<th>Waiting Area</th>
<th>Functionality/Manageability</th>
<th>Therapeutic/Psychological</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Initiative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ensure that the therapist and the consumer enter the counselling workspace together, rather than the consumer waiting inside the counselling workspace alone, which is intimidating.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Manage lines of sight so that consumers never feel on display in waiting areas.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Furniture should not be arranged in lines; this is too formal and impersonal.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Do not have televisions in the waiting areas; views to landscapes or artwork are preferable.</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>In waiting areas, a consumer should be able to see everyone that they can hear, and not see or hear anyone outside of the direct space. Discrete partitioning/separation in waiting areas is ideal to allow a consumer to be on their own, yet aware of others in the space.</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>A waiting consumer should not be able to easily hear other conversations in the waiting area; muffled, indiscernible noise is acceptable.</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Separation of consumers from other consumers where possible is ideal.</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Minimise use of glass doors, windows in doors, and glass separations. This makes the consumers feel scrutinised and controlled.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Consider furniture selection (such as winged armchairs) or other such private cubicles to protect identities of consumers, and allow them to not see another consumer, even from behind.</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Do not allow the consumer to see the counsellor entering and exiting the office from the waiting area.</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

Counselling workspace interior layout design initiatives (see Table 3) relate to how the physical design of the space promotes consumer self-disclosure, communication, empowerment and psychological safety. The layout of the room has strong metaphorical messages to the consumer, particularly in relation to ‘space for the mind’, and circular layouts being reminiscent of ‘going around in circles’. Self-disclosure and communication are affected by the spatial arrangement, which directly affects the therapeutic processes. Empowerment relates to how the space might be flexible, and be adjusted to meet individual consumer needs, and allow them to enact and develop a sense of agency within physical space. This is supportive of therapeutic processes, which also aim to develop sense of
self and agency. As the design is considered from a larger scale (facility wide) to a smaller scale (counselling workspaces) the notion of psychological freedom becomes more significant. Wider scales were found to be less significant to notions of empowerment, identity, sense of self and agency for the consumer than smaller scales; the engagement with specific rooms and spaces, their physical design and layout, had more psychological significance than larger scale considerations. This is suggestive of a closer engagement with these counselling workspaces, and a stronger connection between the design of these spaces, mental states and therapeutic processes.

Table 3: Counselling workspace interior layout design initiatives

<table>
<thead>
<tr>
<th>Counselling Workspace Interior Layout</th>
<th>Functionality/Manageability</th>
<th>Therapeutic/Psychological</th>
</tr>
</thead>
<tbody>
<tr>
<td>Promote flexibility in the interior layout, with moveable furniture, objects, and enough space to allow this rearrangement of environment.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Have one entry door which is used to enter the counselling workspace, and have this door visible and accessible by all chairs in the room. Where the consumer sits should have more ready access and a clear line of sight to this door (do not have their back to the door). If necessary, an additional egress path can be provided through a doorway to a courtyard, which appears enclosed from the room, but may have a discrete side door. Do not have additional doors from the counselling room which are unclear where they lead.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Seating layout should provide for seating between therapist and counsellor which is at 45°. Seating directly opposite is too confrontational. There should be a side table for each person, which can be adorned with a lamp, plant or items such as tissue boxes. This can be moved between seats if the consumer desires a barrier. There should be no intervening desk, coffee table or barrier between therapist and consumer, and enough room that if both people were to stretch out their legs they would just touch feet. There is also room for each chair to be moved forward or backward from this position. A couch may also be specified to allow the consumer to sit closer or further from the therapist. There should be a piece of artwork or a window directly in front of the consumer’s seat, to allow them to disengage visually. Include an additional chair which is not to be occupied by a person but is a space for the consumers’ mind (equivalent to the personal space of one person). This also makes the space feel more natural and informal. Even spacing between the chairs is also ideal; do not have one chair off to one side, for example. Chairs should all face the centre of the room/each other.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>A spacious room of approximately 5m x 5m x 5m is suggested. (3.5m x 3.5m x 2.4m at minimum.) If there is a smaller floor area, have an increase in ceiling height. Counselling workspaces on the ground level if possible; fluctuating cognitions can cause consumers to destabilise; being able to see ground and sky is idea; in this situation. If the space is on the second or third level, have some anchoring aspects like a view to a tree nearby, to anchor and give a sense of connection to the ground. Where administration functions are also included in the counselling workspace, have this in a separate area. All computer screens should be off during a session.</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
and not visible to the consumer.

The composition of the room as a whole should not be circular – this is seen as a metaphor for ‘going around in circles’ in therapy (often the case with very small counselling spaces).

Counselling workspace furniture and fitting selection design initiatives (see Table 4) are significant in two key ways: firstly, reducing stress, and secondly, through symbolic meanings. By reducing stress, through soft lighting, informal furniture, and minimal anti-ligature features, the consumer is able to more readily engage in the therapy, which illustrates how the design of the space is supporting its function of therapy. Consumers also attach symbolic meanings to features, which were found to be significant and directly impacted the therapeutic processes. For example, having an overly personalized room allowed for the presence of the therapist to be dominant, both within the physical space, and within the psychological therapeutic space occupied by therapist and consumer, which reduced engagement in therapy by the consumer. Materials showing trace and previous inhabitation made consumers feel connected to and distracted by previous consumers who had occupied the space, and these consumers’ potential mental health issues, and so must be avoided.

Table 4: Counselling workspace furniture and fitting selection design initiatives

<table>
<thead>
<tr>
<th>Counselling Workspace Furniture and Fitting Selection Design Initiative</th>
<th>Functionality/Manageability</th>
<th>Therapeutic/Psychological</th>
</tr>
</thead>
<tbody>
<tr>
<td>Informal furniture selection is considered a better choice than furniture which is very formal. However, the furniture should be clear in their function and the overall function of the room. Minimise the presence of security and anti-ligature features. Include artwork, which is detailed in nature, and able to be viewed easily by the consumer. Provide storage space for art materials and sensory modulation equipment. Consumer and therapists’ chairs should be either matching, or all different but of a similar level of quality and formality, with optional cushions. Therapist and consumer should have equal eye level. Furniture that permits movement should also be considered, such as swinging egg chairs or rockers of some sort. Provide a choice of seating options for the consumer including at least two chairs and a space on the floor. Provide cushions and a rug for the consumer to engage with. Couches should not be oversized. Leather, vinyl or wooden furniture is preferred, or upholstery that is not at all worn and is well maintained. Ensure furniture does not keep the imprints of previous inhabitants. Overhead and fluorescent lighting is not ideal. Side lamps are preferable. Natural light is also emphasised. Minimise use of vinyl on floors; instead select wooden floorboards or tile. In general, select materials that will not show trace or weathering over time. Promote consistency of items/props in the space – variation is threatening (it makes the consumers feel they must deal with the chaos internally, so regularity of the environment makes them feel safer).</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Do not allow the therapist to personalise the space to a high degree; this presence disallows the patient to be comfortable and present in the space, physically and psychologically.

Minimise the inclusions of bookshelves where possible (this reinforces the stigma and separation between therapist and consumer). Where books are included they should be behind glass doors.

5. Conclusion, limitations and future research directions

The design initiatives presented in this paper were developed through fieldwork undertaken by the author, with the aim of understanding perceptions of spatiality of individuals who self harm, and the design initiatives which are significant in the built environments of their therapy. This is a defined user group, individuals who self harm, thus further research is suggested for the applicability and significance of these design initiatives to other mental health conditions. This study began with the focus on counselling workspace design, but concluded with design implications for wider areas of built environments delivering mental health services, such as waiting areas and circulation, as these were also evidenced significant in supporting the function of these built environments. Thus, further and more specific research is also suggested into the use of the tabled design initiatives for designing spaces for mental health outside the counselling workspace, such as inpatient ward design. Research is also suggested into each design initiative, its experience and significance in relation to other design initiatives which might be employed; this is not a definitive list of design strategies but rather a platform upon which further research can expand the possibilities for architects and designers to draw from.

References


Urban Papakainga: Programming Cultural Criteria, by using Multi-Agent Systems

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Abstract: This research investigates the use of multi-agent systems to simulate the dispersal of modular agent types along culturally explicit criteria in the production of a Māori, pan-tribal, high-density residential project or urban papakainga (a traditional New Zealand Māori settlement). Underlying this research is a particular interest in the transition from rurally based and tribally specific papakainga, to the possibility of establishing a new urban papakainga typology that identifies the complexities of tribal diversity within the Māori culture. We look closely into the optimisation of spatial parameters within culturally based territories that regularly face potentially significant fluctuations in user numbers, and how culturally defined building envelops and social spaces can be manipulated to reflect the demands of the diverse programmes that arise due to unique aspects of cultural specificity. The paper ends with a discussion into how multi-agent systems have the potential to provide a rich framework for the understanding of an architecture that strongly reflects and enables harmonious living within collective tribal identities.

Keywords: Indigenous housing typologies, multi-agent systems, urban integration, social and spatial integration

1. Introduction

This research looks into the appropriation of digital architectural systems to the housing demands of indigenous cultures. The increasingly intelligent world of digital design has exposed the ability to mimic human behavioural systems, and this investigation focuses on how these intelligent behavioural systems can be adapted to explore the spatial behaviours of a particular indigenous group, and the implications which may arise while using these tools to create culturally informed designed architectural solutions.

The following research is both engrained in real life scenarios, and participating in a discussion of a hypothetical nature, where in the improvement of indigenous architectural understanding is of a priority, and multi-agent systems provide a vehicle for furthering this understanding. The project, by which this research is informed and tested, is the design of a residential apartment block (urban papakainga), for a collective of indigenous, pan-tribal, New Zealand Māori families in the urban setting of Wellington, New Zealand.
2. Multi-Agent Systems

In order to understand the complex relationships between multi-agent systems and the communities they serve, the intricacies of the system itself must first be established, both in terms of a general understanding, as well as a deeper insight into project specific aspects of the system.

2.1. Background

Distributed Artificial Intelligence (DAI) is a concept from the mid 1970’s that spawned the study into intelligent systems that have evolved into what we now know as multi-agent systems. Weiss defines DAI as (1999, pp. 1):

The study, construction, and application of multi-agent systems, that is, systems in which several interacting, intelligent agents pursue some set of goals or perform some set of tasks.

An agent is an intelligent entity with scripted behaviours and traits that is contained within an environment to which it responds, simulating scenarios of varying degrees based on programmable functions. Multi-agent systems emerged as a way to simulate scenarios on larger scales, with multiple agents operating as individuals within the same field, rather than working with many isolated agents.

The behaviours and traits from which agent intelligence is derived can be categorised into a series of relationships. Agents operate on a local network, interacting with surrounding masses, the connections that form between the agent and environment, and the agent and other agents could instigate any number of a series of dictated responses. These reactions are based on the rules and goals that each agent may have, whether it is a common goal or unique to the specific agent. By logical reasoning, deemed ‘agent intelligence’; agents prioritise and adjust reactions to find the most appropriate response to the situation at hand. This is what provides the technical foundations for multi-agent systems.

2.2. Principles of Flocking

In his 1987 paper, Reynolds introduced the revolutionary concept of flocking within multi-agent systems, that is the notion of creating system behaviours that act on a collective of agents to influence a larger scheme, rather than treating all agents within a system as individuals. This type of system is most often compared to that of a flock of birds, from which Reynolds took its name, and his inspiration. The flock acts as a collective, behaving in a synchronised manner with an overarching behavioural structure. Within this collective however, are individuals, all interacting with each and every other surrounding agent within certain proximity in the group, and responding accordingly. While group behaviours had been tested previously, the degree of independence afforded by the instinctual behaviours of a flock is unique to Reynolds interpretation. The key aspects of his model are the principles on which the agent behaviours are based, those of collision avoidance, velocity matching, and flock centring, or as they will be referred to from here on; separation, alignment, and cohesion. Put simply, these are as follows:

- **Separation** operates on the grounds of impact avoidance; as a bird does not want to fly into another, an agent with or without mass will not occupy the same space as another.
- **Alignment** concerns the uniformity of movement within the group, matching velocity as a vector, therefore both speed and direction, ensuring group movement behaviours are synchronised.
• **Cohesion** is the degree to which the group is drawn together, a stronger level of cohesion makes for a tighter group with less of a chance of deviation, and a lesser level makes for a looser group structure with more independent individual behaviours.

These rules can all operate within a hierarchy system, the varying degrees of influence make for a highly adaptable and encompassing system that provides a base for the use of flocking systems in the simulation of any behavioural structure.

### 2.3. Contemporary Uses of Flocking Systems

Reynolds concept of flocking has had implications on a global level, finding implementation across many disciplines in the contemporary world. With cameos in movies, providing simulation of bats flocking in “Batman Returns”, and wildebeest stampeding in “Lion King”, to multichannel radio programming, defence systems and data visualisation, multi-agent systems have their place in modern technology. A widely recognised application of multi-agent systems is within traffic control, managing issues of congestion using flock traffic navigation (Resnick, 1994). The implementation of flocking systems in traffic management allows for the control of vehicles at a collective level, making intersection control and traffic flow far more accurate, generating safer systems with greater collective intelligence.

In the architectural world, multi-agent flocking systems have been explored most notably within the work of Roland Snooks and Robert Stuart-Smith with “Kokkugia”, and Francois Roche with “New Territories”. “Kokkugia” is an ‘experimental architectural research collaborative’ with a highly speculative nature, focusing on the ‘development of a behavioural design process’ (Kokkugia.com, 2016), and “New Territories” has a similar mantra of ‘Research as Speculation’ (Roche, 2016). Both practices make very clear the explorative nature of this type of architecture, and because of this both produce very expressive and organic creations. In terms of real applications, this needs to be a little more grounded for the practicality of accessible architecture.

### 2.4. Context within Research Application

The unique portrayal of collective behaviours within flocking simulation is why multi-agent systems have been so appropriate within the aforementioned projects, and why it can lend itself to so many scenarios that concern human interaction.

In terms of this particular project, the flocking behaviours that are afforded by multi-agent simulations can be used to explore hypothetical social and spatial interactions of a particular cultural group, offering insight into instinctual narratives based upon the values and behaviours common amongst this group in real world scenarios. This entails programming agents with common social behaviours and spatial traits that are specific to people of the Māori culture, and using this information to simulate how Māori family groups would navigate among themselves to create a living matrix, from which, for this specific project, the spacial planning of an urban papakainga can be derived.

### 3. Cultural Overlay

The group with which we are working is a group formed by culturally based relationships. The New Zealand Māori culture is one with very strong tribal ties, and a very distinctive way of living, and the understanding of these qualities will help provide the parameters for the social behaviours and spatial traits that are key to our investigation of the use of multi-agent systems in culturally informed designs.
3.1. Cultural Values

The traditional Māori way of living is a highly community based, tribally orientated system. There are certain values which stand out as being unique to this indigenous culture, values which are apparent in traditional rural papakainga settlements, but as of yet have had no place in the sprawling urban context, a condition that severely limits cultural growth and retention within the younger generations in these environments. The knowledge of these values is based upon previous experience, and reinforced within the work of Cropp (2015) and Burhardt and Swallow (2014, pp. 11-15).

These values include:

- A predisposition to live in small tribal or sub-tribal groups in rural regions
- A territorial affiliation between tribal groups and land, based on cultural heritage
- Sprawling spatial arrangements, as the shift to high rise has not yet been approached
- A strong community atmosphere; shared spaces, open layout, and indistinct boundaries
- Multi Generational Households (MGH), sometimes approaching three or even four generations
- Fluctuating populations due to changes in extended and immediate family situations

These values help form the social behaviours and spatial traits of the people within this community, and in a scenario with such a strong focus on maintaining collective identity and desired tribal interactions, it becomes apparent how appropriate the application of a flocking system is, in which collective intelligence is the driving force of agent behaviour. Throughout this process we are treating each family unit as an individual agent with its own variables, therefore cultural values are applicable to the family unit, rather than the individual person. This ensures familial relationships are maintained in close proximity despite any logical agent reasoning which may recommend otherwise.

3.2. Social Collective Behaviours

Many of the values identified above are concerned with the social collective behaviours that emerge within the Māori community, and these will have considerable influence over the living environment that is best suited to a group that is formed under this common behavioural model.

A great deal of emphasis is placed upon the relationships that form between family groups in these community environments, both internally and externally. The interfamilial relationship structures are more pertinent to the spatial traits of each unit, while the external relationships that form between the family units, and those that form between the family units and the surrounding environment is what predominantly makes up the social behaviours within the group, and spatial planning stems from this.

Using Reynolds principles of flocking, external behavioural relationships can be translated into rules by which the agents can abide. With separation, alignment and cohesion, we can begin to dictate the behaviours that will occur between units of certain criteria, the variables assigned to each unit will be instrumental in the building of a network of relationships to act as a locality model. An example of the implementation of these principles for the purpose of translating Māori cultural values into a digital system is the enactment of the first value; dealing with tribal relationships. The desire for exclusivity within tribal living is founded in rural papakainga living, however in the urban context we have to accept that pan-tribal living is the most appropriate option to deal with the shift to city centers, as there are not enough numbers from any individual tribe to make this move alone. Therefore, in order to maintain identity within a pan-tribal scenario, while avoiding tribal isolation, we need to ensure that in terms of location within the papakainga, units with corresponding tribal affiliations cohere to a certain extent, in order to create the possibility of small tribal groupings within the settlement.
Each one of the values identified above have a similar influence over the social behavioural relationships that form within this community. The state of the relationship (whether it is a connection that desires strong proximity, no proximity, or is ineffectual) will contribute to where the unit navigates amongst the other units within the papakainga, and the layering of these relationships will add incremental levels of complexity as the units logically reason the best location to keep all relationships as healthy as possible.

3.3. Inter-Unit Spatial Traits

Some of the cultural values above extend to having implications beyond that of social behaviours, they also influence the core components of the unit themselves. Up until this point we have been discussing the investigation in terms of cultural relationships that determine spatial occupation on a collective level, however at this point we must acknowledge that when working with an agent representative of a family unit, the unit itself is also under consideration.

Values that have particular influence over the spatial properties of each unit are the tendency for Multi Generational Households (MGH), and the unpredictability of fluctuating populations. The fact that MGH is such a common occurrence indicates that there are different family values within the Māori community, with different family compositions to design for, and households with different priorities and requirements to what may usually be considered. The inconsistencies of household populations also indicate a priority within the Māori value system, by which the understanding of a family and a home are flexible, and this flexibility needs to be catered to with a flexibility of design.

An investigation into the composition of agent units in terms of family types, and their influence on housing types is essential to addressing the question of spatial traits, so that typical unit sizes can be established for a spatial simulation of the relationships formed by typical Māori social behaviours.

4. Agent Composition

System behaviours are informed by profiles of agents that address variables such as typical family types, house types, and variables that influence social behaviours such as iwi affiliation/s, desired community interaction, and desired relationships with the external environment, etc. These profiles inform both the spatial traits of the unit, and provide the information that dictates social behaviours. Most variables are specific to the individual, for example iwi type depends on the iwi, singular or multiple, that the unit may be affiliated to, community involvement works on a scale of high – low, and desired external relationships vary per case, for example families with elderly occupants will want more accessible, lower level units, families with children will have a particular desire for a connection with outdoor spaces etc. Other variables are so broad that a typology system has been devised in order to categorize units, the two variables of concern being the family types and house types with which we are working with.

4.1. Family Types

Using independent research based upon the work of Fitzgerald et al. (2006, pp. 51-56, 120), a selection of family typologies have been created for this system. Fitzgerald et al. established a set of typologies themselves, however due to the high percentage of Māori households that are made up of ‘complex families’ (Fabian and Goodyear, 2014, pp. 66-67), where a family has additional person(s), or multiple families under one roof, we have adjusted their typologies to consist of one smaller set of family types, with additional outlying factors that can account for the situations where additional person(s) or families
The repetitive analysis of the importance of extended family within the Māori culture leads to the necessity for an outlier to cater to families that frequently undergo rapid expansion and contraction due to the responsibility of housing extended family during times of fluctuation due to temporary gatherings. In cases where this is a frequent pressing issue, architectural considerations must be made.
4.1.5. Long Term Addition(s) – (Tangata Karioi)

Long term addition(s) allow for cases wherein a grown adult choses to live with extended family rather than alone, which is not uncommon in a culture that thrives off closely formed relationships and support systems. These types of additions highlight the necessity for understanding the importance of relationships formed by Māori social behaviours when analyzing spatial occupation.

4.1.6. Additional Families – (Honoa he Whanau)

This outlier acts as an indication that this family should be paired with another family with this outlier in a multi unit dwelling, that of a duplex type, or similar housing composition. The families shall be treated as two separate entities, however will be linked inexplicably with such a level of cohesion that they are located side by side for the creation of a multi family unit.

4.2. Housing Types

In order to accommodate the family typologies above, certain housing model typologies have been analysed and selected based on what we deem appropriate to provide the most variety towards meeting the needs of the groups we are working with. Fabian and Goodyear (2014, pp. 80) identify that a major issue within Māori housing is that 1 in 4 houses are deemed by the Canadian National Occupancy Standard (which they identify as best fit within the New Zealand social context) to be overcrowded, in that the capacity of the unit is exceeded. However, the perception of and the reality of overcrowding are not necessarily aligned within the Māori community (Joynt et al. 2016, pp. 16), as extended family living and communal spaces are traditionally embraced, therefore overcrowding guidelines shall be considered but not strictly adhered to. In order to partially accommodate this issue, all rooms shall be designed larger than standard requirements, and an emphasis shall be place on ensuring adequate household amenities such as bathrooms and kitchen facilities (Dupuis and Lysnar, 2014, pp. 60-61).

The unit compositions are as follows:

4.2.1. One Bedroom Unit

One bedroom unit maintains a small degree of relevancy for the single person, and single elderly family types living in close proximity to larger family types. Appropriate for those want their own space without needing extra space to deal with short-term fluctuations. (1 Bed, Living, Kitchen, Dining, Bath).

4.2.2. Two Bedroom Unit

The two-bedroom unit would be an option for those who could be catered to by the one bedroom unit, but have more demand for the extra space due to a lesser support system surrounding them, and have the financial stability to have a permanent spare room. (2 Bed, Living, Kitchen, Dining, Bath).

4.2.3. Three Bedroom Unit

The three-bedroom unit is expected to be popular with families that do not have any of the outlying factors that are common within the Māori culture. It offers a small amount of flexibility in housing that can cater to fluctuations and small expansions, however within a particular volatile family composition it
may not be adequate to accommodate sufficiently without leading to crowding. (3 Bed, Living, Kitchen, Dining, 1-2 Bath).

4.2.4. Four Bedroom Unit

Dupuis and Lysna (2014, pp. 47-57) identify four-bedroom houses as the most appropriate solution to meeting the needs of Multi Generational Households, and with the larger family types that have resulted in crowding issues mentioned earlier, four-bedroom units are expected to be the most common unit type within this model. (4 Bed, Living, Kitchen, Dining, 2 Bath).

4.2.5. Duplex Unit

The duplex unit provides a great option for those with less income, or less stable family typologies. As long as the paired households are suitably matched in order to establish a healthy relationship, the shared unit structure offers a huge amount of flexibility that caters to fluctuations, outliers, and larger family types. (3-4 Bed, Living, Kitchen, Dining, 2 Bath, Shared Outdoor Space).

4.2.6. Penthouse Unit

A more luxurious option is offered for those who desire or need it, and in the case of Māori housing, luxury is closely associated with space to accommodate families without forced crowding, therefore, in this case a larger unit is the result. (5 Bed, 2 Living, Kitchen, Dining, 3 Bath, Outdoors).

4.2.7. Communal Spaces

Additional units acting as communal spaces have been factored into the system to account for the traditional cultural needs of meeting houses (Marae/Wharenui), and kitchens/dining halls (Wharekai). These spaces are essential for maintaining cultural identity (Fitzgerald, pp. 23); they are used for weddings, funerals, religious purposes, childcare, and activities such as sports/performing arts/etc.

5. System Application

With the parameters of the system in place, and the variables with which agents are constructed have been identified, the system has entered its iterative testing phase. This is the current stage of research, increasingly adding the layers of complexity into the system, beginning with basic behaviours and spatial traits, and getting more complex as each step is accurately included within the system.

5.1. 2D Social Behaviour Simulations (Mapping)

The first level of testing was working with simple behaviours to establish a foundation to work with, and in this case the testing could provide valuable information in the form of urban mapping. The territorial affiliation between tribal groups and their land (identified earlier as a key cultural value) is the basic social behaviour we investigated first. When working with multiple tribes in an area with which other tribal groups operate, it is very important that we do not develop in a territory where one or more of the tribes we are working with are deemed to be encroaching on others tribal territories. To eliminate the risk of this, the first testing phase of the system was to use a database of existing and past locations of Māori significance to trial agent responses to locations where certain tribes are welcome, and others are likely to avoid. This proved to be very successful as a mapping exercise, the uninterrupted agent
paths identifying areas free for development according to the cultural criteria we are following (Figure 1). This testing phase opens up a realm of possibilities in which to establish our project, however it will not been further investigated until testing is complete.

5.2. 2D Social and Spatial Simulations (Spatial Planning)

The secondary testing phase introduced the concept of the spatial traits of a family unit, in conjunction with social behaviours including tribal affiliation and the grouping of complimentary household types. This phase gives more of an idea of how units would fit together on a single level floor plan, while adhering to the cultural tendencies they have been assigned. While we are working to explore verticality within papakainga living, this initial step was key to understanding how to read the system that has been created, and culminated in the idea of representing units at a scaled up size in order to witness the relationships that are forming most strongly, as well as using identifying features to monitor the way units rationalize their movements (Figure 1).

5.3. 3D Social and Spatial Simulations (Occupation Planning)

The third testing phase has moved into three-dimensions, and this testing phase shall be the last, however through an iterative process it is expected to progress far beyond the complexity it has now, to result in a less speculative design that begins to convey architectural intention. At this point the notion of physical space has been introduced, however it has not yet been contained to realities beyond that of a bubble conveying mass, as of now we are still introducing behavioural traits, the most recent being the prioritizing of certain units to optimal locations within the confines of the envelop with which we are working. Penthouse suites are navigating to the upper most levels, and units with elderly are navigating to more accessible areas within the system (Figure 1). This phase will have added complexities; communal units shall be explored, more behaviours and relationships added, and a greater level of detail, at which point we shall be able to investigate the use of this model in real scenarios.

6. Conclusion

A reflective analysis of this research to date demonstrates how multi-agent systems are potentially the future of design within cultural communities. These systems lend themselves to collective intelligence,
and cultures that have maintained their identity have done so through maintaining the collective behaviours that make them unique, the degree of symbiosis evident between the system and the reality of the cultural behavioural scenarios indicates the applicability of multi-agent modelling to this design process. This has the potential to provide a rich resource for the improvement of urban papakainga for the Māori community, not only is it intended to help frame designs in a more culturally appropriate manner, by acknowledging cultural behaviours and customs, but it also begins a discussion concerning the use of multi-agent systems to explore non western philosophies, and if the inception of this idea is within the design of Māori urban papakainga, it brings a focus to this otherwise under developed area of study. While this analysis undertaken is specific to a certain cultural group, it is clear to see how the framework could be calibrated to respond to other cultural contexts that share similarly intertwined community environments, with similar subtleties that can be accounted for on an individual level. The success of this particular investigation is, as of yet, undeterminable, however the potential it holds in finding the relatability between multi-agent systems and collective groups with a common living factor is of particular interest to the improvement of a more personalised form of urban apartment living, cultural or otherwise. Lastly, this investigation provides an example of the extents to which digital architectural methods are expanding, rather than being confined to the world of digital visualisation and simulation, we are now expanding architectural design into the worlds of coding and digital manipulation, creating designs informed by the digital interpretation of real living considerations. This investigation is still in the testing phases as of now, but we are very excited to see where this may lead as complexities increase and the system can begin to be implemented in simulations that are reflective of the physical world.

References


Modelling the evolution of housing and socio-spatial processes in low income settlements: case of Davao City, Philippines

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Abstract: Previously, low income households in Davao City, Philippines, were classified into five different types from informal to formal housing. Furthermore, self-help provision and incremental construction of different housing types were explored in the course of their development. To further understand housing as a material expression of the status of the urban poor, and to explore socio-spatial processes in progressive settlements, the aim of this paper is to model the evolution of housing in low income settlements. Housing evolution is illustrated from the time when homeless people first built their shacks in squatter settlements, to transitions of different housing types from informal to formal, through to formal ownership of permanent houses. With formal ownership, the houses had evolved to either one-storey or two-storey permanent structures. This observed evolution of housing in low income settlements demonstrates that housing is socially constructed. From the point of view of social constructionism, the discussion of this paper emphasises the importance of political, economic and cultural factors in low income housing provision. Thus, this paper renews timely lessons about how the engagement of people in sustainable housing provision must be valued, especially in developing countries which are rich in human resources.

Keywords: Housing evolution; informal settlements; Philippines; socio-spatial processes.

1. Background to the study

The ability of the urban poor to contribute to the provision of sustainable housing, from life in informal settlements to formal ownership of housing units in the course of urban development, is valued in the works of several influential authors. 50 years ago, John Turner (1968), highlighted the importance of people as agents in self-help housing as a result of his observations in Lima, Peru. In due course, when housing was viewed as markets and submarkets in the 1980s, Lim (1987) proposed a model that illustrated a multi-step transition that the urban poor undergo through a series of housing submarkets until they became owners of formal housing. More recently Payne (2001), with his focus on land tenure,
claimed that homeless people undergo a series of tenure categories, from a pavement dweller to a
freehold owner of land title. These socially rooted paradigms where emphasis is placed on the agency of
the urban poor exemplify social ecological principles. However, traditional housing policy and
programmes are implemented based on technical and creative methods. The aided self-help and sites
and services programmes popular in the 1970s as a consequence of Turner’s revolutionary ideas relied
on high government subsidies. Due to limited funds, these attempts were viewed as unsustainable in
developing countries. Furthermore, with the adoption of neo liberal market oriented policy in the 1980s,
the market sector widened its role in housing provision. However, both attempts made by the welfare
state and the market oriented policies are practised based on a traditional paradigm whereby housing is
viewed as an object. From the point of view of urban design, Madanipour (1996) asserts that failures in
urban design are due to the lack of recognition of socio-spatial processes in the environment. Socio-
spatial processes include socio-political, socio-economic, and socio-cultural considerations respectively
acted by the ‘regulators’, ‘producers’, and ‘users’ (Madanipour, 2006) of the built environment.

From this perspective, housing is not only the result of both creative and technical processes. In an
informal housing settlement, the built environment created and inhabited by the urban poor
themselves is importantly a social process and not merely a physical environment. In the ongoing
pursuit of sustainable development, articulated in the Philippine Agenda 21 document, the role of
government, business and civil society as key actors for sustainability of the environment is
acknowledged (Philippine Council for Sustainable Development, 2012). In the discipline of urban design,
Madanipour (2006) identifies regulators, producers, and users of built environment. Following this
same framework, the social processes and their influence on housing provision in the low income sector
identified in this paper are discussed in terms of socio-political, socio-economic and socio-cultural
processes. Hence, the engagement of people is prioritised in the search for sustainable housing policies
and programmes appropriate in developing countries.

2. Aims and objectives

In a preliminary study conducted in Davao City, Philippines (Malaque III, 2013), a case study of one
informal settlement indicated an apparent transition to improve the formality of the settlement in
terms of housing structure and land tenure. However, this phenomenon has not received sufficient
attention, and housing policies and programmes continue to fail due to misunderstanding of the
complexities of this dynamic urban phenomenon. Given the preliminary findings, a subsequent study of
74 households in 11 settlements, in the same city, was conducted (Malaque III et al., 2014). The study
revealed that urban households can be classified into different types in a range of contiguous categories
from informal to formal housing. Furthermore, a multi-step transition process was observed, which
means, either an inhabitant moved from one housing type to another in a different location, or an
informal housing unit in a progressive urban settlement was upgraded to become a formal housing unit
in the same location. Moreover, another subsequent case analysis was conducted to explore the
incremental construction of different housing types in the course of their development (Malaque III et
al., 2015). Research revealed that incremental construction was a direct result of the improvement of
security of tenure. For example, a simple dwelling in an informal settlement was upgraded with
permanent building materials and standard methods of construction when the inhabitants’ degree of
security improved. Over time, the physical condition of the house deteriorated when the inhabitants
focused on payment for land. Eventually, the completion of the house, defined as a formal structure,
coincided with legal ownership of the land.
Despite being the subject of scholarship, this typical incremental housing pattern in informal environments, built by the urban poor, requires more detailed understanding in order to provide effective housing interventions, especially in terms of architectural design and practice, which are both appropriate and sustainable in developing countries. Thus, in order to further understand housing as a material expression of the status of the urban poor, and to explore socio-spatial processes in progressive settlements, the aim of this paper is to model the evolution of housing in low income settlements. From the point of view of socio-spatial processes, the discussion of this paper emphasises the importance of political, economic and cultural factors in housing provision.

3. The study area

This study was conducted in Davao City, Philippines, located a thousand kilometres south of Manila. This is the same study area presented in previous papers (Malaque III, 2013; Malaque III et al., 2014; 2015). Recently, the Philippine population based on the 2015 census is 100.98 million, reported by the Philippine Statistics Authority (PSA). In 2012, the population of Davao City was 1.45 million. It has increased to 1.63 million based on the 2015 census (Philippine Statistics Authority, 2016). Davao City is the only city outside the National Capital Region that has a population of more than one million. Reiterating an observation presented in previous papers, the city has experienced significant immigration of impoverished people who have settled in precarious informal settlements. Like any of the other highly urbanised cities in the country, housing provision in the low income sector is one of the major issues in the context of local urban development which highlights the need for this continued scholarship in housing research.

4. Methodology

For the current study, data collection was conducted in accordance with fieldwork protocols approved by The University of Adelaide Human Research Ethics Committee (January 2014). Extensive fieldwork was conducted from February to April 2014. The first author gained access to a total of 74 households in 11 settlements. The selection of settlements and representative household cases was discussed more thoroughly in a previous paper (Malaque III et al., 2014). In a subsequent case analysis, another previous paper (Malaque III et al., 2015) explored the incremental construction of a representative sub-set of 16 of the 74 household cases. The 16 housing cases were selected from progressive urban settlements to represent the range of respective housing types. The data informing the analysis in this paper was derived from the physical documentation of individual dwellings and interviews by the first author with householders. The incremental construction of urban poor housing was preliminarily analysed in terms of the initial construction and improvements to housing structures, preceding the present form of housing units. This analysis of the history of the individual dwellings considered the incremental developments, the agents of housing provision and the building materials and methods of construction. In order to forecast the future development of the dwellings, the interview respondents’ aspirations, preferences and future plans were further considered in the analysis. The aggregate incremental housing construction, the present housing status, and the preference and the future plans of the survey respondents, were further used to analyse and demonstrate the evolution of housing in low income settlements. Finally, results and discussions were synthesised in the context of socio-spatial processes in the built environment.
5. Results: evolution of housing in low income settlements

The evolution of housing in low income settlements is illustrated from the time when homeless people build their fundamental shelter, and transitions from informal to formal housing types, to ownership which shapes the permanent urban landscape (Figure 1). The urban poor begin to provide their own shelter by assembling shacks to mark their invasion of the squatter land. As the preliminary form of self-help shelter provision by the urban poor, these simple shacks, defined as ‘informal’ (Type V) housing in a previous paper (Malaque III et al., 2014) mark the first stage in the process of evolution. Makeshift shacks were usually made of recycled materials. Despite their short life, this ephemeral architecture manifests the urban poor’s need for housing of their own to enjoy the ‘first freedom’ as it is defined by Turner (1968), wherein the squatter community welcomes anyone to join the association as long as there is enough land available. Thus, the temporary nature of a shack is an architectural statement that demonstrates the urban poor’s participation in the creation of new community, despite the informality. Once inhabitants are identified as part of a squatter community, with assigned lots, their shacks eventually evolve to ‘informal’ (Type V) housing, which is the case of the Lamanilao house (Figure 2) in the Kobbler settlement. When the Lamanilao household joined the invasion in 2003, their shack was built of recycled materials measuring 2.40 metres square, a floor area defined by two standard pieces of plywood (typically 1200 x 2400 mm). Extensions to the house and installation of better building materials such as substandard fibre cement boards were completed in 2006. This was followed by the addition of another bedroom in 2010, as the house appeared during the fieldwork in 2014. In terms of their future plans, the Lamanilao family aim to live in a two-bedroom house complete with living spaces and amenities comparable to those constructed and sold in completed housing subdivision projects.

Figure 1: Evolution of simple shack dwelling to permanent residential building.
Modelling the evolution of housing and socio-spatial processes in low income settlements: case of Davao City, Philippines

Figure 2: Evolution of the Lamanilao house.

It is noted in the previous papers (Malaque III et al., 2014; 2015) that ‘informal’ (Type V) housing evolved to ‘in-transition informal’ (Type IV) housing when the squatter inhabitants organised themselves to apply for security of land tenure. Eventually, ‘in-transition informal’ (Type IV) housing may evolve to either a one-storey or two-storey structure. This is implied in the present construction of houses or based on the stated preferences by inhabitants during the interview process. For example, the Abarquez house (shown in Figure 1) in Arroyo Compound, began as an ‘informal’ (Type V) house with an open plan and toilet and bath in a 60 square metre lot. Based on its status when the fieldwork was conducted, the house was classified as ‘in-transition informal’ (Type IV) housing according to the classification defined by this study, and by the structure itself, it is anticipated that the structure will be upgraded to a two-storey house in the future. On the other hand, the Agan house (shown in Figure 1) of the same housing type and settlement as the Abarquez house, is currently a one-storey structure. However, with the inhabitant’s stated plan to add another level, it is also expected that it will be upgraded to a two-storey house in the future. On the contrary, there are ‘in-transition informal’ (Type IV) housing cases which are currently single-storey structures and will remain the same as they transcend towards ‘semi-formal’ (Type III) housing. For example, in the case of the Wagas house (shown in Figure 1) in Kobbler settlement, after a series of evolution and incremental improvements from 2004 to 2011, the inhabitants expressed no plans to convert their house to a two-storey structure in the future during the interview in 2014.

Figure 3: Evolution of the Domingo house.
Further improvements to the security of tenure influenced the transition of ‘in-transition informal’ (Type IV) to ‘semi-formal’ (Type III) housing, in the same way as their manner of evolution towards better housing structures. For two-storey ‘semi-formal’ (Type III) housing units such as the Albios, Linasa, and Talin houses (shown in Figure 1), it is assumed that they will also be upgraded to a two-storey structure but with more permanent building materials in the future. In some cases, one-storey ‘semi-formal’ (Type III) housing may eventually evolve as two-storey in the future. This is exemplified with the Domingo house (Figure 3) in Matina Aplaya Shanghai Village. In which case, after the series of steps from a simple shack to a ‘semi-formal’ (Type III) house as it is defined in this study, the inhabitants plan for major renovations to create a two-storey building in the future.

Security of tenure underpins the evolution of urban poor housing to achieve permanence. The attainment of secure tenure may be by ownership of legal land titles after paying for the land through government assisted programmes or through direct negotiation and payment to the original private landowner. In some cases, although legal land titles are not yet owned, the regular payments for the purchase of land grants constitute another form of secure tenure for the inhabitants. With fully secured land tenure, the ‘semi-formal’ (Type III) housing evolves to ‘almost-formal’ (Type II) housing constructed with near compliance to the standards of the building code. This phenomenon is exemplified with the cases of the Sereno house in Piapi I settlement and the Amad house in Toril II settlement, which were respectively beneficiaries of slum upgrading and sites and services programmes by the government in the 1980s. When the fieldwork was conducted in 2014 the Sereno house (shown in Figure 1) was classified as ‘almost formal’ (Type II) housing. Based on the interview with the head of household, the house began as an informal structure when their present settlement was a squatter site in the 1960s. It went through a series of steps from purely self-help housing until the householders benefited from land tenure assistance from the government. Currently, the house is a two-storey multi-family dwelling. The original household head, also the interview respondent, and his wife, are currently living in a housing unit which is part of the entire two-storey house which is occupied by the families of their children. On the other hand, the same ‘almost formal’ (Type II) housing, the Amad house (shown in Figure 1) began with a 20 square metre plan when the inhabitants moved to this settlement in 1989. The house was completed with all living spaces, including two bedrooms in a total floor area of 40 square metres, when the fieldwork was conducted. The Amad family, being a small household, only plans for a bigger living area and a separate dining with a refurbished kitchen. Contrary to the case of the Sereno house which is currently a two-storey structure, the Amad house is expected to remain a single-storey structure in the future when it becomes a permanent house.

‘Formal’ (Type I) housing is attained when both land tenure and building structure are legal. At this point in the course of development, the house that is built in accordance with the standards of the building code may already be a permanent architecture, or still in the process of evolving further to meet the preference of its inhabitants. The housing cases covered by this study in progressive settlements, despite being classified as ‘formal’ (Type I) housing, have the same classification and description as those built in completed housing subdivision projects, and are foreseen to evolve further from their current status. Based on the preference and future plans of the inhabitants, for the single-storey structure, this may become a two-storey structure in the future. For those which remain with the same building structure, further refurbishment means the addition of rooms with high quality building materials and finishes, formalising the house or establishing permanence. In the case of the Nacorda house in the Matina Aplaya Shanghai Village (shown in Figure 1), classified as ‘formal’ (Type I) housing in this study, it went through a series of steps from an informal house when the inhabitants moved in 1976, at a time when the present site was a squatter settlement. The house was initially built in a self-
help manner by the inhabitants with some assistance from the community. Until the inhabitants became beneficiaries of the government’s Community Mortgage Programme, the house was classified under its current status when the fieldwork was conducted in 2014. Despite attaining ‘formal’ (Type I) housing status, the Nacorda family preferred bigger living spaces with individual rooms for their growing children and planned for the addition of another floor. This means that the house is expected to be a two-storey building in the future. On the other hand, the Rafales house (shown in Figure 1), of the same housing type and settlement with the Nacorda house, will retain its current structural form as a single-storey house, except for further improvements to the finishes. This house went through a series of steps until it attained its current status, however, painting and other finishing were still underway when the fieldwork was conducted.

6. Discussions: socio-spatial processes in low income settlements

The evolution of housing in low income settlements is demonstrated in the way the architecture of houses from different housing types transforms from one physical form to another in the course of development. This dynamic spatial process found in progressive urban settlements reflects the various social factors apparent in developing countries, which is the focus of discussion in this section.

6.1. Socio-political

The socio-political process in housing provision reflects the act of the regulators. Viewing their role in urban design, Madanipour (2006, p. 174) mainly identifies the regulators as ‘the government and its role in regulating the economy, which in the urban development process is mainly reflected in planning’. In the area of shelter provision for the low income population, the act of the regulators is manifested in the implementation of housing programmes. The Philippines is influenced by various international trends and ideologies in policy making. In addition to the major political shift in the country following the 1986 People Power revolution, it is interesting to note the historical development of housing provision, most especially in the low income sector, from a socio-political point of view.

Notable government housing initiatives in the Philippines were initiated during the Martial Law regime of President Marcos in the 1970s. The creation of the NHA and the adoption of slum upgrading and sites and services schemes were indicators of how the country’s urban governance was influenced by the World Bank’s interest at that time and inspired by Turner’s school of thought. In this study, these programmes played an important role in providing land tenure assistance to the informal inhabitants. In the discussion of incremental construction of housing and progressive development of settlements, it was observed that improvement of land tenure was the forerunner of the formal construction of houses and the physical development of the settlement site. For example, the Piapi I and Toril II settlements examined in previous papers (Malaque III et al., 2014; 2015), which were recipients of earlier slum upgrading and sites and services programmes, were able to progress formally as indicated by the presence of ‘almost formal’ (Type II) housing units and developed site infrastructures. Contrary to the centralised programme implementation of the Marcos regime, the land tenure assistance initiative became more participatory in nature in the post-People Power revolution period. The community-based Community Mortgage Programme aimed to legalise land ownership by purchasing the squatter land from the legal land owner, or alternatively, relocating the informal inhabitants to another site, encouraged the participation of NGOs to act as originators on behalf of the urban poor community beneficiaries. Furthermore, decentralised urban governance is indicated by legislation of the 1991 Local
Government Code, and pro-poor housing policies were mandated by the 1997 Urban Development and Housing Act. It goes without saying, that the current socio-spatial processes in low income housing settlements manifested by active participation of the NGOs and empowered self-help initiatives of the inhabitants themselves are reflective of the current socio-political development in the Philippines.

6.2. Socio-economic

The socio-economic process in housing provision reflects the act of the producers. Viewing their role in urban design, Madanipour (2006, p. 174) identifies the producers as ‘those who build the city, predominantly developers and their financiers and team professionals, including designers and construction companies’. However, in the context of informal urban development, the urban poor themselves are the main producers demonstrated in self-help housing schemes found in progressive urban settlements. The urban poor, who mostly relied on transient urban labour and other forms of informal income, were not qualified to access formal housing loans offered by banks and other formal finance and credit institutions. For this reason, they formed themselves into community savings organisations, which then, for example, provided the foundation for the organisation of the Homeless People’s Federation Philippines (HPFP). In the 1990s, the HPFP originated in the dumpsites of Payatas, Quezon City, to bring together low-income housing groups. Recently, the Federation is active in 17 cities throughout the country (Vincentian Missionaries Social Development Foundation Incorporated, 2001; Papeleras et al., 2012).

The community savings organisation offers micro credits or small loans to its members, which is the source to finance the incremental construction of housing units. In this study, some of the informal inhabitants in the Arroyo Compound were recipients of financial assistance from the HPFP and its associated NGO, the Philippine Action for Community-led Shelter Initiatives, Inc. This is the case for the Albos house where the beneficiary was able to purchase more permanent building materials because of the financial assistance offered by the NGO. Despite the location in an informal settlement, the house, is thus classified as ‘in-transition informal’ (Type IV) housing. Furthermore, the NGO’s institutional role in urban poor housing provision brought the design professionals and civic organisations to offer technical support, labour and sweat equity in the construction of houses in traditional Filipino bayanihan manner. It goes without saying that this case study of urban poor housing in informal environments in the Philippines provides new insights to redefine the producers of the built environment.

6.3. Socio-cultural

The socio-cultural process in housing provision reflects the act of the users. Viewing their role in urban design, Madanipour (2006, p. 174) refers to this broad category as the ‘urban society’. In this paper, they are referred to as the low income population, or the urban poor who lived in informal settlements and strived to improve their housing status until they achieved permanent architecture. The progressive form of low income housing provision observed manifests the cultural expression of self-help housing at a household level, which is extended at community level as organised self-help initiatives. In the Philippine setting, the traditional bayanihan spirit visually translated with ‘people-carrying-a-house’ promotes a unique culture of citizen participation in the provision of urban poor housing and the formation of low income settlements. Bayanihan was traditionally celebrated when a family who wanted to move their house offered a party to friends and neighbours who gathered to carry the house to its new site. Today, the festivities associated with the bayanihan tradition are reflected in the agency participation of all stakeholders in housing provision including the NGO, professional and civic groups,
and community-based organisations. Currently, this unique Filipino tradition is being treated in many ways. Firstly, it is being institutionalised in the organisation of Philippine-based NGOs such as the Gawad Kalinga (Odivilas and Odivilas, 2015; Santos-Delgado, 2009). Secondly, it is being integrated in the implementation of foreign funded projects such as the upgrading programme of the Asian Coalition for Community Action in Baseco site in Metro Manila (Galuszka, 2014). Thirdly, from the international perspective, it is seen as an important component in the enhancement of social capital (Labonne and Chase, 2009; 2011).

The Filipino bayanihan tradition further enhanced the organisational capability of community-based low income groups. For example, beyond savings as a main strategy in the organisation of the urban poor federation like the HPFP, the community-based savings initiative means not only a financial tool but also a social mechanism to build a network of communities. This cultural trait empowering the organisation of urban poor communities in the Philippine setting played an important role in the evolution of housing from a simple shack to become a formal permanent residential building. It has been discussed that the organisation of informal inhabitants to negotiate for the purchase of their squatter land, or to access government or NGO assistance, is the first indicator of an evolution. In the preceding discussions on socio-political and socio-economic processes, it is noted that the government’s role in housing provision moved away from being the provider, and the producers of the built environment are being redefined, with reference to the urban poor with institutional support from NGOs. With the increasing role of culture in urban poor housing provision, it is evident that the socio-cultural factor must be given more value in policy making and programme implementation.

7. Conclusion

The dynamic housing phenomenon in low income settlements in a case of a city in a developing country was presented in previous papers (Malaque III et al., 2014; 2015). Firstly, the phenomenon was discussed with the concept of ‘multi-step transition’ from the point of view of housing provision (Malaque III et al., 2014); and secondly, with the concept of ‘incremental construction’ from the disciplinary perspective of architecture (Malaque III et al., 2015). Furthermore, the ‘evolution of housing’, from a simple shack to a permanent residential building, is evident with the cases presented in this paper. This shows that housing in low income settlements is socially constructed, and should not be viewed as an object. With reference to the discourse on socio-spatial processes, this paper illustrates that housing, despite being provided by the urban poor themselves, is a material expression of the society where it is created, altered and permanently shaped. Although informal housing has long been viewed in a pejorative sense within traditional paradigms of architecture, urban design and planning, this study shows that it must be viewed, instead, as the most affordable and accessible type of shelter for the urban poor. Thus, it deserves attention in the discipline of architectural science, which is demonstrated in this paper. In addition to modelling the physical evolution of housing, this paper redefines the respective roles of different social actors of the built environment defined by Madanipour (1996). In the context of informal urbanisation in developing countries, the urban poor who are the users and main beneficiaries, are also defined as producers of housing and the built environment. Accordingly, with the focus on the role of the government as regulator, housing provision is now centred on the people who have the capacity to build and to provide their own shelter. The recent trend in policy making has widened the participation of all agents in housing provision, most importantly the institutional role of NGOs in empowering communities at grassroots level. These redefined roles of key actors in the formation of the built environment must be considered in architectural design and
In the twenty-first century with half of the world’s population living in urban areas, the role of the people must be given more value in housing provision and the formation of sustainable urban environments, most especially in developing countries which are rich in human resources.

References

Agile housing for an Ageing Australia

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Abstract: By 2055, Australia’s 65+ population will have doubled and, if current strategies are followed, it is likely that the housing available will be inappropriate. Today’s housing stock will still be in use yet few developers and designers are capitalising on the potential of agile housing and, more broadly, the creation of age-friendly neighbourhoods. Current changes in design and prefabrication technology, along with government initiatives for ageing at home in preference to institutional care, have the potential to transform the way we consider housing design to support changing demographics. This research considers agile housing for an ageing population from the perspectives of urban planning, design, prefabrication, sustainability, life-cycle costing and social gerontology. We highlight the need for interdisciplinary perspectives in order to consider how entrenched policy, planning, design and construction practices can be encouraged to change through advocacy, design speculation and scenario testing to deliver right-sized housing. A cradle-to-grave perspective requires the exploration of the social and practical benefits of housing in multigenerational communities. This research links to concurrent work on affordable housing solutions and the potential of an industry, government and academic partnership to present an Australian Housing Exposition, that will highlight the possibilities of a more agile housing approach.

Keywords: agile housing; seniors housing; design and prefabrication; rightsizing.

1. Introduction

Australia is facing housing challenges with an increasingly diverse, urbanised and ageing population. The number of people aged 65 and over is expected to double in the next forty years (Commonwealth Treasury, 2015). In the last century life expectancy has increased resulting in a new group of active middle agers alongside a frailer 80+ group (Simpson, 2015). With housing affordability at crisis levels in our largest cities (Kelly and Donegan, 2015) agile housing strategies that allow homes to adapt to the changing needs of occupants will enable more efficient use of housing stock. New housing remains polarised, with inner city precincts oversupplied with small units for individuals and couples, and family dwellings in the peri-urban fringe, frequently located far from jobs, transport and services (Wood et al., 2014; Whitzman et al., 2015; Birrell and McCloskey, 2016).
The research project was funded through a University of Melbourne competitive grant process and addressed three main questions: (1) what alternative housing typologies and construction innovations could better support the needs of Australia’s changing demography? (2) how might these respond to a wide range of household compositions, age groups and income ranges? (3) how can we begin to educate and advocate for these changes with developers, government and consumers? Because of the complex nature of this research area, the project brought together experts from the disciplines of urban planning, design, construction innovation, sustainability, life-cycle costing and social gerontology.

Australia has some of the best research on housing in the world through the Australian Housing and Urban Research Institute (AHURI) but some of the worst housing outcomes (Whitzman et al., 2015). Almost nine in ten private renters in the lowest income quintile pay over 30% of their income on housing (Hulse et al., 2015), the percentage considered the threshold level for unaffordable housing. Housing prices in Sydney and Melbourne are amongst the world’s most expensive.

New housing in Australian cities does not sufficiently consider design, construction or tenure to accommodate our diverse household types and our ageing population (Olsberg and Winters, 2005). More examples of agile housing design, able to readily adapt and adequately respond to changing household composition and ability, are needed if Australia’s conservative housing market is to respond. Worldwide, there is an increase in the number and percentage of lone person households. Concurrently, the number of multi-generational households is also increasing for complex reasons including housing affordability, ageing, adult children yet to leave or returning home and cultural preferences. While the number of single person households was one-quarter of all Australian households in 2011, multigenerational households comprised just less than one-fifth (Liu et al., 2015).

In this paper, we present international best practice and local innovations that demonstrate architecture and construction innovation; typologies and tenures suitable for adaption in Australia; and the notion of age-friendly design facilitating greater social diversity and community cohesion. The data is based on a horizon scan of best international practice, policy documents and workshops, including a literature review. We undertook case study visits and interviews with suppliers in northern Europe, the USA and Japan using a systems approach to better understand the interrelationships between design, policy and outcomes. The first part of this paper identifies key issues from the multiple perspectives of the contributing authors and a suite of strategies for encouraging more agile housing approaches.

2. Defining Agile housing

For the purpose of this research, agility in design and construction has been taken as adaptability over time of individual homes or multi-residential contexts. Agility in terms of tenure goes beyond the traditional options of ownership and rental, and looks at alternative approaches such as co-housing and community land trusts.

In Australia, whether housing is developer-led and speculative or client-driven, designs are typically focused on a single type of housing occupation whether this be an individual, a family, or a couple. Unlike the UK, Australia has few guidelines that are mandated in order for housing to meet diverse needs across the life span. In parts of the UK universal design is mandatory and ‘lifetime homes’ encouraged (The Foundation for Lifetime Homes and Neighbourhoods nd). Lifetime homes have such characteristics as wider and accessible car parking, potential for entrance level bedrooms, showers and WCs.
2.1. Agility through age-friendly design

Age-friendly design requires a combination of strategies that operate at different scales. The World Health Organisation has developed guidelines for age-friendly cities (World Health Organization, 2007); these principles are broad in scope and include social and civic criteria as well as design of physical space. Neighbourhoods that are age-friendly facilitate ageing in place but only if housing is also age-friendly. Rather than design for the needs of the aged alone, a useful concept is universal design or design that meets the needs of all occupants in terms of being accessible, barrier free and inclusive. Inclusive design is based on seven principles developed by architects, product designers, engineers and environmental design researchers at North Carolina State University in 1997 (Preiser and Ostroff, 2001) including equitable, simple and flexible use, clear information, low physical effort, and appropriate size. Such principles allow individuals to access housing regardless of physical, mental ability or age. Livable Housing Australia (LHA) provides advice, advocacy, guidelines and certification with the aim that all new housing be universally designed by 2020. With all of these aspirations, we should also deliver on ‘design’ so that a quality of experience is supported by quality in design.

There is a strong research case for improving the design of both housing and the associated urban environment as there is a large body of evidence linking well designed physical environments to positive health and social outcomes for older people (Dufty-Jones and Rogers, 2015). Supportive housing environments facilitate provision of home-based care and reduce care costs. Unfortunately, Australia lacks reliable data on the number of houses with positive accessibility features so the magnitude of the task to develop age-friendly housing design is not well understood.

2.2. Agility in planning and construction

The concept of agility can be extended to include planning and construction, enabling dwellings to be rearranged, divided or grouped as needs change. The idea of agile or adaptable housing is not new, yet there is now a convergence between emerging digital design and prefabrication technologies, the design community’s interest in design-led construction innovation and burgeoning societal needs making innovation more viable (Newton et al., 2015).

Paradoxically, Australia has a housing affordability crisis concurrently with a glut of empty bedrooms across the states (Darcy, 2014; Wood et al., 2014; Birrell and McCloskey, 2016). Householders aged over 50 occupy around half the detached housing with few desirable options currently available for them to downsize (Birrell and McCloskey, 2016).

Building upon Brand’s (1995) temporal understanding of buildings as having seven layers, new building prefabrication technologies have the potential for components such as bathroom pods to be added or exchanged according to need. Such prefabrication approaches can play an important role in housing adaptability over time. Designs with moveable walls, pack away components and ‘plug and play’ technology are maximizing both spatial use and longevity, enabling more options within smaller footprints. Smart houses with technology that track use will help the safety of the frail elderly. Technology developed at the Technical University of Munich along with industry partners offers smart wall panels to assist the elderly in their own homes, for example the ability to issue a warning if the apartment’s occupant has not taken the front door key from the key holder when the front door is opened. Australia’s off-site construction industry faces similar transformation with 2016 federal government funding for an Industrial Transformation Training Centre that brings prefabricated housing researchers and industry together to develop new products for market.
2.3. Agility, tenure types and financing options

Home ownership reduces the overall cost of living in later life (Bradbury and Gubhaju, 2010), provides security of tenure, and has psychosocial benefits such as reinforcing independence, autonomy, belonging and achievement (Olsberg and Winters, 2005). Some older home owners are asset rich and cash poor (Wood et al., 2010) and many low income home owners struggle to meet housing costs. By 2046, home ownership for those 65+ is expected to drop from 80% in 2006 to 72% (Yates et al., 2008)

Australian tenures predominantly consist of private ownership and short-term private rental. The Reserve Bank of Australia has suggested that an answer to Australia’s housing affordability crisis ‘lies in more innovative and flexible use of the land that we have so that the marginal cost of adding more stock of dwellings is lower’ (Hutchens and Mason, 2015). Two key innovative approaches, more common in northern Europe and America, are co-housing and community land trusts. Both have potential in Australia to provide greater housing agility.

Co-housing emerged in Denmark as families sought to create intentional communities with shared facilities, a level of communal living and a sense of neighbourhood (Durrett and McCamant, 2011). The strategy is for individuals to co-purchase land and develop both housing and amenities for shared use. The concept has been successfully translated to the United States, the UK and more recently to Australia. In Australia, examples include friends grouping to help with the costs of a first home, intergenerational families, and downsizers seeking to live close to family and friends while having access to shared amenities and support of their own choosing.

Community Land Trusts provide a tenure approach that involves trust entities maintaining ownership over the land then renting or selling dwellings through ground leases. It is an approach that is particularly suitable when public housing is considered for redevelopment by community housing organisations, as has been the case in the UK (Moore and McKee, 2012). The ground leases include affordability formulae that balance limited equity gain while maintaining perpetual affordability (Whitzman et al., 2015). When an owner-occupied dwelling is sold, the equity is shared between the Trust and the seller due to limitations placed on resale prices as set by the Trust. What makes them unique is their focus on community involvement in or ownership of the organisation, and their focus on balancing the rights of the household with the rights of the broader community or society (Crabtree et al., 2013).

Service integrated housing by community and private sectors represents just 5.9% of dwellings for households aged 65+ (ABS 2006 Census). Retirement village or seniors’ housing formats range from resort-style or townhouse-style options, to inexpensive transportable options. Leasehold arrangements often help buyers avoid home purchase stamp duty taxes (Jones et al., 2010).

2.4. Agile housing case studies

The authors considered case studies exploring a range of agile housing principles summarised in Table 1. These principles spanned co-housing, the different layers of a building’s construction, a home’s ability to be adapted, use of prefabrication, potential for reconfiguration or relocation of buildings or elements, and the typology of housing.

Three case studies then illustrate distinct approaches to the provision of agile housing, from the perspectives of design and construction, innovative tenure and urban planning and policy.
Hydeborg Care Facility, The Netherlands – The Use of Prefabrication

As part of an upgrade of the Hydeborg Care Facility, provision of a high quality decant facility was an urgent yet temporary need. HDVN Architecten (now Studio Nine Dots) described how the temporary facility (Figure 1) was designed, prefabricated and installed in less than a year to provide the decant space. As a facility for individuals with cognitive impairments, the quality of the building was critical even though it was only temporary. The choice of prefabricated modules was central to the overall strategy as the modules were pre-designed to be dismantled and reconfigured elsewhere in the local community as permanent community housing at some later stage.

Figure 1: Hydeborg Care Facility, The Netherlands HVDN, 2010. (Source: HVDN, 2012)
Swan’s Marketplace Co-housing, California USA – Creating a Village Ambience

Swan's Market Co-housing in San Francisco was established in 2000 as an intentionally multigenerational community (Figure 2). It integrates a 20-unit cohousing community within an eclectic mixed use facility including affordable apartments, retail units, office space for local businesses, together with public spaces, creating the sense of being in a small village contained within a city block.

Figure 2: Swan’s Marketplace Cohousing (Source: http://ebaldc.org/home/swans-marketplace-apartments-and-co-housing)

Laneway Housing, Vancouver, Canada – Diversified Housing Stock

The City of Vancouver changed planning regulations to allow small laneway houses and increased urban density (Figure 3). In addition, the laneway houses brought agility through providing housing for a variety of users from ageing family members to adult children and carers. Within a community they provide more opportunities for people to live near their work and provide a larger variety of housing types within a neighbourhood.

Figure 3: Laneway housing Vancouver, (Source: http://vancouver.ca/home-property-development/building-your-laneway-house.aspx)
3. Strategies for future proofing Australia’s housing

3.1. Encouraging agile house designs

Incorporating agility in design is not difficult if the market is encouraged and educated to consider design for tomorrow’s needs. Three strategies should be encouraged through legislation, design standards and/or education: (1) housing pre-designed to be subdivided would enable older people to downsize in place; (2) enabling policy such as Vancouver’s Laneway Housing would encourage more diversity and density within our middle ring suburbs which are dominated by detached housing; and (3) tangible examples such as demonstration projects that provide useful ‘proof of concept’. The regulatory framework is a critical catalyst. For example Victoria, unlike NSW, does not have secondary housing policies which permit small units to be built adjacent to housing without planning permit.

While the design and construction of new housing can easily be adapted to consider an agile housing approach, additions to the housing stock represent no more than 2% per annum (ABS, 2015). An equally important challenge is in addressing accessibility and adaptability of existing housing. Strategies for retrofitting such agility will be unique and more difficult without incentives, through policy or otherwise.

3.2. Encouraging agile house construction

Until recently, Australia lagged Japan, Germany and northern Europe in prefabrication innovation. The gap is closing with new products and designs that take advantage of off-site construction manufacturing. Products such as bathroom pods are one area of growth, and although many of these are destined for the healthcare sector there are significant possibilities for the retrofitting of homes. Two strategies that would assist in changing buyers’ mind-sets are: (1) developing prefabrication display centres such as the Fertighaus display villages in Germany and the HIVE display village in New Zealand to showcase innovation and dispel myths around prefabricated homes being of lower quality; and (2) providing open house examples of the many new prefabrication providers.

3.3. Encouraging agile house tenure

Cohousing has potential to make buying or renting a home cheaper but also enables sharing of bills, cars and household goods, as well as trading of services such as babysitting and care for the elderly. With over 30% of households in Australia being lone occupants by 2026, cohousing provides a balance between community and privacy. Australia has fewer urban innovations than North America and northern Europe but this is gradually changing with the WestWyck Eco Village in Melbourne <http://www.westwyck.com/> and the Illabunda Village near Sydney <www.illabundavillage.com.au>.

Community Land Trusts are common in the US and the UK, but there are none yet established in Australia due to our residential tenancies legislation (Crabtree et al., 2013). However in Tasmania, NSW and Victoria it is possible to get an exemption, so there are now a number of organisations planning to establish trusts in Victoria and Tasmania (Whitzman et al., 2015).

Co-housing and Community Land Trusts options have potential to provide greater agility and self-determination using strategies that support all life stages from first home buyers, families and people in later stages of life. Strategies to be considered include: (1) encouraging research through post-occupancy evaluations of new cohousing and community land trust developments; and (2) housing options on leased land as long term rental propositions which take into account life-cycle costings.
3.4. Considering life-cycle costs

The concept of agility in design and construction also extends to life-cycle costs of housing, which typically include heating, cooling, and maintenance but should also include the cost of alterations and modifications to a home over its lifetime. Agile approaches that include flexibility for change often entail a higher capital outlay however the ability to adapt a home over time to suit changing needs could be considered a worthwhile investment enabling future-proofing by allowing for economical change. The emphasis of agile thinking must shift from initial cost of construction to life cycle cost, and from housing affordability to life cycle housing affordability.

In the current practice, finance for home ownership is often based on the initial capital cost of the house, as well as the cost of finance and repayments. These are often assessed on the basis of current income and outgoings of the prospective home owner. The future changes in expenditure profile as a result of changes in circumstances such as family structure and running cost or cost-in-use of the house, and so the life cycle expenditure profiles are often ignored. Agile housing initiatives need to incorporate lifecycle affordability into the design. In that regards, agile design needs to adopt an integrated life cycle design approach which focuses on life cycle quality and life cycle performance of the house. Housing design must be optimised to achieve a low capital cost and low operating and maintenance cost by considering functionality in use, alternative materials, convenience, safety, health, building traditions, business culture, architectural styles and trends, aesthetics, initial capital costs, running costs, end of life costs, energy costs, environmental burden costs (if any), and waste cost (Sarja, 2002) amongst other things. Whole life costing method should be applied during design to assess and evaluate all cost that could arise from owning, operating, maintaining, and ultimately disposing the house. Design process must search for a building that minimises life cycle ownership cost to achieve a financially viable investment in the long term.

3.5. Encouraging downsizing and rightsizing

Judd et al. (2014) have outlined the complex reasons behind housing choices and the need for downsizing.

- Encouraging an adequate supply of options for the current as well as the future aged by incorporating downsizing and upsizing potential into new homes and apartments.
- Considering a ‘last-home buyers’ grant such as stamp duty exemptions to encourage rightsizing.
- Develop a secondary housing to supply diverse housing types within established suburbs.
- Develop awareness of options for those entering or in retirement.
- Shifting public debate away from the idea of the aged occupying valuable real estate more suitable for family housing by presenting better options for the elderly.

The term ‘rightsizing’ as an alternative to downsizing is explored in ‘Generation Stuck’ (Beach, 2016) in which Beach argues that emphasising alignment between housing and the aspirations of occupants at any age is a more useful concept than the expectation of downsizing in order to free up housing needed by younger families.

3.6. Educating through demonstration projects

Tangible demonstration projects that illustrate the impact and possibilities of agile design are required. Members of the author team are currently working on a multi-university/multi-sector project with government to make an evidence based business case for a Melbourne Housing Exposition. The
Exposition would promote new housing typologies and innovative construction as well as alternative tenure and financial approaches that include life-cycle costing in addition to capital costs, creating a permanent legacy of quality, future-proofed housing. The aim is to fundamentally challenge the current market offering, while also leveraging the research opportunity by developing the brief of the Exposition as a best-practice evidence-based document, monitoring during construction, followed by post occupancy evaluation, all through multiple disciplinary lenses.

4. Conclusion

There is a tension between Australian policies that support ageing-in-place and the lack of appropriate and affordable housing in our rapidly growing urban centres. This paper argues that more agile housing solutions that enable a better fit between housing needs and aspirations across the life of the building in alignment with the changing needs of occupants would better accommodate Australia’s changing demographics. We identify that the concept of ‘rightsizing’ rather than ‘downsizing’ is useful, understanding that with good design rightsizing could occur without relocation. Alternatively rightsizing into age-friendly communities could be encouraged by ‘last home buyer’ incentives alongside ‘first home buyer’ schemes.

The variety of elderly housing options is increasing. Building prefabrication, together with its endless potential for embedded technology and plug’n’play building elements, has potential to transform the housing sector and offer greater agility across the whole life course. Regulatory frameworks require review and advocacy so that more agility is mandated, whether in individual house design or urban planning contexts. Innovative tenure models, common in northern Europe and America, have potential in Australia. This paper argues that cross-sector conversations on housing futures are needed. Learning from the Housing Exposition precedents in Scotland and Finland, members of the authorship team with other academics and industry stakeholders are currently developing a business case for an Australian Housing Exposition to test and demonstrate new housing models and influence Australia’s conservative housing market. This agile housing research is feeding into that work.

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A time-use study of rooms and possible impact on the design of housing for an aging population

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Abstract: According to Statistics New Zealand the 65+ age group is projected to increase 114.2% over the next 30 years. The results from an online questionnaire survey found these New Zealanders respectively spend 12.8% and 98.2% more than the New Zealand average at home indoors and at home outdoors. This trend has both health, in terms of stimulus exposure and sedentary behaviour, and environmental impact implications. Time-use studies assist in identifying the home environment attributes that promote physical activity and thus, the health of older people. Further analysis of the survey of time-use in various rooms found those aged 65+ have different time-use patterns for the sleeping bedrooms and study while their time-use patterns for other rooms are similar to other age groups. This again suggests particular house arrangements that are suitable for the ageing New Zealand population.

Keywords: Time-use; house design; aging population; room layout.

1. Introduction

According to Statistics New Zealand (2015), in New Zealand the 65+ age group has nearly doubled since 1981. The 2013 census and its projection further suggest a quarter of New Zealand’s population will be over 65 by mid-century. Around 75% of people aged 65 and over own or partly own the dwelling they usually live in, while the average for the whole of New Zealand is 49.8% (Statistics New Zealand, 2015). These figures suggest the houses of older people make up a considerable proportion of the total New Zealand housing stock. Given the fact that housing plays a significant role in people’s lives, it is essential to understand how these houses are used by this age group, as it is likely that more older people will be spending most of their time in their own house. Furthermore, accurate knowledge of how this age group spend time at home can assist in identifying the housing characteristics that support appropriate activity patterns and occupations for older people’s health. Research has also found that in order to achieve a higher level of physical activity and thus reduce the health-related effects of insufficient exercise, “access to supportive physical environments” is necessary (Giles-Corti and Donovan, 2002). This highlights the significance of time-use data in establishing effective design strategies for housing the 65+ age group.
2. Background to time-use studies

As discussed above the way people use their time could have health implications (Chilvers et al., 2010; Hearle et al., 2012; Sprod et al., 2016). Studies have found a significant disparity in activity patterns between older and younger people (Ujimoto, 1990; Khajehzadeh and Vale, 2016). Ensuring people can participate in activities is also considered to be an influential factor in the general well-being of the ageing population (Theaff, 1978 in Ujimoto, 1990; Hearle et al., 2012).

Time-use studies of older people have mainly been restricted to occupations, activity patterns, and general well-being and health (Ujimoto, 1990; McKenna et al., 2007; Chilvers et al., 2010; Hearle et al., 2012). Little is known about the possible interaction of environmental design and occupation choice and ensuing activity patterns, although time-use data can provide insights into duration, frequency, location of activities, and links to social networks (Ujimoto, 1990). Statistics New Zealand (2011b) see the utility of time-use study in providing valuable insights into people’s energy consuming behaviour and hence forecasting future energy use. This is also important for an ageing population who need to be able to afford to keep their houses warm in winter.

While some time-use studies aggregate data on the number of activities, they also measure the perceived usefulness and enjoyment of associated activities, although the latter is greatly influenced by how people feel about the same activity at different times or the fact people have different perceptions of the same activity (Ujimoto, 1990). However, no studies have been found on older people’s time-use from a physical environmental design perspective. Although the number of activities seems to have been researched and linked to the well-being of older people (Ujimoto, 1990), the duration of each activity and where it occurs within the home has not been not considered.

3. Methodology

As a part of a PhD study on the effects of large housing on occupant behaviour and resource use in New Zealand an online survey was undertaken from mid-February to mid-April 2015, using the web-based service Qualtrics (Qualtrics, 2015). To limit the scope, the questionnaire targeted three owner-occupied household types: single person households, couples and couples with 1 or 2 children as statistics show that large housing mostly accommodates small families (Statistics New Zealand, 2011a).

The questionnaire first asked for general information about family members. It went on to ask about the type and number of spaces in their home, furniture and its location and the time spent in each room of the house, at home outdoors, and out of home by each occupant over one day. This on-line method is popular in time-use microenvironment studies (Wu et al., 2012). The survey was anonymous and a snowballing recruitment method was used.

This paper focuses on the time use of the 65+ age group in the sample and other results can be found in Khajehzadeh and Vale (2015; 2016) and Vale and Khajehzadeh (2016a; 2016b). This group of older New Zealanders has a different time-use pattern from other age groups both at home indoors and outdoors (Khajehzadeh and Vale, 2016) and in various rooms of the house (Khajehzadeh et al., 2016). International time-use studies have also proved that age has a significant effect on time-use (Matz et al., 2014; Wu et al., 2011; Schwab et al., 1990; Schweizer et al., 2007; Brasche and Bischof, 2005; Hussein et al., 2012; Conrad et al., 2013; Yang et al., 2011; Freeman et al., 1998).

Time-use data for all individuals were transferred to SPSS for further analysis. Time-use at home indoors, at home outdoors and in rooms for the various age groups was then analysed to find significant
differences using ANOVA one-way tests. Where a significant difference was found, a Post HOC using Tukey HSD test was also performed to see the details of such differences.

4. Results

4.1. Time-use at home indoors and home outdoors

Overall, 445 households took part of which 214 (48.09%) households finished the whole survey and 285 (64.0%) households only finished the house and furniture parts. The survey thus provided a data set for the time-use of 538 individuals, out of which 54 (10.04%) fall into the 65+ age group.

Results show on average New Zealanders spend 15.94 hours/day at home indoors and 0.55 hours/day at home outdoors in summer, with the corresponding figures for the 65+ sample being 17.98 hours/day at home indoors and 1.09 hours/day at home outdoors (Khajehzadeh and Vale, 2016). This shows that older New Zealanders respectively spend 12.8% and 98.2% more time at home indoors and home outdoors than the New Zealand average. While the average 65+ time-use at home indoors is more than all other age groups, the results of the Post HOC test indicate the difference is only not significant at 0.05 level between age groups 65+ and 0-4 (Khajehzadeh and Vale, 2016). The same pattern occurs for time-use at home outdoors. Figure 1 presents the average time-use by different age groups at home indoors and outdoors.

![Figure 1: Time-use at home indoors and outdoors by different age groups in summer in New Zealand](image)

4.2. Time-use in rooms of the house

As seen above, the 65+ group spend around 2 hours/day more at home indoors than the New Zealand average. Using an ANOVA one-way test, the average time-uses of various rooms of the house were
compared and the details of significant differences were found using Post Hoc Tukey HSD tests. This process showed the time-use by the 65+ group of sleeping bedrooms is not significantly different from other age groups except for age group 0-4 (Khajehzadeh et al., 2016). The same time-use pattern was found between age group 0-4 and all other age groups (Khajehzadeh et al., 2016). Accepting the fact that those aged 0-4 spend more time sleeping, this shows the 65+ group do not spend their extra 2 hours at home in a sleeping bedroom. No difference between 65+ use and other age groups was found for the living room, dining room, kitchen (or any combination of these) and specialized rooms such as games room, but use of a study was different (Khajehzadeh et al., 2016). Those aged 65+ on average spent 1.89 hours/day in a study while age groups 0-4, 5-11, 12-19 and 20-64 respectively spent 0.07, 0.07, 1.34 and 1.10 hours/day in this room. This shows that older people are using a study more than all other age groups and the ANOVA one-way test results indicate this difference is significant at 0.05 level ($F(4, 247) =4.26$, $p<0.001$), although results of the Post HOC test indicate this difference is only significant between age groups 65+ and 0-4 ($M=1.82$, $SD=0.58$) and 65+ and 5-11 ($M=1.83$, $SD=0.53$) at 0.05 level (Khajehzadeh et al., 2016). This shows that part of the extra time at home indoors is spent in a study.

The ANOVA test showed no significant difference for living room, dining room and kitchen (or any combination of these) with age which was an unexpected result. The reason could be related to the 7 room combinations (separate living room, separate dining room, separate kitchen, combined living room/dining room, combined living room/kitchen, combined dining room/kitchen and combined living room/dining room/kitchen) leading to few samples of each. To increase sample numbers, time-use in all of these room types were added and renamed time-use in all living, dining and kitchen areas. This showed that the 65+ group on average spent 6.09 hours/day in this revised room group. The ANOVA one-way test results showed a significant difference for time-use in this space with age at 0.05 level ($F(4, 533)=4.72$, $p=0.001$). Further analysis showed that the time-use in all living, dining and kitchen areas by those aged 65+ is 0.9-2.2 hours/day more than other age groups. The Post HOC test results revealed that these differences are significant for all age groups (65+ & 0-4 ($M=1.74$, $SD=0.58$), 65+ & 5-11 ($M=1.77$, $SD=0.54$), 65+ & 12-19 ($M=2.17$, $SD=0.64$)) apart from age group 20-65. This shows that a significant part of the extra time the 65+ group spends at home indoors is spent in this revised room group. While this is a combination of three room types, time-use results for a separate kitchen and separate dining room show age group 65+ respectively spend 0.36 hour/day in a kitchen and 0.11 hour/day in a dining room. Although it is incorrect to subtract these figures from the time-use in all living, dining and kitchen areas, it seems very probable that the 65+ group spend most of this extra time at home in the living room part(s) of living, dining and kitchen areas. Figure 2 compares the average time-use in study and all living areas by age group.

5. Discussion

5.1. Implications of time-use data for house design

This study shows that for people aged 65+ approximately half (48%) the time spent at home indoors (17.98 hours/day) is in sleeping bedrooms and one third (34%) is spent in a living room, dining room, and kitchen or a combination of these. This implies that only 18% (including 10% in a study) of total time is spent in the other room/bedrooms and service areas. These figures are significant both for environmental considerations and health implications. Unheated spaces in a house that are seldom used can lead to mould growths, although this is an area that needs further investigation.
According to the New Zealand Time-Use Survey (Statistics New Zealand, 2011b), in 2009/2010, on average the 65+ age group described 30% of the day (7.25 hours/day) as “free time”, which is considered as “non-productive primary activities” in time-use studies. Putting these figures together and with the fact those aged 65+ on average spend 10% (1.89 hours/day) of time at home indoors in a study suggests at least part of this free time is spent in sedentary activities.

Kaushal and Rhodes (2014, p.235) state the domestic environment plays a significant role in physical activity and sedentary behaviour. However, results from Saidj et al. (2015) highlight the significant role of home-environmental attributes in reducing sedentary behaviour. Findings from the study which is the subject of this paper also show people aged 65+ spend more time in living areas in cellular plan houses than in open plan houses. This is comparable with average New Zealand figures for all age groups (Khajehzadeh et al., 2016), where in open plan houses people spend the extra time in sleeping bedroom and out of home (Khajehzadeh et al., 2016). This is an important consideration when it comes to designing smaller houses for an aging population, where an open plan kitchen, dining and living room is the norm. It seems people want more choice in where they spend time at home and do not want to be forced effectively to sit in the kitchen. This could lead to dissatisfaction with housing.

Saidj et al. (2015) identified the strong relationship between “leisure-time sitting” and household size, type of dwelling and house size describing a reverse association with household size and house size. This means that for instance living in a small dwelling increases sedentary behaviour (Saidj et al., 2015). Research also suggests people living in smaller households (Saidj et al., 2015) and being alone (Burton et al., 2012 in Saidj et al., 2015) are more likely to have higher leisure-time sitting. Evidence from the New Zealand Time-Use Survey (Statistics New Zealand, 2011b) found in 2009/2010, on average those aged 65+ spent more than one third of a day (9.3 hours/day) alone and approximately half of the day (12.02 hours/day) with a family member within their household. Additionally, Statistics New Zealand (2015) found in 2013 that 51.1% of those aged 65+ in private dwellings were couple-only householders and
28.8% were single-person households, meaning that just under 80% of people aged 65+ either lived with their partner or alone. By 2050, speculation is most older people will live in their own home typically alone or with a partner (Saville-Smith, et al., 2009). These figures coupled with the ageing in place scenario make it seem that sedentary behaviour will be common in the ageing population.

Occupant exposure to pollutants is another health-related consequence of spending more time indoors. Other results from the study that forms the focus of this paper show that older New Zealanders on average spend 1.07 and 5.24 hours/day respectively in a separate kitchen and combined kitchen/dining room/living room. Considering the kitchen as the main source of pollutants within the home it seems the most detrimental open plan scenario in terms of human exposure to kitchen pollutants is the combined kitchen/dining room/living room, followed by combined kitchen/living room and combined kitchen/dining room, which compared to a separate kitchen increase the chance of exposure by approximately 5.0, 3.1 and 1.8 times respectively (Khajehzadeh et al, 2016). This gives another reason for rethinking the open plan when it comes to designing smaller houses for an ageing population.

Data from the survey indicate that older New Zealanders spend 92% time at home indoors in sleeping bedrooms, a living room, dining room, and kitchen (or a combination of these) and a study and the remaining 8% in other bedrooms and service areas, suggesting that some parts of the houses are underused. Furthermore, evidence from a study of older downsizers in Australia suggests that Australians aged 65+ are more likely to be living in larger dwellings (with three or more bedrooms) than their younger counterparts (Judd et al., 2014). However, for those who have downsized, less floor area rather than the number of bedrooms, and having a smaller yard or garden, seem important as extra spaces to accommodate visiting family and relatives are needed as well as space for activities and hobbies (Judd et al., 2014).

Results from the New Zealand Time-Use Survey (Statistics New Zealand, 2011b) show that in 2009/2010, the main way those aged 65+ spent their time were personal care including sleeping (11.42 hours/day), mass media and free-time activities (4.78 hours/day) and house work (3.23 hours/day). A comparison of these figures with average figures for the 12+ age group indicates people aged 65+ on average spent 1.68 and 1.2 hours/day more on “mass media and free-time activities” and house work respectively. Judd et al. (2010) also found older Australian homeowners described the living room (often combined with dining room and kitchen) as the most frequently used space in the dwelling accommodating various activities including sitting, reading, socialising with friends, listening to music, watching television, playing with grandchildren, and doing crosswords or puzzles.

The issue, therefore, is the appropriate size of dwellings for the 65+ age group which can accommodate their occupational needs and preferences and at the same time be space and resource efficient. Statistics New Zealand (2013, p.9) also suggest that “having fewer people per household does not necessarily mean one- and two-bedroom homes will be the norm”. In a study of Australian dwellings use of bedrooms for activities other than sleeping was observed (Judd et al., 2010). Spare bedrooms were mainly used for a wide range of activities including (from more to less frequent occurrence) home office/study, guest bedroom, hobbies, storage, ironing and reading. Findings from their research show that a high proportion (95%) of the respondents had one or more bedrooms not used regularly for sleeping and this figure was 63% for those who had two or more (Judd et al., 2010).

Another factor to consider is that the 65+ group spend nearly twice the average time at home outdoors (1.09 hours/day), where they may well not be simply engaged in sedentary activities but are looking after the garden (Figure 1). This suggests housing needs to incorporate appropriate garden
space for this age group. Judd et al. (2010, p.83) also found outdoor space significant for older Australians remaining in the community as a means to achieving “active and healthy ageing”. Their study also found that efficient use of dwellings is significantly associated with the level of liveability of both dwellings and land for this age group (Judd, et al. 2010). In a study of Welsh residential care homes Hearle et al. (2012) found the majority of residents spent their time in the lounges sitting silently or sleeping and observed limited interactions with other residents and staff. Considering the fact that integrating nature into built environments increases wellness and quality of life, and thus enhances human health (Beatley, 2011, Husk et al., 2013), designing private or semi-private green open spaces throughout a residential complex could give those who are active a chance to garden and provide an amenity for those no longer able to do this.

5.2. Home attributes and time-use data

The implications of an ageing population and the occupational engagement of the 65+ group highlight the significance of investigating the characteristics of appropriate housing. In order to create an appropriate domestic environment consideration should be given to accommodating a number of factors including activity patterns associated with leisure, exercise, and community engagement. Together these necessitate an investigation of the characteristics of an appropriate context for these activities in order to assure safety, autonomy, and comfort, and thus satisfaction and well-being.

One such example in housing design could be the integration of indoor spaces such as living areas with open space or a deck to encourage use of the outdoors and provide space for pleasant social engagement such as family events. Another illustration could be creating spaces with different qualities in terms of ventilation, light (natural or artificial), temperature (providing adequate temperatures for health are achieved) and size, each appropriate for particular activities, so that people can move between spaces. This might mean designing the spare bedrooms that people want for occasional use by family members so they can accommodate other hobbies, which will mean providing appropriate storage. It might mean designing different spaces within in living room, such as creating a place with good daylight for reading apart from somewhere to watch television.

Considering the preference of a great proportion of people aged 65+ to age in place for as long as possible and the fact that this and other time-use studies of older people show a large number of older people spending most of their time in living areas and studies within the home suggest that these rooms also need to be designed to accommodate the needs of people as they age and become more frail. Taking these issues together, several problems should be addressed when assessing housing design solutions for the 65+ group:

- The extent to which the associated space is responsive to the needs of people of this age group in terms of accommodating a wide range of desired activities through providing physical and spatial features that improve the quality of home environment. This research into time-use suggests multipurpose cellular rooms could be an alternative to single purpose rooms if they can accommodate visitors and exercise and study activities. These solutions would also assist older residents in reducing their resource consumption (land, energy and materials) through living in more a manageable and affordable dwelling.
- The extent to which housing design meets their needs in terms of outdoor space available to them. This needs to be small enough to be well maintained but large enough to support their outdoor activities such as gardening, and hosting outdoor family events.
Given these two considerations and their implications for housing decisions and policies, studios and small apartments with no or limited access to outdoor spaces, may not be suitable dwelling options for many in the 65+ age group.

5. Conclusion

According to Davey (2006), because of the attention currently being given to ageing in place, a larger number of older people are likely to remain in their family home in the future. This will lead to concern for the health, satisfaction with life, and overall well-being of people remaining in their housing as they age. On the other hand, “The positive ageing principle” suggests that having the opportunity to make choices can make older people more satisfied and hence experience a healthy life (Office for Senior Citizens, 2013). Research also suggests that “active, productive and social activities” can contribute to the positive experience of ageing (Depp and Jeste, 2006 in Chilvers et al., 2010). Therefore, age-friendly built environments need to be provided for this age group.

Although this time-use study did not set out to investigate people aged 65+ its findings illustrate how people in the 65+ age group are currently using their owner occupied houses in New Zealand. This should provide guidance for appropriate future housing for the elderly, especially if this housing is smaller through a desire to downsize, in that it shows the importance of having separate rooms that are sufficiently flexible to support a variety of activities together with good access to sufficient private outdoor space.

References


A time-use study of rooms and possible impact on the design of housing for an aging population


Learning spaces: challenging what you see and what you hear

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Abstract: When considering school design and occupation, what you see is sometimes not the same as what you hear. Using a multiple methods approach, this study describes a case study ethnography undertaken over several years in one school. The outcomes and observations from this research are useful for designers, as well as educators, in order to develop more nuanced understanding of the impact of school design in terms of pedagogy as well as qualitative experiences and values. The case study is one of the template designs constructed across many Victorian government primary schools with federal funding provided in response to the Global Financial Crisis. The templates are interesting because they enable teachers to choose to teach solely in the classroom or spread into the shared adjacent learning spaces. In this paper, the focus is on the occupation of the shared learning spaces from the perspectives of the principal, the teachers and Year Five students. The methods include interviews, observation and photo elicitation.

Keywords: learning spaces; design assessments; photo elicitation; space and pedagogy

1. Introduction

School infrastructure accommodates two million Australian primary school students and one and a half million secondary school students (Australian Government, 2014). Understanding how students and teachers occupy space will help ensure future spaces are effectively designed for learning and teaching. In researching the impact that space has on the lives of teachers and students, it is useful to consider evidence from both quantitative and qualitative perspectives. This paper adds qualitative observations that complement the many quantitative studies exploring the impact of school architecture.

Many quantitative studies have been undertaken on how space impacts learning outcomes particularly through the more traditional building science perspective focussed on indoor environmental qualities such as temperature, acoustics, carbon dioxide levels, mould, and lighting (Schneider, 2002; Higgins et al., 2005; Woolner et al., 2007). Curiously Hattie’s (2009) meta-analysis of quantitative research into student outcomes found space had no positive impact on student learning outcomes. In the USA, particularly in doctorate research, there have been many studies correlating deficiencies in the indoor environment with poorer test score outcomes (Earthman, 2004; National Research Council, 2006; Filardo and Vincent, 2010). The American National Institute of Building Science through the
National Clearinghouse for Educational Facilities (NCEF) has been collating much of this research on K-12 facilities since 1998. More generally there is research linking infrastructure investment with student outcomes (Hong and Zimmer, 2016) and research linking school facilities to health and performance of students, the environment and to issues of equity (Filardo, 2016). While there is evidence that spaces with poor indoor environmental qualities correlate with students’ lower learning outcomes, what is less clear is whether spaces need to be more adequate (Higgins et al., 2005).

Interlinked to this body of building science research is research and practice undertaken as Post-Occupancy Evaluations (POE) (Cleveland and Fisher, 2014). POE investigates building performance in the contexts of value for money, fitness for purpose and user evaluation. Early writing on building evaluation and POE by Preiser (1988; 1994) highlights the links between POE and building science arguing:

> We should be anticipating the pivotal role of POE in the emergence of the discipline of building science, a field of study and knowledge which incorporates multi-disciplinary analyses of building performance as well as psychology and a sociology of the human use of space. (Preiser, 1989, page 342)

Student-centred learning environments have started to be implemented over the past decade in response to changing approaches to pedagogy. Higgins et al (2005), in their literature review, stated more research is needed to understand these integrated learning environments. A recent Australian literature review also highlighted gaps in the literature (Blackmore et al., 2011). The authors noted further work is needed on the types of practices emerging in new spaces such as group learning and social interactions as well as organisational cultures and leadership. This paper focuses on the inhabitation of the shared learning spaces within the school given these kinds of spaces are not commonly available within traditional, classroom-based schools.

Research focused on linking building quality, design or indoor environmental quality to learning outcomes risks oversimplifying correlations into cause and effect. Schools as complex systems require multiple research approaches linking design and education to understand how learning spaces link with and facilitate learning. Within this context of exploring and understanding how space is occupied and perceived, this research introduces some of the findings from a case study approach. The question I was seeking to understand is whether teachers and students expand learning beyond the classroom into shared spaces or remain predominantly within their classroom environment if given a choice.

2. The school template case studies

This research into the occupation of school template spaces is timely. In 2009, the Australian Federal Government announced an unprecedented capital funding for schools to help address the Global Financial Crisis (GFC). Called Building the Education Revolution (BER), the initiative disrupted the normal mode of school provision across Australia and resulted in new school infrastructure for most primary schools across Australia. Due to the economic need for ‘shovel ready’ projects, the government required template designs to be constructed in most government primary schools across the state of Victoria. The selected case study is one of the template floor plans.

Figure 1 shows the template floor plan studied in this research. It is one of the largest templates and able to be occupied in multiple ways. The six classroom settings could be used as traditional classrooms with doors closed to enable single teachers to work with classes of students. Alternatively the sliding walls could be opened between classrooms and onto the central communal area to enable team
teaching. The plan is also interesting in that it is mirrored to form two communities either side of a
small circular pivot point.

This paper focuses on observations from just one school although the broader research included an
identical template in another school for comparative purposes. By focusing on a single case study I was
able to observe how the use of space evolved over time.

3. Methodology

The methodology was informed by ethnographic researchers working in education settings (Atkinson et
al., 2001; Heyl, 2001; Spindler, 2002) and insights from human geography on how power structures play
out spatially (Soja, 1989). Using a multiple methods approach, I explored the occupation of the template
used by two schools over several school terms observing and sketching. Multiple methods were to help
crystallise how space and pedagogy intersect (Schwandt, 2007) and enable thick descriptions to be
made as well as a triangulation of observations. Triangulation in this sense is defined by Denzin as
multiple kinds of data informing a single project or issue (Smith, 1978).

Data was collected from interviews, focus group discussions and ‘conversations with a purpose’
(Burgess, 1988) informed by Kvale’s (2007) metaphors for the interviewer as a miner or as a traveller.
Rarer than mining data with a focus on later analysis as though knowledge is something waiting to be
found, I was interested in how knowledge is a co-construction influenced by social dynamics. In
analysing the transcripts, I initially looked for key words and concepts followed by more careful line-by-
line reading using NVivo software to seek more detail on themes and keywords. I looked for repetition
of concepts, surprises, explicit statements and reflections in the principals’ interviews. Students and
teachers knew my background as an architect and seemed unperturbed by my presence. I was invited to
visit the school without notice. During visits I positioned myself at the edge of the spaces either standing or sitting at a vantage point where I could observe teaching and communal spaces.

In addition, three methods were used to gather visual clues. The first was simply to observe the spaces for visual traces of occupation in terms of furnishings, fittings, equipment and decoration. As a second method I sketched and photographed activities across the building (Figure 2).

![Sketches](source: Author, 2015)

**Figure 2:** Sketches of students working in the common area (source: Author, 2015)

The third method involved photo elicitation. Each student spent around ten minutes photographing spaces that interested them and then each student spoke with me about the photographs they had selected and why. Students were free to photograph classroom spaces, outdoors or communal spaces.

4. **When what you see is what you get**

The design of new Australasian schools has changed in the last decade with a shift away from the classroom as the generally accepted teaching and learning space. In new schools spaces are provided to more easily accommodate team teaching strategies, better access to digital technologies and more student-centred learning. Australasia along with northern Europe has been recognised for innovation in school design by the Organisation for Economic Cooperation and Development (OECD, 2006; Kühn,
The way schools are changing to accommodate new teaching strategies include providing making-spaces, spaces for collaboration, cooking spaces, individual learning spaces as well as spaces for instruction (Nair et al., 2009).

The BER template spaces studied are particularly interesting as they are a hybrid between a classroom setting and an open plan setting. Teachers could close doors or open into larger zones with shared spaces between classrooms. Visiting across three school years, I was able to observe the shared spaces becoming more important within the school program for the whole school but particularly for the students who had the template building as their home base.

The shared spaces evolved over time with new facilities, furniture and equipment. The library space used by the whole school was developed at one end of the shared area with reading nooks and a reading corner. A school television station was installed at the other end of the common area with a weekly lunchtime broadcast prepared and delivered by students to the whole school. The kitchen program for all students linked closely to the kitchen garden and a new wood-fired pizza oven. Art installations were developed by each graduating year as a gift to the school. A new outdoor science area was developed in the final year of observation using donated material and parent labour.

Evidence of communal use and innovative programming was overtly visible in the way the common areas were developed within the school. The sketch below (Figure 3) is an example of site notes taken during the research process showing furnishings. The outdoor science space was added later.

![Figure 3: Research notes showing shared space layout (source: Author, 2014)](image-url)
5. When what you hear is what you get

The principal felt the new BER space was enabling new modes of behaviour. In our fifty minute interview he reiterated the communal nature of the space fourteen times saying:

All under the same roof ... all connected to each other ... better sense of cooperation ... part of a big team ... pulled the whole team together ... shown we are all on the same page ... we are all in this together ... opportunity to do that, share that ... the opportunity to be under the one roof was sensational ... the flexibility to talk to a colleague ... the flexibility to run an idea by someone ... great sense of collegiality ... greater sense of sharing ... bigger sense of the team. (Principal)

The principal described his ambition for students to be 21st century learners and when I asked him to elaborate what he meant by 21st century learning he spoke carefully:

Twenty-first century learning to me is more about [pause] providing students with the resources to be able to learn. ... Our job as facilitators/teachers is to actually provide spaces that actually stimulate children, to want to learn and to want to participate so in that particular building—cooking and the TV station—there are just other areas where children can expand their skills and come up with their own ideas and next year with the iPad program—same sort of thing. (Principal)

The teachers interviewed within a focus group made comments that overlapped with the principal’s perspective on the value of the communal space. The teachers were also enthusiastic about the shared space, affirming and adding to each other’s comments:

Kids like working out there. They like being together. I also find that some of the kids work better because they remove themselves from the classroom ... and they actually get the job done ... It’s developing that independence. [Teachers]

The teachers and the principal saw benefits in having access to shared, informal learning spaces. The principal saw symbolic benefits that could be translated into new practices of collaboration between teachers. The teachers highlighted the social and pedagogical benefits of the informal learning spaces for the children.

6. Sometimes you see what you hear

Students were invited to take images of spaces that could be good or bad or interesting. The overlaps in the selection by students on what to photograph revealed a surprisingly shared visual experience of their learning settings that aligned with the principal’s focus on collaborative and experiential learning. The photographs (Figure 4) and the summary below (Table 1) highlight the shared spatial experiences of student cohorts even though students were not aware or what each other photographed. For example, all five students photographed the television studio in the shared space. All photographed the kitchen space. Only two chose to go outside in the 2013 cohort but in 2014 all three students photographed outside areas. Perhaps most surprising was that only two of the eight students photographed the classroom spaces. The follow-up discussions with students gave more detail on their choice of selection. The 2013 cohort were Year Five students photographing towards the end of the year. In the interviews, the students highlighted the significance of the commemorative artwork prepared each year by the departing Grade Six students. They also highlighted how much they valued the activities and learning spaces in the shared areas.
Learning spaces: challenging what you see and what you hear

(Figure 4: Photo elicitation by students. (source: Author, 2016)
Table 1: List of spaces photographed by students at one school

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(source: Author, 2016)

7. Sometimes what you hear is not what you see

When visual data confirms what is apparent within interview data or quantitative data such as test scores there is a sense of internal validity in the results. The concept of triangulation means that outcomes from one method confirm the outcomes using other methods. While triangulation corroborates findings and gives reassurance, ‘the absence of similar findings does not, however, provide grounds for refutation’ (Barbour, 2001, page 1117). Qualitative research allows for contradictions because knowledge is understood as relational rather than stable. The term, “crystallisation” introduced by Richardson (1994) complements the concept of triangulation by providing scope for multiple and nuanced understandings depending on the research perspective.
Here is one example of how students and teachers express a shared understanding of rules but then freely adjust the rules in their daily occupation of the teaching and learning spaces. I asked each student during the interviews whether they were able to choose to work in the shared area outside the classroom. Each student was clear that they could only work in the shared space if they asked the teacher first. Likewise the teachers said that students could work in the shared spaces but only if they first asked permission from their teacher. Curiously, by the end of each year, students were moving freely between the classroom and the adjacent shared space without seeking permission.

The observed student behaviours within learning spaces revealed students had, by the end of the year, a clearly developed subliminal understanding of the times when they could choose to leave the classroom without asking. Teachers were giving students implicit approval but also students were claiming control over their learning environment. This is a significant shift in power between the teacher and the student. Students taking control of where they learn is more difficult within the physical constraints of the traditional classroom.

8. Conclusion

The hybrid BER template designs enable teachers to work in more fluid ways with students in and out of classrooms. How teachers and students can gradually adapt to new spaces is useful for both designers and educators. Space that is not specifically allocated into classrooms provided teachers and students with new opportunities for learning. By focusing on the perspectives and experiences of the participants it was possible to better appreciate the many factors influencing learning space occupation. In this case, the principal’s vision for 21st century learning, collaborative teaching and student-centred learning influenced how space was occupied. Students and teachers gradually develop shared strategies of spatial occupation that linked to pedagogical, social and leadership contexts.

Teachers and students share a common understanding that students can only use communal space if they first request teacher permission. In practice, students are making their own decisions about where to work with implicit teacher approval. This shift is power is significant when compared with traditional classroom settings. In interviews, teachers and the principal share a language of collaboration. Students appear to have a surprisingly high level of shared spatial experience within a cohort that is time specific. Students in each cohort chose to photograph distinctive elements within their school in preference to their classroom settings. Follow-up data, provided in interviews, indicated the students’ appreciation of the non-traditional aspects of their school learning in alignment with the views expressed by the principal.

In this case study it was possible to observe a visual culture of spatial occupation that differed from the narrative of occupation. As trust builds between staff and students, students become free to choose their own learning settings. Interestingly, the way students occupied space seemed to follow implicit rules rather than the stated rules agreed between teachers and students. This is visual evidence that spaces are occupied according to rules developed iteratively and intuitively.

Acknowledgement

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Addressing the call for medium density housing innovation through design

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Abstract: Increasingly, people in New Zealand are finding it difficult to get into housing that is affordable and that fits with their needs. Although the government is unwilling to see this as a looming crisis, it has addressed the problem by introducing means by which housing can be built more quickly. A large proportion of the new housing is expected to be in the classification of medium density. With some 30,000 new homes required in the short term in Auckland alone, the current situation presents an opportunity to rethink how medium density housing (MDH) is configured in New Zealand. The paper develops a design framework for MDH that accounts for more sustainable, adaptable and affordable housing that can better meet the needs of New Zealanders now and in the future. The research sets out the potential for MDH to make use of prefabrication and modular design to enable efficiencies today and flexibility in spatial configuration over the building’s lifetime. The framework would inform design solutions that are more efficient to produce, more flexible for occupants and that would have higher sustainability ratings than those of speculative housing that is currently being produced.

Keywords: Medium density housing; Prefabrication; Modular design; aging in place.

1. Introduction

According to media reports, New Zealand is in the midst of a housing crisis that is affecting people in all areas of the housing market (Sachdeva 2016). At the bottom rung of the ladder, a shortage of appropriate housing is leading to increasing numbers of people sleeping rough and living in temporary accommodation. Across the country it is estimated that efforts to increase housing supply are falling short of their targets by up to 10,000 dwelling units per year and the severe housing shortage in some markets is seeing prices rise at alarming rates (Law and Meehan 2013).

Many local authorities have become interested in compact housing typologies as an approach to address the shortfall. In 2008 the New Zealand Government set up a taskforce to explore issues related to medium density housing (MDH) and to recommend how better intensification outcomes could be provided for. Intensified areas use the land resource more efficiently, provide bases for public transport infrastructure and economic development, create opportunities for enhanced social opportunities and support energy efficiency initiatives (Urban Taskforce 2009). However, there is considerable resistance
to housing intensification from people already living in the neighbourhoods where medium density housing is proposed. To counter this, the government has taken steps to minimize local opposition to housing redevelopment and to streamline processes for large scale development (Government 2013, Government 2015). There is evidence that projects are being built but progress toward meeting New Zealanders’ housing needs is almost entirely dependent on the private sector. Even state sponsored housing is being built by private enterprise.

The housing that gets built is largely determined by developers and their aversion to risk finds them repeating the typologies and methods that have been built previously and are known to be saleable. Although there are exceptions, the market seems unable to provide innovative solutions in the area of medium density housing. Is this good enough? It would seem that opportunities exist to look at different forms of medium density housing, if only to enable people to choose. This paper explores alternatives to the dominant ‘compact suburbia’ approach to MDH in New Zealand. In particular, there are opportunities to look at housing that is built more efficiently, performs better and that addresses the needs of people who might choose to live there. This paper presents a review of literature in the field, leading to a design framework that will be used to develop alternative MDH models through a design research methodology. The projects will investigate production efficiencies, housing that will be adaptable to people’s circumstances over their lifetimes and that are created in ways that minimize our carbon footprint and energy use.

2. Fundamental MDH design issues

New Zealand’s housing density is low relative to other countries (Vale and Khajehzadeh 2016), reflecting a long-standing attraction to the quarter-acre section and amenity values associated with this iconic lifestyle. There are clear indications that New Zealand society struggles to accept housing at densities over 30 dwellings per hectare (Turner, Hewitt et al. 2004), which in this context is the lower threshold for medium density. Intensification is seen to jeopardise the traditional, if somewhat nostalgic, lifestyle on the basis that any move to build more apartments might threaten the existing value of standalone houses, neighbourhoods and communities (Chapman 2016). This is reflected in the “nimby” (not in my back yard) reaction seen in the context of Auckland’s housing problems.

Nevertheless, when done correctly medium density housing can be an effective intermediate step between quarter-acre suburbia and higher density apartment living. MDH can help reduce the negative environmental and social impacts associated with urban sprawl, one of the key attributes that makes it attractive to many academics and policy planners (Sharpin 2006). Two significant areas of concern are the way the infill development fits with its surroundings and the standard of residential amenity within the development (Popova and Aburn 2001). These matters are representative of the tussle that takes place in private enterprise driven by the [largely financial] interests of the developer and those of local residents as well as those who will eventually come to live there.

Environmental fit refers to the physical character of a new development and how it fits within an existing urban context. Intensification developments often take place in areas that have “developed a distinctive and unified character which is highly valued by their residents and, in some cases, is of heritage significance” (Judd 1993). Visual character of the built environment derives from many sources, but those relevant in a discussion around infill residential development include the grain and scale of buildings, architectural style and form and landscaping (Popova and Aburn 2001). It becomes important for designers to consider the appropriate extent to which the physical fabric of new development (form, scale, site plan, and site coverage) should fit with existing grain. Too little continuity within an urban
setting leads to a lack of identity and character in an overall area. Too much continuity leads to repetitive designs that lack individuality within an identified setting.

Another issue that arises with increased density is the level of amenity residents are provided with. In MDH the key residential amenity qualities are privacy, access to outdoor space, access to sunlight and outlook, sufficient space (Cooper Marcus and Sarkissian 1986, Dixon, Dupuis et al. 2001). In the private context, a study conducted by Carroll, Witten and Kearns found that the biggest residential amenity issues for Auckland families and children in medium and higher density developments were security/safety, solar access/natural daylighting, privacy and a lack of private, outdoor, storage, kitchen and play space (Carroll, Witten et al. 2011). At a public scale, issues affecting the health and well-being of residents also arise from poor qualities of open public space, pedestrian accessibility/wayfinding, traffic and safety, vehicular access, street parking, noise and communal privacy.

Effective urban intensification requires careful consideration for the provision of amenities, especially in a flexible MDH development where the relationship between buildings and outdoor space is subject to continual change. Judd notes that where quantitative measures of residential amenity (public and private) cannot be provided for, then the quality of the designed environment must be sufficiently high to meet the needs of residents.

As density increases, the proportion of landscaped to built area decreases and dwellings become more closely related.....However, as the quantity of landscaped area decreases, quality of landscaped design becomes more important and strategic in relation to issues such as building scale, solar access, safety, security and privacy and requires closer integration with the design of building form (Judd 1993).

Provision of on-site amenities such as access to ground level outdoor space, privacy and even dwelling floor space is often challenged as developers seek to optimise returns on sites that are often too small to allow for economies of scale (figures 1 and 2). Land ownership is widespread in New Zealand and this can frustrate efforts to amalgamate residential sites in order to allow larger developments (Turner, Hewitt et
A particular outcome of this condition can be seen in figures 1 and 2, where the ground planes of new developments are often dominated by requirements of the motorcar.

3. Housing for life

Ageing in place has been identified by elderly people as “an advantage in terms of a sense of attachment or connection and feelings of security and familiarity in relation to both homes and communities.” (Wiles, Leibing et al. 2011) Relocating is often associated with the need to realign the home to accommodate the transition between various life stages and the consequent demands of each stage. (Wiles, Leibing et al. 2011). Due to the lack of flexibility in current housing, shifting house is more common than attempting to alter the current home. The need to house people for life has become more apparent as it has been estimated that the population of 65+ year olds in New Zealand will have increased from 422,667 in 1996 to 1.15 million by 2050. (Bulleyment 2001)

A universally accessible home would enable people of all abilities to live in their own home for longer, making sound economic and emotional sense. When aiming to house people for the duration of their life it is important to make provisions to quite literally, expect the unexpected. A universally accessible design enables the user, no matter their level of ability. As BRANZ suggests in ‘Homes without Barriers’, “when a person is unable to live in a house because of physical barriers it is the house that is inadequate, not the person.” (Bulleyment 2001). Understanding that the home is considered a place of comfort and refuge, especially to the older generation or people of different abilities, the home should facilitate independence and seek to extend the possible boundaries of housing for life.

An adaptable home aims to facilitate the dweller to comfortably age in place through independence and autonomy but with the support and security of familiar surroundings. Adaptable dwellings offer flexibility to respond to the changing needs of occupants, creating a home suitable for all stages of life. Through reciprocating the changing needs of the household via expansion and contraction, people will be encouraged to remain in well-established communities; a common request of the elderly population.

In time it may become necessary to move due to health or comfort reasons in old age. Participants of a study by Wiles, Leibing et al. (2011) found that choice around where a person has the opportunity to age ageing was necessary and recognised that “getting too attached to a place can limit a person’s ability and willingness to move to a more appropriate living environment when necessary”. The study participants identified the need for independence with a strong desire to remain living in the community in housing that they are accustomed to. For this to be possible, the home must be universally accessible, with certain features to aid safely. Davey (2006) reported on the features that older people required to ensure an environment that would allow for security and comfort in later life. The list included:

- No stairs—all on one level
- Easy access from the street
- Warm and sunny
- A garden that is small and easy to manage
- A modern bathroom and kitchen
- Room for visitors and for an office/hobby space (many now need space for a computer
- Low maintenance (brick, aluminium windows, low-maintenance roofs)
- Safe (steps that are not slippery and with rails; grab rails in the bathroom)
- Accessible for transport, health services and social networks.
If the home is unable to meet these requirements, consideration is given to moving. It is often sought by the elderly population to downsize in retirement due to safety and maintenance issues. This new typology would allow downsizing to occur without the stress associated with having to move home (Gottschalk 2006). Home has a deep psychological meaning, not only in the form of the house but the community as well. Through housing communities over the course of their lifetime, a well-integrated neighbourhood of all ages is likely to form, where residents feel a sense of belonging. This identity and place making is said to have positive effects on both the mental and physical health of people over the course of their lifetime, lessening the risk of serious health problems in later life. (McNeill 2016)

As people age, increasing health problems tend to hinder mobility. An adaptable housing typology could provide an alternative solution to this issue as well as to mitigate the growing health issues associated with poor living conditions through residential amenity. Recently published results of the Dunedin Longitudinal Study suggests that loneliness, stress and isolation in early life are directly correlated to deteriorated health in later life. Not only are these factors detrimental to the mental health and wellbeing of people, but to their physical health as well (McNeill 2016). If an adaptable housing typology could seek to integrate people into a community to establish a sense of belonging, it could be possible to reduce the effect of ill health in later life. The benefits of this could be vital to relieving strain on public facilities and aged care in the future as the forecast of elders in New Zealand is set to total a quarter of the population by 2050.

Designing for prefabrication could help bring the idea of an adaptable home to reality. This method of construction encourages home ownership through the ability to grow the home as financial situations improve or circumstances change. Prefabrication also offers a sense of individuality through mass customization and personalisation, creating a home that offers safety and security in an environment that people have become accustomed to over their lifetime. Housing people for life is designed to create community oriented environments. The move to increase density while considering the good health and wellbeing is necessary to reduce the strain on housing as well as aged care facilities in the future as life expectancy and population continues to increase.

4. Prefabrication

Prefabrication is the offsite construction of building elements, ranging from framing timber and trusses through to larger segmented buildings which assemble on site. In the New Zealand housing context, prefabrication takes a variety of forms and can be categorised into four typologies of increasing complexity and scale, namely; components, panelised, modular and complete manufactured homes (Page and Norman 2014). Given the time and cost constraints that impact mass housing production, developers have turned to a variety of efficient production techniques that require a degree of standardised production. The search for efficiencies in standardised housing typologies has led to repetitive use of proven and reliable building components and materials, plan configurations and construction technology which has contributed to the monotonous housing sprawl expanding outwards from city centres. This drive for production efficiencies has resulted in tensions between private developers (seeking to standardise and maximise housing production) and the urban planners, architects, and the public who seek variety in housing aesthetic, higher levels of personalisation, customisation and quality. The problem is in part driven by buyers who aren’t prepared or able to pay for the additional costs associated with bespoke designs. Buyers put the greatest value on the square metres their dollar will buy, rather than on the visual character that is conveyed.
The question that should be asked is whether anything less than aesthetically varied and interesting housing should be viewed as acceptable? This is where modular design innovation opens possibilities for developers to veer away from standard practices, taking on greater responsibility to provide efficiency, quality, flexibility and customisation at no greater expense to themselves or their customers.

The building industry has for many years seen prefabrication as a way of gaining building efficiencies. It is based on the concept first implemented on a major scale by Henry Ford’s Model T assembly line which revolutionised production efficiency techniques in the 20th century onwards. Prefabrication is in general synonymous with ideas of ‘mass production’ and ‘standardisation’, streamlining the production efficiency of buildings through factory manufacturing processes. Monica Elliot observed that “it turns out that putting cars together on an assembly line is not unlike putting houses together on an assembly line” (Elliott 2005). Prefabrication is intended to allow maximisation of output and quality, lessening input times and output costs. It ordinarily relies on standardisation, which is the repeated production of standard sizes and/or layouts of components or complete structures to maximise production efficiencies (Page and Norman 2014). It is applicable to all scales and typologies of the prefabrication industry.

The traditional model for prefabrication sees standardisation and customisation as mutually exclusive alternatives and, by definition, independent of one another. In general, outputs are either mass produced in standardized form or they are one-off unique products. Customised factory production often operates at minimum efficiency, and while there are some time and quality benefits as compared to in-situ construction, the cost paybacks are negligible for both buyer and seller. Customised house construction leads to builders being onsite for longer periods and even factory produced installations for such houses, such as kitchens, are built on a one-off production basis.

Standardised factory production is planned to operate at maximum efficiency, with little or no ability to vary products. This is a calculated trade-off. Smith (2010) notes “...limitations in the variety of product produced, so that machines may be able to output set lengths, widths, and assemblies. This removes the waste associated with variability options and the margin of error in end products.” In this definition of standardisation the term limitation identifies the key disadvantage of standardised production of a small number of options. A restricted product range is a key contributor to utilitarian outcomes that lack design flair. This is not, however, a reflection of prefabrication per se, but rather of how it has been applied over time. An opportunity exists in the way standardised outputs are assembled to create uniqueness, and in this way to customise outcomes.

This is where concepts of interchangeability fit with ideas of standardisation and mass production to generate the model for mass customisation. Interchangeability involves a standard output (i.e. components, panels, and modules) having enough flexibility to be applicable to a number of end products. This can be likened to the concept of LEGO which operates with modular, three dimensional form. These standardised, mass produced plastic components of limited form and scale act as building blocks that can be interchanged to an incredible number of custom forms and scales. In the context of the individual LEGO block, each block is modular. In the context of panelised construction the ability to alter the block itself by breaking the modular structure down further to separate structure and panelised infill, would offer much wider potential for flexibility, optimisation (through mass-production and standardisation) and customisation. This reflects Schneider and Till’s understanding that “the most productive approach to prefabrication for flexible (efficient) housing is probably not one that invents new systems from scratch, but one that assembles existing prefabricated elements” (Schneider and Till 2007).
Combining panelised and modular construction techniques allows development of a hybrid system that allows efficiencies with flexibility and the ability to personalise individual constructions. This “...move towards hybrid prefab systems is a logical progression for the local construction industry. However, more research and prototyping is needed if this system is to meet current and future housing demand” (Eglinton 2013). Flexible modular construction allows this fine balance to be met, contributing diverse and new construction aesthetics, continued variation in housing form and a level of personalisation while still allowing enough flexibility in form, scale, materiality and colour for appropriate fit with existing built fabric.

Accordingly, with modular construction strategies it is important to assess the future feasibility of expansion and to emplace planning guidelines and rules which dictate how and where indoor and outdoor private space could change with consideration for solar access, security, privacy and other amenity factors.

5. Cradle to cradle approach

Designing for sustainability should adopt a holistic approach. Designers are encouraged to become aware of where the materials they specify come from and the quantities of energy used in their manufacture. Such an approach also encourages awareness of long term effects (Lawson 1996). The literature provides steps and methods for designing holistically, including site and climate through to manufacture, transport and construction. “Sustainability in the residential environment is likely to be achieved when a comprehensive approach ...is taken” (Friedman 2012). However, the literature also acknowledges that a fully sustainable approach may not be feasible and that “applying some of these aspects will no doubt stand to make a difference as well” (Friedman 2012). The cradle to cradle concept is a known holistic approach that has become popular in the sustainable world, however its principles are the belief that doing less bad is no longer good enough. The cradle to cradle approach is to see waste as food; in other words, everything should be part of a continuous cycle whether technological or biological (McDonough 2009).

Sustainable development can be seen as operating along a scale. In architectural discourse there are levels of sustainability known as strong sustainability and weak sustainability. For weak sustainability advocates, the depletion of non-renewable sources and toxic emissions expelled into the atmosphere are acceptable if compensated for by production of man-made capital. While strong sustainability is open to interpretation, its basic argument is that natural capital/resources are irreplaceable and it is therefore of primary importance to preserve these (Neumayer 2013). Neumayer goes on to argue that in the field of architecture there is imbalanced focus on reducing energy consumption by using products that may themselves cost substantial energy and material resources to produce. It is also often overlooked how materials might be reused.

When it comes to property development, complete cradle to cradle methodologies encounter hurdles in application. Freedom to use time and money is restricted in development, which means that applying these resources toward developing cradle to cradle solutions for construction is unlikely. Avi Friedman outlines the principle of the path of least negative impact as a developmental approach toward sustainability. This principle argues for decisions that reduce negative impacts on the environment, society, culture and the economy. This can be a useful start toward introducing more sustainable practices to the development industry (Friedman 2012).
An example of poorly advised material design can be seen in concrete, where supply companies are keen to highlight the good bits they put into their products. They do this in order to portray themselves as environmentally friendly and to distinguish themselves from their competitors. However, “concrete manufacturing is one of the worst producers of greenhouse gases in the world...TecEco introduces magnesia into their concrete mix along with recycled materials like fly ash...yet each kilogram of Eco-cement made results in net carbon emissions of 0.23 kilograms” (Meisel 2010). Examples like this represent where the industry positions itself in terms of sustainability, companies aim to be partially sustainable in order to get credit, while still having cost effective methods. There is still a way to go before materials that are completely sustainable, and affordable enough to become available on mass to the market.

Within the design and specification stage of building development, the selection of materials is vital to the sustainability of the entire process. One of the techniques that is being increasingly adopted by professionals at this stage is the life cycle assessment (LCA) (ISO 2006) This selection process assesses materials from manufacture to disposal (Friedman 2012). This type of analysis is also referred to and supported by environmentalists as a cradle-to-cradle analysis. Opposite to this method is the Life cycle-cost analysis, which is defined as a time-phased cost analysis over a specific planning period. This is known as the cradle-to-grave assessment (Friedman 2012). William McDonough (2009) is a leading advocate of the cradle-to-cradle approach, and since releasing his revolutionary book researchers and environmental organisations have been promoting its application in all walks of life. Uptake of the cradle to cradle approach has been extensive, ranging from the Leadership in Energy and Environmental Design Standard (LEED) to the European Standard of Environmental Management life cycle assessment requirements and guidelines (ISO 2006, Meisel 2010). Those operating in New Zealand can refer to the Life Cycle Association (LCANZ), which also helps guide cradle to cradle assessment practices.

6. Conclusion

The need for housing to meet current and anticipated demand over the medium term will precipitate an unprecedented level of new house construction. Many of the new houses to be constructed around the
key hotspots of Auckland, Christchurch, Wellington and Tauranga will take the form of medium density housing, driven by planning imperatives to reduce urban sprawl and to realize the social and economic benefits that accrue with these typologies. There are signs that private developers are responding to the opportunities, aided by government action to ease resistance to redevelopment and housing intensification in existing areas. However, there are also indications that new development is based on existing models and methods of building medium density housing. With the programme of work ahead there exists an opportunity to innovate toward new models and methods.

After touching on the prevailing MDH development paradigm the paper has discussed approaches that could lead to new medium density models in New Zealand. There are opportunities to develop housing that is able to be adapted to suit the needs of owners as they change over time, responding first to limited financial capability and what is likely to be smaller numbers of occupants. Such housing would grow with the needs of the residents, utilising prefabricated modules. Prefabricated components and modules could help ensure new housing remains as affordable as possible – setting aside the thorny issue of land costs - and that it achieves a high level of quality, commensurate with factory production. Parallels were drawn with development of the automobile industry. Moreover, new housing methods of construction could and perhaps should adopt a more critical view of the environmental costs of development in order to embrace techniques and materials that enable cradle-to-cradle approaches.

Underlying all medium density development is a need to ensure projects fit well with their settings and that they provide appropriate levels of residential amenity. This includes attention to people’s needs to be able to enjoy relative privacy, to be able to enjoy outlook and access to sunlight as well as to have adequate space in which to conduct their lives. The design and evaluative framework that drops out of these approaches is shown in figure 4 below. The overall aim is to improve the health and wellbeing of residents in the long term through both residential amenity of the home as well as the community. The models will be tested in the next phase of the research but the current stage has developed the design framework for each.

**Figure 4: Evaluative framework for design of medium density housing in New Zealand**
References


Assessing external double skin envelopes coupled with night ventilation and thermal mass for passive cooling in the tropics

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Abstract: The paper conceptualizes and investigates the potential of utilizing double skin envelopes consist of thermal mass coupled with night ventilation for passive cooling in warm humid climates. On-site thermal performance investigations resulted in redefining thermal mass effect in double skin envelopes. The work demonstrates that thermal mass in the double skin envelope contributed to work as a heat sink thus promoting passive cooling although the tropics are characterized with slight diurnal ranges as compared to hot dry climates. Results provide evidence of passive cooling with internal air temperatures moving 2-3.5 degrees C below the ambient levels due to envelope dependency with heat removal, stack force and night ventilation primarily created due to double skin envelopes. Findings show empirical evidence of passive cooling suggesting that the double skin envelopes can play a positive role in addressing extreme climatic conditions.

Keywords: Passive cooling, External double skin envelopes, Thermal mass, Night ventilation.

1. Introduction

Validity of energy sustainability of buildings lies in the optimization of climate, building and occupant interplay. This is known as bioclimatic design (Olgay, 1953). This interplay when manipulated properly using passive strategies can reduce energy demand in buildings (Syzkolay, 1987). In the context of the tropics, where climate plays a major role in making buildings overheated much energy is consumed for cooling purposes. Thus, passive cooling becomes vital. However, with the complexities involved with climate interaction, the components of building design can play a dual role in climate response. For example, envelopes can promote daylight and ventilation, but heat gain through daylight and ventilation can be a problem in making buildings truly climate responsive and sustainable in terms of operational energy. A previous study (Rajapaksha et al, 2015) conceptualized a set of interventions involving a double skin envelope for passive cooling in tropics. The specific focus of this research is worked out in further justifying this concept and presenting the significance of design interventions at the building envelop level for building – climate interplay with a filed investigation.
2. Buildings in the tropics and indoor overheating

Climate responsive design is based on the way a building form and structure, moderate climate for human good and well-being (Hyde, 2000). Environmental load dominancy is a common behavior in tropical warm humid climates if the building design does not behave as a selective mode (Hawks, 1996). However, buildings located in warm humid climates face more challenges when perform as selective mode of operation due to the penetration of irradiation through openings or glazed areas and the heat flow through the external wall surfaces and roof into indoor spaces. This results in an indoor heat gain, role of natural ventilation being in conflict and seen as an unresolved duality associated with thermal performance functions of the building components, in particular building envelope.

2.1. Passive cooling, ventilation and thermal mass.

Passive cooling has the potential to cover almost all the processes and measures which support to minimize the cooling requirements of buildings in warm climates. It consists of each and every preventive method to avoid overheating of building interior, strategies that reject the heat entering through the building envelop and remove heat generated within the interiors of the building. The modification of climate variables is possible by the effects of basic passive strategies. As shown by the bioclimatic charts, the comfort zone can be extended within the given outdoor temperature ranges by using following effects with the use of building design; Airflow effect and Thermal mass effect with night ventilation

2.1.1. Limitations in ventilative cooling

However, ventilation can create a heat gain in buildings in warm climates and seasons. This results in the interests of controlling overheating and the role of natural ventilation being in conflict (Rajapaksha, 2004). The prevention of overheating is a useful pre-condition for passive cooling of buildings and natural ventilation is desirable when the outdoor air is at a lower temperature than the indoor air or when it can prevent the elevation of the indoor temperature above the outdoor level, caused by direct or indirect solar gain (Givoni, 1998).

2.1.2. Thermal mass for climate modification in tropics

The thermal mass of a building absorbs heat during the day and regulates the magnitude of indoor temperature swings, reduces peak cooling load and transfers a part of the absorbed heat into the night hours (Antinucci, 1990). The most important features of thermal mass are the moderation of internal temperatures by averaging diurnal (day/night) extremes (stabilising internal temperatures) and delaying the time at which peak temperatures occur inside. This is more effective in maintaining indoor air temperatures within comfort limits if the mean outdoor temperature of the day does not exceed the comfort limits and the nocturnal ventilation is coupled with the thermal mass. Thermal mass can act as a heat sink. When interact with climate, some of heat is stored, and released later to the environment or indoor spaces when the outdoor temperature reaches its peak and starts decreasing. This is a repetitive cycle over a 24-hour period, referred to as periodic heat flow (Koenigsberger et al, 1974:83). This behaviour of thermal mass can influence the thermal behaviour and thermal landscape of a building and thus the indoor air temperature. Two previous studies (Rajapaksha, 2014,2015) suggest that high mass envelop coupled with night ventilation has the potential to lower the indoor air temperature than the
Assessing external double skin envelopes coupled with night ventilation and thermal mass for passive cooling in the tropics

ambient during daytime and restore indoor thermal comfort even in February, March, April and May, the warmest period of the year in Sri Lanka.

3. Thermal performance of External Double Skin Envelopes (EDSEs)

External double skin envelope offers an opportunity in softening the transition and dialogue between inside and outside. It is a manipulation of mutual connectivity between the indoor environment of the shelter and the natural environment. Thermal performance of external double skin envelopes (EDSE) depends greatly on the architecture of the EDSE and chosen means of “building + climate + occupant” interplay. Daylight and ventilation can be two of the main concerns for a selective mode building where building design plays a major role in modifying indoor climate in maintaining indoor comfort. Authors have attempted to classify EDSE in respect to thermal performance expectations of climate types (Beldinelli, 2009). The work highlights that approach to EDSE has to take the climatic factors into account to improve climate response and thus energy efficiency.

Indoor air temperature behavior in and around a double skin envelop and thus inside a building are results from many concurrent thermal, optical and fluid flow processes which interact in a dynamic way (Haase et al, 2009). These mechanisms greatly depend on the geometric, thermo physical, optical and aerodynamic characteristics of the EDSE and building design itself. The complexity of this concept and technology requires an appropriate composition of all design variables involved namely “microclimate, plan form, sectional form and envelop”. Heat transfer due to conduction and convection are complex depending on the air temperature distribution within the cavity or the buffer space inside the EDSE, air flow behavior and velocity, type of ventilation receive and pressure levels inside the EDSE and main indoor volume inside the building.

The effect of EDSEs for reducing indoor overheating potential has been discussed in the context of natural and hybrid ventilation (Gratia. Et al, 2007). The shading inside the cavity of EDSEs, amount of thermal mass and its location have a greater impact on the behavior of heat gain control due to environmental and internal loads as well. However, the potential of EDSEs in severe year-around warm humid climates such as in tropics are known to be less understood. Literature suggest that thermal mass in the EDSEs can play a greater role in manipulating outdoor-indoor climate modification thus enhancing bioclimatic influence of buildings which act as climatic filters. To optimize climatic performance, thermal mass in the EDSE must be allowed to interact thermally with the interior or exterior, known as thermal coupling, by all forms of heat transfer. It is aimed to conceptualize the characteristics of EDSEs for increasing the time constant and heat storage capacity of the building form and envelope. The best way to promote this is to ventilate the building and its structure in the night through EDSE.

4. Developing a design matrix for EDSEs – a conceptual stage

An integrated building-climate performance model (Figure 1–right) is proposed for EDSEs based on a design matrix which is a conceptualization of the built environment as a bioclimatic system. Within the design matrix an EDSE can be seen as a complex system which interacts with the microclimate, plan form, sectional form, main envelope and even mechanical systems efficiency. For the optimum interactive performance, a hierarchical order (Hyde, 2000) can be identified in respect to increase the passive influence of the building design and grouped in four orderly interventions.
4.1. EDSEs for office buildings in the tropics

Opportunities for bioclimatic influence of EDSEs in the tropics may be attributed to thermal mass effect with shading and night ventilation. Since the diurnal temperature variation is relatively smaller in tropics, the potential of thermal coupling during daytime become more challenging. The specific challenge of this paper is to show how this challenge can be met by manipulating architecture of EDSEs in association with the plan form, sectional form and the complete envelope. The work presents and justify a conceptual form consisting of “supply air types” EDSEs with shading and night ventilation to the windward facades and “exhaust air type” EDSEs to the wind shadow orientations in buildings (Figure 9).

5. Methodology of the research

Method of research employed two case studies associated with filed investigations in two stages, a multi storey office building and an office cum residential building. The stage one aimed at exploring the efficiency of thermal mass and night ventilation for indoor climate modification and the stage two explores the potential of double skin for cooling spaces in real case buildings. The base building for stage one onsite investigation was selected through a desk evaluation of the seven locally certified green office buildings. The Energy Utility Index (EUI) was used as the basis of the sampling and the building with the lowest EUI (Figure 2) was selected as the first stage case study representing most general characteristics of the heat gain problems. The office cum residential building was selected as the 2nd stage case study due to its cooling indoor environment. One space of this building is designed with a masonry double skin (Figure 4).

5.1. Instrumentation

Hobo UX 100 temperature/RH 3.5% data loggers used for measuring hourly climatic data. Surface temperature using K-alloy thermocouples and Wind velocity data using VelociCalc- model TSI 9565 were
also taken in hourly intervals. Ambient climatic data were downloaded from Met, Department which is located just 100 meters away from the case study building in Colombo

5.2 Research plan

Initial on site field investigations were carried out for at least 24 hours with the selected building sample during February 2015, for indoor air and wall surface temperatures. New seven storey office building of Central Engineering Consultancy Bureau, which is the first case study building with EUI of 190 KWh/m²/a was observed as a potential base case due to it’s a) free running mode in weekends including Fridays, b) external accessible buffer zones which seems to offer an opportunity to integrate an EDSE for simulation and c) simple rectangular form.

5.2.1 Case study 1 - Detail field investigation on seven storey office

First, a detailed hourly thermal performance investigation was carried out for 48 hours during the weekend under free running mode for external and internal air temperatures, wall surface temperatures, wind climate and daylight levels (Rajapaksha et al, 2015). The objective of the field investigation was to identify the “level of indoor climate modification” and “heat sink capacity” of the building envelope. Thermal performance measurements were recorded from 13th– 16th Feb, 2015 across the sectional volume involving external outside microclimates on both northeast and southwest orientations, external and internal surfaces of the wall on both these orientations and internal space at the 5th floor, a typical floor. Behavior was monitored during 13th, 14th and 15th for “free running mode”. Nocturnal ventilation was provided by keeping the windows open through the night on the 14th February.

5.2.1.1. Results and Discussion on case study 1

A. Naturally ventilated mode without night ventilation on 14th of February:

Internal air temperature behavior between 9 am to 5 pm moved around 29.5 degrees C which is around 0.5 degree lower than the ambient level (Figure 4). Auliciem’s comfort formula \( Tn = 11.9 + 0.534 \, To \) suggests that 24-28 can be a comfortable range with high RH levels for Colombo. “Tn” is the predicted neutral temperature and “To” is the mean outdoor temperature for the months in question. The
behavior shows a mild passive cooling potential but not fully realized during the daytime because indoor air is moving above the comfort range suggesting bioclimatic influence of the building form needs to be revisited. Since, the internal air temperature and climate modification is just 0.5 degree C lower than the ambient, the inside situation can be critical when outside air reaches 30-33 degrees on a typical common day for most part of the year in Colombo. The ambient of the investigation period was not high as usual. In addition, night time indoor air temperatures moved higher than the cooler ambient and diurnal range was observed as 7 degrees C suggesting a climatic opportunity for heat sink effect of thermal mass (Figure 3).

B. Naturally ventilated mode with night ventilation on 15th of February:

As reported in the previous paper (Rajapaksha et al, 2015) the effect of night ventilation was seen on the 15th of February, 2015 (Figure 4-Right). Internal air temperature at 10 am was 4 degrees C lower than the ambient and 6 degrees C lower than the ambient around 2 pm. The elevation of indoor air during this day was just 4 degrees when the elevation of ambient moved up to 6 degrees C at 2 pm. A time lag of indoor and ambient was not observed due to availability of ventilation. However, indoor air remained just above comfort zone suggesting full potential of bioclimatic influence is not visible.

Further readings showed a comparison of surface temperatures, indoor and outdoor air temperatures. Results showed a “mild heat sink effect” and “weaker insulating capacity” of the thermal mass on the external envelope.

5.2.2. Case study 2- detailed field investigation on office cum residential building

The case study 2 was used to investigate the effects of a west facing EDSE on indoor air temperature adjoining the double skin. The cavity inside this EDSE is about 600mm wide with masonry brick wall construction. The cavity can be ventilated in the night. A comparison of thermal performance was carried out with another adjoining space which is enclosed with a single skin envelope in the same building. A detailed hourly thermal performance was carried out for both indoor spaces during the same period for 48 hours in naturally ventilated mode. HOBO readings were taken for external and internal air
temperatures, all wall surface temperatures, external outside microclimate and ambient air temperatures from the 16th -18th March, 2015 in 15 minute intervals and later averaged for hourly values. Thermal performance of the internal and external surfaces of the external wall of the double skin and the internal surface of the internal wall of the double skin too were recorded accordingly. The objective was to identify the level of indoor climate modification and heat sink capacity of the building envelop. Similarly, the thermal performance investigation was repeated from the 19th-21st March 2015 for 48 hours with the provision of nocturnal ventilation by keeping the windows open throughout the night.

Figure 4: Cases study 2 – Investigated space with the masonry double skin

5.2.2.1 Results and discussion on case study 2

A). Naturally ventilated mode without night ventilation on 17th of March:

Indoor air temperature inside the occupied space of the building was observed to be lower than the ambient through the daytime from 10 am to 3 pm, in the indoor space with Single skin thermal mass whereas in the indoor space enclosed with a EDSE integrated with thermal mass, the lowering of indoor air temperature was visible from 6 am to 9pm, a longer time than the other space. A significant reduction of indoor air temperature was seen in the space enclosed with an EDSE which consists of high thermal mass than the indoor space surrounded by a single skin thermal mass (Figures 5 and 6).

Figure 5: Indoor place close to single skin wall thermal mass

Figure 6: Space close to double skin wall thermal mass
For example, indoor air temperature at 4 pm moved around 30.7 Degrees C in the space enclosed with Single skin thermal mass walls, which is a reduction of about 1.3 degrees C than its ambient counterpart of 32 degrees C whereas in the space enclosed with an EDSE consists of high thermal mass moved around 29.1 which is a reduction of about 2.9 degrees C than the ambient. The evidence illustrates a passive cooling status throughout the day time. Internal surface temperature of the internal skin of the EDSE moved significantly lower than the indoor air temperature compared to the internal surface temperature of the single skin wall illustrating its higher heat sink capacity.

Higher Insulative capacity of the EDSE was seen with surface temperature behavior of double skin wall (Figure 6). For example, surface temperatures from most external surface to most internal surface at 4 pm are as follows which shows a gradual lowering of values.

- External surface of the west facade: 42.6 degrees C
- Internal surface of single skin: 30.4 degrees C
- Internal surface of internal skin of EDSE: 28.5 degrees C

Monitoring was conducted for three days involving 17th March 2015. Similar behaviors were observed during the total investigation period.

B.) Naturally ventilated mode with night ventilation on 20th of March:

The effect of night ventilation was seen on the 20th of March, 2015. Internal air temperature moved much lower than ambient during the day due to the effects of night ventilation on the 19th March in both the spaces. The reduction was much significant in the space enclosed with the EDSE than the single skin wall on the same orientation. For example, indoor air temperature at 10 am was 3.8 degrees C lower than the ambient and 3.7 degrees C lower than the ambient around 2 pm in the space enclosed with the EDSE while indoor air temperature at 10 am was 1.8 degrees C lower than the ambient and 1.6 degrees C lower than the ambient around 2 pm in the space enclosed with the single skin wall.

With the introduction of night ventilation on the previous day, internal wall surface temperature moved lower than the indoor air temperature in both the spaces where the reduction was higher in the space in which EDSE integrated as thermal mass. The results suggest some promising thermal behavior indicating the potential of night ventilation and EDSEs for passive cooling on the following day.
Research findings:
The on-site thermal performance investigation used to justify thermal mass effect in double skin envelopes. The work demonstrates that thermal mass in the double skin envelope contributed to work as a heat sink and thus passive cooling although the tropics are characterized with slight diurnal ranges as compared to hot dry climates. Results provide evidence of passive cooling with internal air temperatures moving below the ambient levels due to envelope dependency with heat sink effect and night ventilation primarily created due to double skin envelopes. Findings show empirical evidence of passive cooling suggesting that the concept developed for double skin envelopes with thermal mass and night ventilation can play a positive role in addressing extreme climatic conditions.

6. Conceptualizing a generic sectional form for EDSE for tropics

According to the theoretical evidence and based on research findings a building should have two different types of DSEFs, namely exhaust air and controlled supply air in tropical situations. Exhaust air type envelope promotes a stack force within the indoor volume and thus heat sink effect of the total building envelop by removing hot air. As a result of this, a vacuum of air is created at the lower zone of the building’s indoor volume. If the vacuum is filled with air without heat, and facing windward orientation the lower air zone gets relatively higher pressure levels. In addition, if this vacuum zone is provided with shading, darkness and protected from solar radiation, the air pressure in this area can be maintained continuously at a very much higher level than the zone closer to upper level of the exhaust air envelope on the leeward orientation.

Figure 9: Conceptual section showing integration of double skin external envelop. The exhaust air type on the leeward side promotes heat removal and supply air type envelop on windward side encourage selected airflow through a shaded air gap.

This thermal landscape can be an ideal situation which generates buoyancy driven air flow within the building volume. The total scenario helps to remove heat from interior in both day and night and
even flush the entire envelope mass with cold air in the night. This conceptual model needs a detailed investigation for its thermal performance.

6. Conclusion and future research

Thermal performance of a double skin high thermal mass envelope was seen applicable to a certain degree with night ventilation in tropics. The effect of lowering air temperature inside a building by more than 1.5 degree C was evident with this assessment of case study. Future research has been focused on more real life building practices to explore the maximum potential of EDSE in tropical situations. The work is being carried out with more field investigations to find out evidence and then justify this conceptual characterization for future practice and application in non-domestic buildings.

Acknowledgement

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References


Housing and microclimate: improving liveability in Adelaide

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Abstract: Integrating urban climate knowledge into building design and urban planning practice have been proven to be the best effective approach in mitigating Urban Heat Island (UHI) and unexpected hot days. Climate-conscious design needs to be implemented in structural and environmental development of any city components to improve microclimate and human wellbeing. This paper addresses a review of recent literature about the impacts of urban geometry and ground surface materials on microclimate and urban heat islands. The method adopted for this research is a review of scientific literature on both experimental and simulation studies about effective heat mitigation strategies at pedestrian level and canopy layer. Strategies for mitigating UHI need to be integrated into a holistic approach to an urban context. This paper also reviews the housing land consumption, contribution and allocation of residential open space in Adelaide from 1836. This research clearly indicates that there is a need for more research into residential open space performance in an urban environment and its potential benefits work towards mitigating adverse effects of urban heat islands. It concludes that all these promising heat mitigation strategies can be applicable to neighbourhood areas and houses landscape in Adelaide by considering the current situation of residential density.

Keywords: Urban Heat Island; housing design; urban microclimate; Adelaide.

1. Introduction

Nature and climate had a great influence on the design of all parts of buildings and urban settings (Beazley and Michael, 1982). Historically, vernacular architectures and human settlement areas have shown different creative ways for building construction in each climate. Therefore, the idea of creating a living place was based on integration of climate condition and human demands. Modern urbanization which captured its source from industrial revolution lost the connection of buildings to climate and human thermal comfort (Freestone et al., 2008). Radical changes of contemporary living area and the use of mechanical heater and cooler facilities caused to fade the meaning of open spaces as an effective part of urban structure in designing a sustainable architecture (Taleghani et al., 2014).
Living patterns of buildings and transforming of natural cover into built environment generate distinctive urban land use. Urban environmental transition typically involves the substantial replacement of natural cover by manufactured materials. Both urban land use and land cover modify the underlying atmosphere and create different climate. Urban pattern, density, urban land cover and other socio-economic aspects of a city play a critical role in determining the effects of urbanization on temperature variation. Physical changes of built environment have caused heat emissions and global warming. Climate change is adding a new set of global threats to sustainable development. A set of sustainable urban development requires weather and climate information which retrofit the climate to make cities more adaptive and resilient. Residential neighbourhood areas are a major component of any city. Adding climate information for residential neighbourhood planning to energy efficiency management has distinct impacts upon Climate-conscious urban design and climate change action plan.

2. Housing at Neighbourhood level

Built environment refers to all range of buildings, green spaces, neighbourhood and supporting infrastructure. An intelligent urban design seeks to consider all aspects of building design in an urban context to improve both residents and communities’ well-beings and livability. Housing sector is a fundamental component of urban context which can be more effective in controlling unexpected heat and enhancing public health environment (Wong et al., 2009; Ikechukwu, 2015). In fact, minimizing unexpected hot temperature in residential neighbourhood has effects on residential energy consumption and UHI. Potential heat mitigation strategies have been widely studied to provide a heat resilience city. According to Stewart and Oke (2012), to measure the intensity of UHI, each climate zone needs a guideline to compile the common heat mitigation strategies in an urban area which is called “local climate zone”. Local climate zone is proposed as a new framework to extract UHI intensity from local temperature observation in a neighbourhood being similar in surface cover, structure and materials. Following sections aim to review and discuss the important heat mitigation strategies that affects temperature variation at pedestrian level including aspect ratio, surface material and green canyon.

2.1. Urban canyons and aspect ratio

Several research on climatic design and built environment are available (Oke et al., 1989; Stewart and Oke, 2012). Land use and land cover are known to be the important parameters governing air temperature variations (Kotharkar and Surawar, 2015). One of the most important connections between land use and land pattern is aspect ratio which affects human thermal comfort and urban heat island. Urban pattern affects climatic elements such as solar radiation, wind speed and air temperature. It is often demonstrated as the Height/Width ratio (H/W) or aspect ratio. The ratio of mean height of buildings (H) and intermediate mean width of street (W) is mainly used in urban climatology. Aspect ratio also depends on street orientation, which comes from urban design strategies and has relation to the sky view factor (SVF). Aspect ratio and SVF affect the level of sun exposure, air velocity within urban canyons and gaining reasonable access to daylight.

Aspect ratio has adverse effect on temperature pattern. Deeper canyons increase both thermal inertia (taking a long time to heat up and cool down) and shading. Shashua-Bar et al. (2004) claimed that wider spacing between buildings could lead to an increase in daytime air temperature by 4.7°C compared to baseline temperature from meteorological references. Deeper open spaced with narrow spacing showed 2.1°C temperature differences. Bourbia and Boucheriba (2010) measured air and surface temperatures at seven different sites in Algeria with the aspect ratio from 1 to 4.8. Their research in a hot-
arid climate showed deeper canyons presented lower values of air and surface temperature. Increase in
SVF leads to a higher diurnal average temperature. Thus, higher aspect ratio and smaller SVF have resulted
in a cooler built environment.

Elnahas (2003) found out east-west street orientation is a preferable orientation in mid-latitude
cities like Adelaide to decrease urban heat island intensity in residential areas. Deeper canyons are cooler
(H/W=0.7 are 0.5˚C cooler than H/W=0.5) and in addition, higher density experiences warmer temperature
during the afternoon until early morning. High-resolution microclimate modelling systems such as Envi-met
and RanMan Pro enabled researchers and engineers to simulate thermal comfort conditions for different
street canyon aspect ratio (Perini and Magliocco, 2014). Abreu-Harbich et al. (2014) simulated 3D street
canyons based on meteorological data over 7-year period. Their research indicated that providing shade on
pedestrian areas and on façade are effects on mitigating the bioclimate thermal stress especially for
canyon with aspect ratio of less than 0.5. An aspect ratio up to 2 improves thermal comfort and shading
area during the daytime more than other ratios. Perini and Magliocco (2014) simulated Mediterranean
climate for three cities in Italy, namely Milan, Genoa and Rome. The study showed that tall buildings
effectively rise thermal comfort level during the daytime owing to their shading effect at street level (1.6m
from ground level). Therefore, the combination of tall buildings and narrow streets (deep canyon)
decreases wind flow and air temperature. It also reduces the negative effects of summertime thermal
comfort by shading of buildings at lower level.

2.2. Surface materials

Heat is re-radiated by urban corridors and pavement materials (Ikechukwu, 2015). Use of
appropriate materials in urban fabric is one of the most effective techniques to mitigate heat islands in
urban areas (Akbari et al., 2001; Synnefa et al., 2008).

According to Santamouris et al. (2011), high reflective materials decrease the cooling load of
buildings however, they may increase heating needs during winter period. Covering streets with low
albedo materials such as asphalt increase the sensible heat flux from the surface and results in warmer
temperature of the canyon. The dark pavement creates urban heat island. In 2012, Santamouris evaluated
the replacement effect of dark coloured asphalt with white painted materials which showed 7˚C reduction
in daily surface temperature (Santamouris et al., 2012). In similar studies, Doulous et al. (2004) claimed that
surface temperature of fresh asphalt is about 35˚C warmer than air temperature, however, light coloured
paving tiles are only 5-7˚C warmer than air temperature in the same conditions. Urban materials have
influence in change of temperatures with respect to absorption and reflectance properties of materials.

Akbari et al. (2001) presented that high-albedo pavement and trees have a substantial effect on air
temperature and help in saving national cooling demands about 20% through a large-scale
implementation. The results from applying a high-albedo coating to a house showed that 80% seasonal
savings of base-case use and a reduction of 25% in peak demand. It also showed that 0.25 increase in
albedo led to 10˚C decrease in surface temperature. Less absorptive (high-albedo) materials covered with
white coating reduce the temperature by only 10 C. Highly absorptive (low-albedo) materials, change the
differences between surface and air temperature up to 50˚C.

The cooling potential of white materials demonstrated a few degree warmer ambient air
temperature during the day and cooler during the night. In parallel, white coatings indicated different
thermal performance compared to natural materials like white marble and white mosaic. Doulous et al.
(2004) asserted that mean daily surface temperature ranged between 29.7˚C (for white marble tile) and
46.7°C (for asphalt tile). In their research, experimental time period conducted on 31.2°C ambient air temperature. Therefore, white marble can be cooler about 2.4°C than white coating in the same conditions. Surface temperature differences range from 4.2°C for common yellow to 11.4°C for common green. Pavement materials such as asphalt, concrete, ordinary soil and vegetation increase UHI by 4°C, 3°C, 2°C and 1°C in air temperature respectively (Ikechukwu, 2015). At the second phase of this type of research, cool coloured materials have been developed by using infrared reflective pigments mixed during manufacturing process. Cool paving materials reduced peak ambient temperature by up to 1.9°C.

Raghavan et al. (2015) monitored temperature variation in different land cover around the buildings on 24th march 2014 and 21st April 2010 in India. He stated that temperature distribution over water body showed a circular pattern ranging 34–38°C from inner region to outer region. The areas near to the lake showed a temperature range of 37–38°C. A small patch covered by vegetation has temperature range of 36–37°C while temperature in surrounding areas increases from 37–39°C. Moreover, Concrete, tile and brick absorbed heat during day time and released the heat slowly to the atmosphere at night time. In addition, wind direction affected the urban heat islands forms and there was a slight cooling effect over the urban areas nearby open fields or barren lands. Temperature range in open field and grounds was mainly increased from 40 to 41°C.

To sum up, the effect of pavement materials has been well-documented in urban conditions and computer modelling. Therefore, the parameters of urban cover and surface materials play a vital role in climate change and ecological imbalance and as the results, an appropriate design leads to decrease in adverse effects of urban areas.

2.3. Green space

Green space affects thermal comfort condition and human health as well as energy consumption and air quality (Akbari et al., 2001; Norton et al., 2015; Verbeek et al., 2010). There is numerous research on temperature changes due to use of green space. Oke (1989) argued that urban parks are 1- 3°C cooler than their surrounding urban areas. A study in Athens showed that the average night time cool island intensity varies between -0.7 and 3.6°C, although the cooling daytime intensity varies between -0.2 and 2.6°C (Skoulika et al., 2014). Air temperature monitoring in an urban park in Melbourne demonstrated 2.6°C cooler than the Melbourne CBD during nocturnal UHI (Torok et al., 2001). Similarly, Adelaide Parklands are found to be cooler by 0.64°C in day times and 1.32°C at night time than the CBD (Ewenz et al., 2012).

The cooling effects of green areas also depend on irrigation, the direction of prevailing wind, presence of trees, traffic volume in the surrounding areas and density of urbanised areas (Svensson and Eliasson, 2002). Zhou et al. (2015) claimed that park cooling effects in London extended to 200m - 400 m distance. Svensson determined that air temperature variation beyond the park boundary in Gothenburg and Sweden was 0.33°C per 100 m² (Svensson and Eliasson, 2002). Chen (2013) simulated thermal effect of city parks and showed that the range of cooling effect of green areas is more than 100 m and less than 400 m when the green areas reached 400 m². In similar studies, Ca et al. (1998) measured air temperature at the height of 1.2 m and showed that a size of 0.6 Km2 Park at the windward side of a busy commercial area reduce the air temperature by 1.5°C. Table 1 lists the studies on the effects of green landscape on air temperature.
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Table 1: Studies on green space on temperature variation

<table>
<thead>
<tr>
<th>Research</th>
<th>Location</th>
<th>Climate</th>
<th>Methodology</th>
<th>Significant findings</th>
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</table>
| Skoulika et al., 2014  | Athens, Greece | Subtropical Mediterranean | Measurement setup by 15 stations in medium size urban parks | • Mobile traverses along urban parks showed temperature gradient between 3.3 to 3.8°C in 5 m/s wind speed and outside urban parks varied between 0.16°C and 1.4°C/100 m.  
  • Parks decrease average temperature by 0.8–1.2°C in comparison with their immediate surroundings (less than 300 m distance). |
| Torok et al., 2001     | Melbourne     | Oceanic climate        | Mobile traverse measurement setup in four small towns | • An urban park in Melbourne showed 2.6°C reduction in temperature of the Melbourne CBD area at night.  
  • UHI effect had decreased to 2.2°C over concrete and 1.7°C over grass. |
| Ewenz et al, 2013      | Adelaide      | Mediterranean          | Mobile traverse measurement setup | • Adelaide Parklands are found to be cooler by 0.64°C in day times and 1.32°C in night time than Adelaide CBD |
| Oke et al., 1989       | Vancouver, Canada | Moderate oceanic climate | Simulation                      | • urban parks are 1-3°C cooler than their surrounding urban areas |

Meanwhile, many of UHI mitigation strategies are still emerging in city level of open spaces. Local climate action plan, as well as planning policy can affect both building codes and energy efficient standards to alter climate conditions. Climate resilience in smart growth projects is an essential step toward urban consolidation. Percentage of green space is declining due to urban consolidation. Hence, focus on greening need be considered in individual potential green assets (terrace, private open space and frontage). There are various studies on public open spaces. However, green open spaces have been more effective by focusing on both public and individual open space which established significant portion of a city.

The literature demonstrated that the mitigation strategies mentioned above can be applied in any residential neighbourhood areas irrespective of local climate action plan. To find out effectiveness level of the mentioned heat mitigation strategies, residential development of a case study is needed to integrate into urban climate-conscious plan.

Adelaide is a nature sensitive city and has developed to a medium density housing (DPTI, 2010a). In a medium density city, residents still have direct connection to nature and this is a potential opportunity to study more on open spaces in different type and size. Next section presents historical evolution of open spaces and land consumption in residential area of Adelaide to evaluate how these strategies could be applicable in housing sector to mitigate heat island intensity.

3. Historical evolution of housing in Adelaide

A climate assessment modelling carried out by CSIRO, in 2002 and 2006 shows that South Australia’s maximum average temperature has increased by 1.2°C, the minimum by 1.01°C and the average temperature by 1.1°C Compared to national trends. Maximum temperatures of South Australia indicate a
faster rate of increase while minimum temperature shows a slower rate (Ridley and Boland, 2012). The city of Adelaide usually experiences long, hot and dry summers in which heat waves are common. It is the only major city in South Australia and is home to over two-thirds of state’s population. The geography of Adelaide which bordered by sea to the west and hills to the east has caused development to stretch north-south over time. It turns Adelaide to a great metropolitan fringe from the CBD compared to other Australian cities. The more intensive use of land for residential development in Adelaide has contributed to housing choice over the few decades. Infill development and medium density housing have been suggested in inner and middle rings located up to 20 km from the CBD. Moreover, government put emphasis to deliver substantial growth in the number of energy efficient houses from 2010 which leads to reduction in energy consumption. Apart from putting emphasis on constructing more energy-efficient to improve the interior condition and energy consumption of buildings, further immediate attempts in controlling climate change in medium density housing need to be addressed. Contribution of open spaces and land consumption rates in residential areas need to be studied to consider the effective urban heat islands mitigation strategies and control temperature variations.

In pre-industrial era, ‘open space’ covered wider areas from an agricultural production area to a semi-urbanized consumption area where people reside, work and recreate. In Adelaide, the provision of open space has been formed based on the concept of Colonel William Light’s 1836 plan. Parklands around the CBD created the important part of initial urban landscape of Adelaide. These unique public parks affected later urban land cover planning in Adelaide. Despite this, there was no legal mechanism for the provision of urban park at the time of land division until 1929. In Town Planning 1929-1957, government allocated some land to open space and town planners held approval if the plan did not provide adequate reserve. Under this Act, approximately 5% of a subdivision created by 20 or more allotments required to be allocated as public reserve (Government of South Australia, 1962). All these attentions to the urban parks affected by the first concept of urban planning made Adelaide as nature sensitive city. From Planning and Development Act 1967, government introduced the provision of up to 12.5 percent open space at the time of land division (DPTI, 2010b). Since Planning and Development Act 1993, local government of South Australia has kept this legislation in Adelaide’s Metropolitan Open Space System (MOSS) to ensure that each resident has access to open space at a regional scale (DPTI, 2010a).

In The 30-Year Plan for Greater Adelaide, the impact of the climate change on urban development is considered. It claims that urban structures, surface materials and other contributing factors such as open spaces affect urban climate by trapping heat which leads to increasing hot days. The 30-Year Plan proposed several strategies to achieve greater liveability in a hotter climate, such as improving the thermal efficiency of buildings and creating a network of the open spaces to have a cooling effect on new and existing areas. The plan provides Metropolitan Open Space System (MOSS) to create enough open spaces across the region on the large scale (DPTI, 2014). Moreover, emphasis on green open spaces (as city assets) will improve resilience of the city towards climate change and promote mental and physical human wellbeing (Burgess et al., 1988; Buyadi et al., 2013; Vailshery et al., 2013). The plan outlines specific policies and components for long-term adaptation and region’s climate change resilience. Based on the Plan, urban planning assumptions will make a contribution to different type of open spaces in reducing both UHI intensity and growth of greenhouse gas emissions.

Urban development policy initiated in early 1980s and it emerged urban consolidation in Australia. The urban consolidation and planning code were laid at commonwealth level, formally established in 1983. This policy meant using less land when constructing new housing. Since the 1990s, reduction in the size of the Australian backyards has been a clear-cut and widespread phenomenon. Under the Town Planning Act 1297-1957 regulations in South Australia, the minimum dimensions of detached dwellings (15×24 m) for a
regular shape allotment were 585 m² with sewerage access and, the minimum dimensions (15×30 m) were increased to 696 m² without sewerage facilities (Sivam et al., 2012). Before 1950, land division consisted of large residential allotments by approximately 700 m² and little public open space. Until Development Act 1993, control planners tried to prevent the creation of small housing lots. However, marketing demands changed and the size of allotments decreased up to 422 and 450m² for the year to December 2008.

Now, Adelaide experiences significant infill development pressure in many older inner and middle ring suburbs. Overall size reduction of residential houses has the results in the supply of open space on individual housing allotments. Relatively, new housing subdivisions have small allotments with tiny backyards (20%) and subsequently, open spaces will available at neighbourhood and local level as compensation. In housing level, planning regulations aim to control the size and shape of courtyards. Besides these regulations, some approximate standards for appropriate design, materials selection and dimension would be required. Minimization of private open space affects aesthetics, biodiversity, carbon sequestration and pollutant removers. Residents also suffer from poor microclimate due to lack of natural ventilation, shading and excess electricity consumption in hot weather. According to Hall (2010), Australians have commonly attributed the move to smaller allotments which directly reduce the size of backyards. Backyards rarely exceed 100 m² and are often less than half of this (Hall, 2010). Site coverage in dwellings is at least 40% and can be exceeded by the 50-70% range. Open space around the dwellings in both infill and new subdivision development is declining. Urban infill development is occurring not in the CBD or inner-city areas but in the outer suburbs. The increase in residential density is resulted from property investment strategies, however it appears to have only a small effect in affordability.

### 4. Findings and discussion

This paper reviews recent research on the effect of urban pattern and pavement materials to mitigate heat island effects in urban environments and how these strategies could be applied to Adelaide. The effective heat mitigation strategies were reviewed in both urban pattern and urban land cover. These strategies in mitigating unexpected high temperatures in summertime were evaluated in an urban context like Adelaide.

It may raise a question why anthropogenic heat and green roofs are not mentioned in literature review which impacting on energy consumption. In summary, according to relevant literature, anthropogenic heat has impact on energy balance equation which is mainly related to energy consumption for indoor air-conditioning and motorized transportation (Hu et al., 2004). Rosenfeld et al. (1995) claimed that contrasting estimations of the anthropogenic heat impact on air temperature is small and negligible in residential areas. It more depends on regular human activities and affects regional and global climate conditions. Furthermore, impacts of green roofs are well-documented on decreasing indoor environment energy consumption and buildings in high-density development (Chen et al., 2009; Wilkinson and Reed, 2009). The studies on for Hong Kong and Tokyo as examples showed that low and medium densities still keep the connection to horizontal and natural green areas and this type of land cover is more effective on microclimate and outdoor environment in comparison to green roofs. Green areas on ground have more impact compared to green roofs in reducing summer potential temperatures and mean radiant temperatures in low and medium density. In low densely urban environment, the ratio of building height and street width (aspect ratio) can be a more sensitive strategy in controlling microclimate. Huang et al. (2005) did a numerical study in Tokyo and implied that application of green roofs on medium and high-rise buildings is ineffective in lower ambient temperature at pedestrian level and near ground level. Thus, the
impact of these two strategies was thoroughly effective in high-residential built-environment and inside energy balance of a house which not directly affect microclimate.

Based on the literature review, aspect ratio was identified as one of the key governing strategies in controlling microclimate. In this regard, the intensity of UHI varies with climate conditions. Adelaide generally has warm and dry summers. The literature showed that higher aspect ratio (deeper canyon) caused lower daytime air temperature in hot seasons. Elnahas (2003) argues, east-west oriented street presents better thermal comfort in mid-latitude cities like Adelaide. Shading from trees or building façade at pedestrian level, simply intercept solar radiation and thus preventing the heating of ground surfaces temperature as well as air temperature. Therefore, the design of forms and patterns in residential neighbourhood directly depends on climatic conditions and geographical positions of a city. The effective design strategy to mitigate UHI in residential areas of Adelaide is to keep open spaces between buildings for air velocity and providing narrow streets or shadings at pedestrian level to decrease the effect of solar exposure.

Effects of vegetation on climate through the process of shading, evapotranspiration and changing the wind pattern have impact in reducing UHI effect. The data on the historical trends of urban development in Adelaide shows proportion of backyards in houses now become at least 20-26% of their total allotments. Since residential areas are main component of a city, this percentage of private open space is still substantial. Therefore, if the size of small allotment in Adelaide is approximately 400 m$^2$ and the portion of backyards is minimum 80 m$^2$, at least 7-10 houses are enough to have cooling effects on neighbourhood microclimate and more important, on air temperature around each block.

By keeping urban materials cooler, the intensity of long wave radiation was reduced and air temperature on summertime can be lowered by as much as 4°C. In a mid-latitude city like Adelaide, by modifying surface albedo from 0.25 to 0.50 air temperature simply reduces by 4°C and surface temperature decreases at least 10°C. White marble and mosaic reduce peak ambient temperature more than other light-coloured pavement materials by up to 2.4°C. Warmest light-coloured material is made of pebble with white and green surface colour which increase surface temperature up to 7°C. In addition, applying a high-albedo coating to residential buildings in Mediterranean climate achieves cooling energy savings of 20-40% and it affects outdoor air temperature as well (Rosenfeld et al., 1995; Bretz and Akbari, 1997). In an urban layout, sidewalks occupy roughly 16 percent of the ground surface and this percentage can be reached at minimum 23% in a typical communal housing complex. Percentage of street is as high as private open space at residential level but it is still not considered in the study of UHI in Adelaide.

5. Conclusion

This review paper addressed the importance of aspect ratio, ground surface materials and greenery at urban context by considering both temperature distribution and heat balance. It also found that the considerable amount of land in different range of housing types is not taken into account in the Energy Efficient provision of Adelaide, while it will be effective in climate change action plan and enhancing health and liveability in a sustainable neighbourhood. The design of neighbourhood areas and contribution of open space provision which can improve communities and residents’ well-being and health. Therefore, modified residential open spaces affect the formation of urban heat island and microclimate. However, detail study will be conducted at private open space to measure and validate the impact of mentioned variables on microclimate.
6. Acknowledgements

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The morphological characteristics and self-construction mode of rural dwellings in the suburbs of Tianjin - Taking Xijingyu village of Tianjin city in China as an example

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Abstract: In this paper, taking Xijingyu village of Tianjin city in China as an example, through on-site field investigations about traditional stone dwellings there, we summed up their morphological characteristics from the points of site selection, overall layout, functional organization and construction craft. During this process, we analyzed the regional living wisdom they contained. Then, we summarized the current situation of the self-construction of vernacular dwellings in Xijingyu village and discussed their self-construction mode. Finally, in view of local actual situation, we offered some appropriate and reasonable proposals for the self-construction mode of the dwellings there. We did this to help record, extract and inherit the traditional regional living wisdom for Xijingyu village, and to provide academic guidance for contemporary self-construction of dwellings. This research can also be taken as reference for the study of rural residential houses in others villages around Tianjin.

Keywords: Xijingyu village; dwelling; morphology; self-construction.

1. Introduction

There are a lot of dwellings that are well worth our exploration in the suburbs of Tianjin. Four kinds of them are collected by Chinese traditional dwellings type published by Chinese Ministry of Housing and Urban-Rural Development. They are the side-yard dwelling that Shijia dwelling in Yangliuqing represents, the adobe house that the houses in Wangjiaying Village, Duliu town and Fengjia village, Liangtou town represent, the brick house that Zhangjia dwelling and Houshi dwelling represent and the stone house that the houses in Xijingyu village, Yuyang town, Jixian county represent. Xijingyu village was famous for its stone rural culture and it becomes the first "Chinese historic and cultural village" in Tianjin(Yang, 2015). In this paper, we regard the vernacular dwellings in Xijingyu village as the research objects.
2. Basic situation of Xijingyu village in brief

Xijingyu village formed in Qing Dynasty is located 2.5 kilometers away from Jixian town of Tianjin city (Figure 1). The geographical position of this village belongs to the cold area in our country. So the winter there is cold and dry, and the summer is warm and humid.

On the other hand, the whole village also belongs to the Ancient World National Geological Park. It is located on the mountain made of stone and built by the stones with distinct regional features: roads paved with stones, houses built by stones, together with the ubiquitous grinding stones and stone mills. The village became a veritable "Stone Village" (Figure 2).

The morphology of the dwellings there did not change much since they were built and the life-style of the villagers was simple and unsophisticated (Yang, 2015). Therefore, the emphasis of our research is the morphological characteristics of these dwellings instead of the morphological evolution.
3. Research of morphological characteristics of the dwellings

3.1. Site selection

Villagers in Xijingyu build their houses conforming to the lie of mountain, so the houses are stacked from top to bottom, which reflect the adaptation to the land form.

Villagers also consider the influence of climate when they decide the locations of the houses. The prevailing wind there is north wind in winter. During the survey, we find that most old stone houses are located on the sunny slope of Bobo Mountain so the cold north wind can be stopped by the mountain in winter. At the same time, the houses can receive sunshine more adequately and obtain better nontechnical environment. The wisdom in site selection fits well with the principle of “Negative yin-yang hold” in Chinese Fengshui theory. (Figure 3)

![Figure 3: The advantage of location in cold winter (source: drawn by authors, 2016)](image)

In addition, the houses there are almost built in the places with rich water, excellent terrain and pleasant natural environment. The superiority in location can make dwellings have good micro climate. The advantages of good micro climate can reinforce the region climate characteristics, and make the living environment more satisfactory.

Site selection is the first step in residential construction, and it well reflects the regional wisdom which is significant reference for contemporary self-construction.

3.2. Spatial layout and function organization

3.2.1. Specific morphology of spatial layout and function organization

Xijingyu village is well away from the city, which avoids the constructive destruction brought by the urbanization, so the stone dwellings remain relatively intact. We visited the village and carried on detailed investigations, especially for the five dwellings blow.
Table 1: The induction and analysis about the five dwellings (source: drawn by authors, 2016)

<table>
<thead>
<tr>
<th>Serial Number</th>
<th>Location</th>
<th>Photos</th>
<th>Arrangement Form</th>
<th>Function Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling 1</td>
<td><img src="image1.png" alt="Location" /></td>
<td><img src="image2.png" alt="Photos" /></td>
<td><img src="image3.png" alt="Arrangement" /></td>
<td><img src="image4.png" alt="Function" /></td>
</tr>
<tr>
<td>Dwelling 2</td>
<td><img src="image5.png" alt="Location" /></td>
<td><img src="image6.png" alt="Photos" /></td>
<td><img src="image7.png" alt="Arrangement" /></td>
<td><img src="image8.png" alt="Function" /></td>
</tr>
<tr>
<td>Dwelling 3</td>
<td><img src="image9.png" alt="Location" /></td>
<td><img src="image10.png" alt="Photos" /></td>
<td><img src="image11.png" alt="Arrangement" /></td>
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<tr>
<td>Dwelling 4</td>
<td><img src="image13.png" alt="Location" /></td>
<td><img src="image14.png" alt="Photos" /></td>
<td><img src="image15.png" alt="Arrangement" /></td>
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<tr>
<td>Dwelling 5</td>
<td><img src="image17.png" alt="Location" /></td>
<td><img src="image18.png" alt="Photos" /></td>
<td><img src="image19.png" alt="Arrangement" /></td>
<td><img src="image20.png" alt="Function" /></td>
</tr>
</tbody>
</table>

According to the table above, we can know that the traditional stone dwellings are courtyard houses in which buildings are organized and centred on the courtyard. The courtyard is indispensable space in local farming culture. Not only does it provide quiet dwelling environment for the villagers, but also it
creates space for some producing activities that could be completed at home (such as airing crop and peeling the skin of the corn).

The specific morphology of spatial layout and function organization is the following contents. The principal rooms face to south and have three bays. The middle bay is a hall and its bilateral bays are bedrooms. The capacious front courtyard which is the main courtyard is disposed at the south of the principal rooms and some vegetables grow in it. There are east and west wings on both sides of the front courtyard. Some dwellings just have an east wing or a west wing. On the south of the courtyard, there is the stone wall or the southern rooms which are used to contain agricultural vehicles or deposit sundries. Another courtyard is arranged on the north of the principal rooms. Unlike the front courtyard, it is very small. (Table 1)

### 3.2.2. Regional living wisdom contained into the spatial layout and function organization

![Diagram of spatial layout and function organization](source: drawn by authors, 2016)

Almost every door and window is open to the main courtyard (the front courtyard) in the dwellings, so the rooms with optimal daylight are the northern rooms. They can also obtain most solar radiant heat. The east wing and west wing are not as good as the northern rooms in this respect and the southern rooms are the worst. Therefore, villagers arrange the principal rooms, which are most frequently used and undertake main living functions like sleeping, cooking and entertaining guests, on the north. The east and west wings are used for dining room or subaltern room. On the other hand, they arrange the rooms used for stockpiling sundries and almost have no requirement for day lighting on the south. (Figure 4)

The spatial layout and function organization above embody local villagers’ living wisdom and should be inherited, extracted and applied in the contemporary self-construction of the dwellings.

### 3.3. Form and material

Because Xiijingyu village is located on the rocky mountain and its soil layer is very thin, the old houses are almost built by the stone, rather than the adobe (Jia et al., 2015). The stone with large thermal inertia and good durability is natural insulation material. It helped local people living through the hard times and was still in use today (Tian Chen Deputy Director).
Most traditional stone houses there have Yingshan Roofs with single lift type, which made up of gray tiles and wooden beams. The heights of most houses are three to four meters and the shapes are cuboids, which make them have a good shape coefficient for heat preservation in winter. (Figure 5)

Figure 5: the form and material(source: drawn and photographed by authors, 2016)

3.3. Construction craft

Besides observation and recordation, we also conducted interviews with local villagers. Through the interviews, we learned that local villagers take delight in finding characteristics and beauty of the stones. They have a special emotion and spirit of craftsman for them. After hundreds of years of life, the native ancient construction craft has been passed down.

First, villagers need to go to the mountain to get stones. It is a difficult and dangerous work, which needs to use the shuttles. In the quarry, they should tap on the stones for good sizes they need, and then pull them to the site.

Then they choose the stones according to the width of the wall. The stones selected should be level off, smooth with straight edge. The average size of the stones is 50 * 60 * 80 cm. The narrower the wall is, the higher the technique requires. Today, there are not much young villagers wanting to learn that, because it is hard and earn little.

Figure 6: the stone wall (source: photographed by authors, 2016)

The last step is masonry. Most stone walls there are built by dry masonry (without any bonding mortar). During the construction process, villagers collocate the stones according to their size. At the
same time, they make the thick stones and thin stones complement each other to balance the pressure from every direction. Piles of stones form the whole wall with this seemingly random method. (Figure 6) What's surprising most people, the walls are so firm that none of them collapsed in Tangshan Earthquake, including the high walls up to six meters.

It is interesting that the special masonry wall is similar to the overlying rock formed hundreds of millions of years ago. Nature seems to be a stonemason that he use this method of masonry building the mountains around Xijingyu village, and the ancients here coincides with nature that they use a similar way build their homes bit by bit. Here, people found the harmonious way to get along with the nature.

4. Research of self-construction mode of local dwellings

4.1. Current situation about self-construction of local dwellings

According to the on-site field investigations, we summarize the current situation about self-construction of local dwellings from three aspects: the spontaneous self-construction of dwellings by local villagers, the meliorative self-construction of dwellings guided by rural reconstruction workers and the transformational self-construction of dwellings aiming to convert them to public space.

4.1.1. The spontaneous self-construction of dwellings by local villagers

Figure 7: Newly-built dwellings similar with urban residences (source: photographed by authors, 2016)

To improve their living conditions and expand residential commerce functions, many local villagers abandon old stone houses and build new dwellings by themselves. Most of these newly-built dwellings are brick houses rather than stone ones, and many of them imitate the design of urban residences, such as Europe Style. Some villagers even use the white ceramic tiles as the facades of the houses, or use bright-color roofs (Figure 7).

4.1.2. The meliorative self-construction of dwellings guided by rural reconstruction workers

In the course of the surveys, we find that there are some rural reconstruction workers in Xijingyu village. They rent some old stone dwellings and guide the villagers to improve and optimize them by professional design and cutting-edge technology. The improvement of Dwellings No.1 is a comparatively typical case. The meliorative methods include: ① adding 240mm brick wall on the indoor side of the original stone wall and pressing them close together to improve the performance of heat preservation; ② converting the primary outworn external windows into late-model windows with good leakproofness and maintaining similar styles; ③ hiding water pipes and electric wires in the walls to make interior space tidy and setting up the connections at correct place to make them user-friendly. (Figure 8)
4.1.3. The transformational self-construction of dwellings aiming to convert them to public space

Rural reconstruction workers also guide villagers to replace the function of old stone dwellings. For example, one of them is transformed into a book bar. The transforming methods include: ①reinforcing the outer edge of original stone wall with concrete and making them have design aesthetics by contrasting the inerratic outer edge with the irregular stones in the wall; ②reserving the original wooden beams and brushing the anti-corrosion paint on them; ③opening up some external walls to transform the indoor space to half-indoor space with the purpose of realizing dialogue with the environment. (Figure 9)

4.2. The analysis and discussion about the self-construction mode of local dwellings

4.2.1. Abandoning stone houses is not a good idea

Abandoning old stone houses and turning to build new dwellings which are like urban residential houses is not a good idea, although old stone houses are difficult to meet the contemporary living demand of the villagers (Figure 10). As is known to all, these old stone houses have high historical value and abandon them will make irreversible damage to the precious heritage. Besides that, it is not desirable to blindly imitate city residential houses, ignoring locals living habits and unique wisdom of regional residential construction. Because it will not only lose the unique regional characteristic of Xijingyu and affect the overall style of the whole stone village, but also reduce the living quality of villagers.
4.2.2. “In use” should be correct way in which traditional stone dwellings realize contemporary regeneration.

Besides the deserted old stone dwellings, we find another extremity: some dwellings which are protected excessively. Some of the old stone houses with high historical value were restored meticulously since Xijingyu village became the "Chinese historic and cultural village". Then they were preserved with the doors locked and gradually became the "specimen of dwelling". Neither being deserted nor becoming “specimen” should be normalcy for these old dwellings in the contemporary era. They were the existence originally filled with the flavor of rural life, and they would lose the source of vitality once nobody living in them. In addition, the sturdiness and durability of the stone houses are very well, so it is possible to live in them comfortably without destroying their historical value through rational design and melioration.

4.2.3. How to make the old stone houses used better through appropriate self-construction

- Enhancing durability and convenience with the help of modern technology
  It should not be contrary for modern construction technology and traditional stone houses. Conversely, they can complement each other. Integrating modern construction technology into the self-construction of traditional stone houses could enhance their durability and convenience, such as brushing anti-corrosion paint on the wooden, adding brick wall inwardly and replacing the original windows with similar-style airtight windows.

- Solving the regional technological problem creatively by ingenious design
  The whole village is located on the stone, so it is very difficult to excavate pipelines. In the book bar transformation above, the designer combines the landscape design with the drainage.

  The yard is divided into a number of polygons to form the landscape and the grooves at the tangent of the polygons is used as drainage canals. The discharge water in the drainage canals is brought into the reservoir in a corner of the yard by the tiny height difference. Then the discharge water in the reservoir will drain away thoroughly by the cave. So the drainage is arranged on the ground rather than under the ground in that creative way. (Figure 11) The grooves solve the problem while being used as divisional boundaries of the landscape.

  The idea of solving technological problems by ingenious design has enlightenment and reference for the self-construction of traditional stone houses. In addition, the problem of exposed pipelines in the streets could be solved in a similar manner.
Figure 11: The combination of landscape design and drainage (source: photographed and drawn by authors, 2016)

5. Brief summary

The research about morphological characteristics and self-construction mode of dwellings in the suburbs of Tianjin is grand. In this paper, we take Xijingyu village as specific region and study on the morphological characteristics and self-construction mode of the dwellings particularly by information access, field survey and academic analysis. We hope that our research could make a contribution to the conservation and construction of the dwellings there.

Acknowledgements

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Mathematical Analysis and Grammatical Generation of Design Instances of Murcutt’s Domestic Architecture

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Abstract: This paper presents a mathematical approach to analysing and generating design instances within a specific language of architectural design. The research develops a Shape Grammar allowing for the analysis of ten domestic designs by Glenn Murcutt and their generation. The Shape Grammar, which consists of eleven rule sets, starts by generating pavilions and ends with a termination rule. After describing the Shape Grammar the paper uses mathematics to directly measure and compare the rules, introducing the use of a Normalised Distance Graph (NDS), to capture the transition sequences of their application through rule transition paths. The results of this paper suggest that this approach can be used to clearly characterise design instances as well as to effectively create new designs in an architectural style. The mathematical approach is widely applicable to other grammatical studies in the architectural and design domains.

Keywords: Shape Grammar; mathematical analysis; design generation; Glenn Murcutt.

1. Introduction

Computational approaches to architectural analysis and generation have been developed and tested since the 1960s. One of the most notable theories from this field is “Shape Grammar”, whose foundation has often been linked to Stiny and Gips’ 1972 seminal article. The typical Shape Grammar approach treats architecture as an amalgam of shapes, examining the logical relationships between various sub-shapes that make up the two or three-dimensional forms of a building. The Shape Grammar approach specifies a set of rules delineating how a design can be composed from shapes. It starts with an initial shape and then proceeds iteratively by applying a set of rules (each of which specify a particular operation or a set of operations) to that shape until an end-state is reached. In this approach, design is assumed to be a rigorous and rational process. Such a conceptual understanding about the design process is central to
most grammatical studies and this reasoning allows researchers to rigorously capture possible processes for generating a language of design (Economou, 2000; Knight, 2003). It is through this generative aspect that the selected architectural subjects are analysed and understood. The new knowledge of design that is developed in this way can then be tested by generating new designs that capture the characteristics of the original architecture, through the application of the same rule sets.

Although Shape Grammar theory has proven to be effective for architectural analysis, with many well-known applications from the field over the past four decades, the typical outcomes are largely descriptive including the definitions of the shapes, rules and sequences of the rule application. This paper proposes an alternative approach which mathematically evaluates the grammatical applications of certain rule sets to develop a language of architectural design (an architectural style). The mathematical measurements have a dual focus on normalised distance and transition probability.

This mathematical approach to the analysis and generation of architecture is demonstrated in the paper using ten of Pritzker-prize-winning architect Glenn Murcutt’s rural houses. The paper starts by developing a Shape Grammar for the design analysis of the selected Murcutt’s Houses. After describing the Shape Grammar the paper applies a range of mathematical means to directly measure and compare the rules and the sequences of their applications as well as the resultant designs. The mathematical approach also enables different designs and their generation processes to be compared and discussed in this paper.

2. A Shape Grammar on Murcutt’s domestic buildings

A Shape Grammar study specifies a set of rules delineating how designs can be composed by applying various operations to shapes. Most research in the field focuses on two dimensional (2D) shapes, typically floor plans (Stiny and Mitchell, 1978; Cagdas, 1996), on which the Murcutt Shape Grammar developed in this paper is also based. Logical structures are common in Shape Grammar research that often selectively adopts sequential structures comprising possible design steps. For example, Stiny and Mitchell (1978) use eight steps for several of their projects, whilst Hanson and Radford (1986) use 12 steps to generate their design instances. The Shape Grammar developed in this paper for Murcutt’s rural houses consists of 11 rule sets in four phrases (see Table 1) which starts by generating pavilions and ends with a termination rule. The conceptual foundation for the generation of design instances typically involves both simplifying the properties of the shapes used in architecture and decomposing them using a modular system.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Rule set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phrase 1</td>
<td>1.x. Generating pavilions</td>
</tr>
<tr>
<td></td>
<td>2.x. Generating basic modules</td>
</tr>
<tr>
<td>Phrase 2</td>
<td>3.x. Configuring a core unit</td>
</tr>
<tr>
<td></td>
<td>4.x. Configuring public zones (e.g. living room, dining room, kitchen, and function room)</td>
</tr>
<tr>
<td></td>
<td>5.x. Configuring private zones (e.g. bedroom and studio)</td>
</tr>
<tr>
<td></td>
<td>6.x. Configuring transition zones e.g. (veranda and court)</td>
</tr>
<tr>
<td></td>
<td>7.x. Configuring hall units</td>
</tr>
<tr>
<td></td>
<td>8.x. Configuring a garage</td>
</tr>
<tr>
<td>Phrase 3</td>
<td>9.x. Defining a main entrance</td>
</tr>
<tr>
<td></td>
<td>10.x. Defining sub entrances</td>
</tr>
<tr>
<td>Phrase 4</td>
<td>11. Termination</td>
</tr>
</tbody>
</table>
Mathematical Analysis and Grammatical Generation of Design Instances of Murcutt’s Domestic Architecture

The first phrase includes two rule sets to initially generate pavilions and basic modules. There are also two sub-rule sets to generate pavilions in the first rule set. Considering site contexts and design strategies, the Shape Grammar can be used to select a pavilion type from either a single-pavilion shape or a two-pavilion shape. Thus, Rule 1.1 generates a one-pavilion shape, while Rule 1.2 develops a two-pavilion shape, including two space units and a hall unit.

The second rule set generates basic modules (structural or functional bays) to standardise and delineate enclosed spaces. The bays can be simplified using a rectangular grid, which conforms to the repetitive column layout found in Murcutt’s domestic architecture. While the dimensions of the enclosed spaces may vary in each of Murcutt’s designs, the column layout is an essential characteristic of each house. For example, the Marie Short House consists of two types of modules (room-type and hall-type). The exact dimensions of modules are not considered in the grammar because of the need to simplify the number of variables used and the dimensions depend on a variety of design contexts that are not part of the grammar developed at the conceptual design stage. Instead, it considers Murcutt’s plan layouts with four basic units with simplified constants (e.g. \(a\) for width, \(b\) for length) in Figure 1, for the mapping of space: room, hall, transit, and core unit – to develop the rules of the grammar.

### Room unit
![Room unit diagram](image)
A room unit is a basic convex space with a defined function. (e.g. living room, bedroom, and kitchen). Generally, the width \((w)\) is \(a\) or \(2a\) and the length \((l)\) is \(b\). ‘\(R_n\)’ is a marker representing a basic room unit, but ‘\(A_n\)’ can also be used for indicating an attached room unit.

### Hall Unit
![Hall unit diagram](image)
A hall unit is assigned as a hall. The length of an attached hall unit is generally \(c\).

### Transit unit
![Transit unit diagram](image)
A transit unit is assigned mainly for a veranda.

### Core unit
![Core unit diagram](image)
A core unit using a marker, denoted as ‘\(R_c\)’, includes a main entrance. The width is \(a\) or \(2a\) and the length is \(b\) or \(b+c\). The core unit is distinguished by assigning the symbol (●) at its corners.

Figure 1: Four basic units for the grammar.

There are three rules in the second rule set – Rule2.1 generating modules consisting of a shape space; Rule2.2 generating a series of modules consisting of a room \((R_n)\) and a hall unit module \((H_n)\) and an attached room unit module \((A_n)\); Rule2.3 generating a series of modules consisting of a space \((S_n)\) and a hall unit module \((H_n)\) – as described in Figure 2. The second phrase consists of six rule sets which configure walls according to spatial functions. The rule set 3 configures a core unit, as a starting point for the remaining configuration, which includes a main entrance in the ninth step of the grammar. Rule3.1 develops a room shape module into a defined core unit \((R_c)\), while two space shape modules are changed to a core unit, which results in a double-size room unit \((2a)\) by Rule3.2. Rule3.3 considers a room unit and
a hall unit as a core unit. Through Rule3.4 the composition of a room unit, a hall unit, and an attached space unit becomes a core unit (see Figure 2).

Figure 2: Rule sets 1-4 of Murcutt’s Shape Grammar (other sets omitted due to space limit).
Rule set 4 configures public zones which consist of living room (L), dining room (d), Kitchen (K), LD, LDK, DK, etc. There are four rules: Rule4.1 generating one public zone (LDK, LD+K) from the side of a core unit; Rule4.2 generating separated public zones; Rule4.3 generating public zones including a core unit; Rule4.4 generating other public zones such as a music room. Rule set 5 configures private zones, e.g., bedroom and studio. There are five rules: Rule5.1 generating one bedroom from the side of a public zone; Rule5.2 generating two bedrooms from the side of a public zone; Rule5.3 generating a bedroom from the side of a core unit; Rule5.4 generating two bedrooms from the side of a core unit; Rule5.5 changing a core unit into a bedroom. Rule set 6 configures transition zones such as verandas. The first rule of this set is skipping and going to the next rule set, while Rule6.2 develops verandas and Rule6.3 generates a court. Rule set 7 configures hall units. Rule7.1 develops hall units into a hall unit, while Rule7.2 changes part of a core unit into a hall unit. Rule set 8 defines a garage unit through Rule8.1 or skips and goes to Rule set 9 by Rule8.2. The third phrase consists of two rule sets. Defining a main entrance involves three rules: Rule9.1 defining a main entrance in a hall space; Rule9.2 defining a main entrance in transition zones; Rule9.3 defining a main entrance in public zones. The process of defining sub Entrances can be triggered more than once. There are five rules: Rule10.1 defining a sub-entrance in a garage unit; Rule10.2 defining a sub-entrance in a hall unit; Rule10.3 defining a sub-entrance in private zones; Rule10.4 defining a sub-entrance in public zones; Rule10.5 skipping and going to ‘Termination’. The final phrase (rule set 11) terminates the generation process.

3. Mathematical analysis on the application of the grammar

3.1. Frequency of applied rule sets

An application of the Shape Grammar is demonstrated using ten houses by Glenn Murcutt (built between 1975 and 2005) syntactically examined in Ostwald (2011a; 2011b). The first part of this section is concerned with the tendency of the applied rules in the cases and the second with an alternative way of characterising each case through a mathematical abstraction using the frequency of applied rule sets, the so called ‘normalised distance’.

Table 2: Rules applied to generate the ten cases.

<table>
<thead>
<tr>
<th>Rule set</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
<th>Case 6</th>
<th>Case 7</th>
<th>Case 8</th>
<th>Case 9</th>
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<td>3.1</td>
<td>3.2</td>
<td>3.2</td>
<td>3.3</td>
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<td>3.4</td>
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<td>3.1</td>
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<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
<td>4.2</td>
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<td>6.2(2)*</td>
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<td>7.2</td>
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<td>7.1(2)</td>
<td>7.1</td>
<td>7.1(3)</td>
<td>7.1(2)</td>
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<td>8.2</td>
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<tr>
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<td>10.1</td>
<td>10.1</td>
<td>10.2</td>
<td>10.1</td>
<td>10.1</td>
<td>10.2</td>
<td>10.1</td>
<td>10.1</td>
</tr>
</tbody>
</table>

* The number inside parenthesis indicates the number of times the rule is applied.
Table 2 illustrates the rules applied to generate the ten cases. For example, in order to generate the first case, the Shape Grammar uses the set of rules, 1.1, 2.1, 3.1, 4.1, 5.3, 5.5, 6.1, 7.2, 8.2, 9.1 and 10.5. In cases 1 to 6, Rule1.1 is applied in the first rule set to generate single-pavilion shapes, while Rule1.2 is used for the two-pavilion shapes in cases 7 to 10. This table provides the information required to conduct the mathematical analysis on the application of the grammar.

The frequency of the applied rules can be recorded within the set of the ten designs. This information indicates a tendency to select a particular rule or pattern. The tendency of each rule forms a typical 'Murcutt-esque' language or style. In order to investigate the tendency, we firstly sorted the applied rules at each step of the grammar. Secondly, the frequency of each applied rule was calculated. Finally, the most frequently applied rule was located in the first sub rule (x.1) and the next frequently applied rule was set to the second sub rule (x.2). This means the rule close to the first sub rule in each rule set, can more likely generate an archetype in the language of design because it is most frequently applied (see Table 3).

Table 3: Frequencies of each applied rule.

<table>
<thead>
<tr>
<th>Rule set</th>
<th>x.1</th>
<th>x.2</th>
<th>x.3</th>
<th>x.4</th>
<th>x.5</th>
<th>Mean</th>
<th>SD</th>
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<tbody>
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<td>Rule1</td>
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<td>-</td>
<td>-</td>
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<td>4</td>
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<td>2</td>
<td>-</td>
<td>-</td>
<td>3.33</td>
<td>1.15</td>
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<td>Rule3</td>
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<td>-</td>
<td>2.50</td>
<td>1.91</td>
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<td>3</td>
<td>3</td>
<td>1</td>
<td>3.20</td>
<td>1.48</td>
</tr>
<tr>
<td>Rule6</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>4.00</td>
<td>2.65</td>
</tr>
<tr>
<td>Rule7</td>
<td>9</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6.50</td>
<td>3.54</td>
</tr>
<tr>
<td>Rule8</td>
<td>5</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Rule9</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>3.33</td>
<td>1.25</td>
</tr>
<tr>
<td>Rule10</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>4.00</td>
<td>2.00</td>
</tr>
</tbody>
</table>

3.2. Normalised Distance Graph (NDG)

Based on the data in Table 3, this paper introduces an alternative approach to analysing the application of the grammar and to visualising the characteristics of each case in terms of the grammatical design process. Table 4 determines the normalised distances that are calculated using applied rule’s normalised frequency in relation to the rule that is most frequently applied. Each normalised value indicates the standardised frequency based on each mean frequency. Rule set space is denoted by \( Rule_x = \{x = 1 \text{ to } 10\} \). \( Rule_x = \{Rule_{xy} : y = 1, 2, 3...k\} \), \( k = \text{max number of sub rule } y \) in the rule set, \( Rule_x \). The normalised frequency of one of the rules \( Rule_{xy} \in Rule_x \) is:

\[
F_{\text{normalised}}(Rule_{xy}) = F'(Rule_{xy}) = \frac{F(Rule_{xy}) - F(Rule_x)}{SD}
\]

Where:

\( F \) is the frequency of each rule being applied in the ten houses, SD is the standard deviation of the frequencies of \( Rule_x \). Each rule’s normalised distance is then calculated by the absolute value of each normalised frequency subtracted by the normalised value of the most frequently applied rule. The sub rules of each rule set are already ordered by the application frequency in Murcutt’s ten houses (see Table
3). That is, sub rule $Rule_{x.1}$ is the most frequently applied rule in each rule set. Thus, the Normalised Distance (ND) of the frequency of one of the rules $Rule_{x.y} \in Rule_x$ is:

$$ND \left( Rule_{x.y} \right) = \left| F'(Rule_{x.y}) - F'(Rule_{x.1}) \right| \quad (2)$$

Table 4: Normalised Distance of each applied rule.

<table>
<thead>
<tr>
<th>Rule set</th>
<th>x.1</th>
<th>x.2</th>
<th>x.3</th>
<th>x.4</th>
<th>x.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule1</td>
<td>0.00</td>
<td>1.41</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rule2</td>
<td>0.00</td>
<td>0.00</td>
<td>1.73</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rule3</td>
<td>0.00</td>
<td>1.04</td>
<td>2.09</td>
<td>2.09</td>
<td>-</td>
</tr>
<tr>
<td>Rule4</td>
<td>0.00</td>
<td>1.17</td>
<td>1.76</td>
<td>2.34</td>
<td>-</td>
</tr>
<tr>
<td>Rule5</td>
<td>0.00</td>
<td>0.67</td>
<td>1.35</td>
<td>1.35</td>
<td>2.70</td>
</tr>
<tr>
<td>Rule6</td>
<td>0.00</td>
<td>0.38</td>
<td>1.89</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rule7</td>
<td>0.00</td>
<td>1.41</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rule8</td>
<td>0.00</td>
<td>0.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rule9</td>
<td>0.00</td>
<td>1.60</td>
<td>2.41</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rule10</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
<td>2.00</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 3: NDGs of applied rule sets to generate ten Murcutt’s rural houses.
Table 4 calculates the ND of each applied rule. Since the first sub rule is the most frequently applied rule in the rule set, its ND is always zero. The farthest sub rule is Rule5.5, whose distance is 2.70. Thus, the NDs can easily demonstrate the disparity of each rule from a typical rule in the set. This also enables effective visualisation of the grammar application to generate design instances. Figure 3 illustrates the Normalised Distance Graphs (NDGs) of applied rule sets to generate the ten cases. The NDGs show that the third case may most closely capture the Murcutt style because of the lowest overall ND values. The NDGs also reveal that cases 1 and 2 would be similar designs due to the similarity of the two graphs.

4. Generation of design instances

4.1. Probability of applied rules

As shown in the previous section, the application of the first sub rule in each rule set, as the dominant rule, may generate a typical instance in Murcutt’s domestic buildings. Thus, the probability of the applied rule enables us to mathematically investigate the generation of design instances.

Rule set space is denoted by $\text{Rule}_x = (x = 1 \text{ to } 10)$. $\text{Rule}_x = \{\text{Rule}_{x,a} : a = 1, 2, 3...k\}$, $k = \text{max number of sub rule y in the rule set } R_x$. The probability ($P$) of one of the rules $\text{Rule}_{x,a}$ by the frequency of all rules in each rule set occurring in the ten houses is:

$$P(\text{Rule}_{x,a}) = \frac{F(\text{Rule}_{x,a})}{\sum F(\text{Rule}_{x,k})}$$ (3)

Where:

$F$ is the frequency of each rule occurring in the ten houses. Table 5 describes the probability of the applied rules to generate a Murcutt houses. For example, the probability of the application of Rule3.1 is 5/10, 50%, while the one of Rule3.2 is 3/10, 30%. The probability of Rule3.1 means that a room shape module is developed into a defined core unit in one out of two cases. The multiplication of the probabilities of applied rules also represents the probability of the generation of such a design instance developed by all the rules. This following section focuses on new design generation using rule transition paths based on the probability.

<table>
<thead>
<tr>
<th>Rule set</th>
<th>Sub rule1</th>
<th>Sub rule2</th>
<th>Sub rule3</th>
<th>Sub rule4</th>
<th>Sub rule5</th>
<th>Total F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.x</td>
<td>6/10</td>
<td>4/10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>2.x</td>
<td>4/10</td>
<td>4/10</td>
<td>2/10</td>
<td>-</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>3.x</td>
<td>5/10</td>
<td>3/10</td>
<td>1/10</td>
<td>1/10</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>4.x</td>
<td>5/11</td>
<td>3/11</td>
<td>2/11</td>
<td>1/11</td>
<td>-</td>
<td>11</td>
</tr>
<tr>
<td>5.x</td>
<td>5/16</td>
<td>4/16</td>
<td>3/16</td>
<td>3/16</td>
<td>1/16</td>
<td>16</td>
</tr>
<tr>
<td>6.x</td>
<td>6/12</td>
<td>5/12</td>
<td>1/12</td>
<td>-</td>
<td>-</td>
<td>12</td>
</tr>
<tr>
<td>7.x</td>
<td>9/14</td>
<td>5/14</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>14</td>
</tr>
<tr>
<td>8.x</td>
<td>5/10</td>
<td>5/10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>9.x</td>
<td>5/10</td>
<td>3/10</td>
<td>2/10</td>
<td>-</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>10.x</td>
<td>6/20</td>
<td>6/20</td>
<td>4/20</td>
<td>2/20</td>
<td>2/20</td>
<td>20</td>
</tr>
</tbody>
</table>
### 4.2. Design generation using rule transition paths

To generate new design instances in the Murcutt language, the research considers the transition probability. The transition probability \( T \) is the probability of transitioning from one rule to the following rule in the sequential step. Thus, generating a certain design can be a response to the given contexts or constraints of the grammar. If a rule is currently in a rule set (state) \( R_{x,a} \), then it moves to Rule set \( R_{y,b} \) at the next step with a probability denoted by \( T_{x.a \rightarrow y.b} \) where \( x, y, a, b > 1 \).

\[ T_{x.a \rightarrow y.b} \] enables us to select more appropriate rules at each rule set in terms of the grammatical application. In addition, adopting a more possible rule at each sequential rule set arguably generates more typical designs in terms of Murcutt’s design styles based on the ten houses. From the applied rules to the following rules, the transition probabilities are determined. For example, the transition probability for Rules set 1 and 2 \( (R_1 \text{ and } R_2) \) is:

\[ T_{x,a \rightarrow y.b} = \begin{bmatrix} R_{2.1} & R_{2.2} & R_{2.3} \\ R_{1.1} & 4/6 & 0 & 2/6 \\ R_{1.2} & 0 & 4/4 & 0 \end{bmatrix} \]

Generally, both the transition probability \( (T) \) and the probability \( (P) \) are used for the grammar application. If there is more than one rule that has the maximum transition probability at each generation stage, the lower numbered sub set rule – the higher probability of the applied rule in Table 5 – is triggered. For example, the probabilities of the generation of two pavilions are respectively 6/10, 4/10. Thus, the application generally selects one pavilion (Rule 1.1). In order to generate the following modules (Rule2.x), if the application chooses the dominant rule, Rule1.1, then it is followed by Rule2.1. Based on these transition probabilities, the research develops rule transition paths considering the maximum value of each transition probability (see Figure 4).

**Figure 4: Rule transition paths considering the maximum value of each transition probability.**

Through the rule transition paths, new design instances can be generated (see Figure 5). For example, “Rule 1.1 → Rule 2.1 → Rule 3.1 → Rule 4.1 → Rule 5.3 → Rule 6.1 → Rule 7.2 → Rule 8.2 → Rule 9.1” can be applied as a typical instance, even if Rule 10.1 is skipped due to the missing garage. Since there is more than one rule that has the maximum transition probability at each generation stage, several design alternatives can effectively be generated through these transition paths.
5. Conclusion

The mathematical analysis and generation of design instances presented in this paper is a general method that can be applied to the other Shape Grammar studies. It articulates the measurement of a grammar in terms of the frequency of the applied rules and the categorisation of rule sets that allow for the exploration of a particular architectural language or style. Thus, the research contributes to a better understanding of the grammatical design process implicit in the architecture that is being analysed.

The method also supports both quantitative and qualitative examination of the grammar’s application. The development of NDGs allows us to visually investigate the rule applications as well as to numerically describe the difference (through ND) of each applied rule to the dominant rule. Together they enable the investigation of the similarity and disparity between design instances as well as the differentiation of a ‘typical’ design instance from an ‘abnormal’ one. The results suggest that this mathematical approach can be used to systematically characterise or compare design instances as well as to effectively create new designs in an architectural style. The rule transition paths illustrated in Figure 4 have sequential steps that have been simplified for the demonstration purpose, nevertheless it provides an effective method for revealing a logical analogue of the design processes which can be used to support academics and professionals using the Shape Grammar.

References


Large-eddy simulations of air ventilation in high-density urban morphologies — A parametric study

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Abstract: This study investigates ventilation performance in parametric urban scenarios using a large-eddy simulation (LES) model. The LES codes are first validated using computational fluid dynamics (CFD) guidelines for building simulations, and then utilized in the simulations of parametric-designed urban configurations. With various combinations of planning parameters, air flows and pedestrian-level velocity ratios in a total of 48 scenarios are investigated. Major findings and recommendations are: First, ground coverage ratio ($\lambda_p$) is the most important factor for good ventilation. Second, the effects of building height differentials and turbulence levels in street canyons on urban ventilation are connected to urban density. Inhomogeneous building heights generate more turbulence in street canyons and have a negative (positive) effect on velocity ratios of low-density (high-density) parametric urban fabrics. The application of this point is that homogeneous building heights are recommended when low density is present, and inhomogeneous building heights may be better in cases of high density.

Keywords: Urban ventilation; parametric study; high-density city; large-eddy simulation.

1. Introduction

Rapid urbanization in the tropical and subtropical regions means that a better understanding of how to design and plan a city with good ventilation performance is needed. Thermal comfort can be achieved by capturing the natural wind (Ng and Cheng, 2012). Good air ventilation is also important for pollutant dispersion in street canyons (Mirzaei and Haghighat, 2010; Yuan et al., 2014). Outdoor air quality can further affect indoor air quality via natural as well as artificial ventilation, as indoor air will be replaced by outdoor air eventually (Ramponi and Blocken, 2012). Therefore, providing good urban air ventilation is very important for quality and healthy living in high-density cities in tropical and subtropical regions (Ng et al., 2011).
Urban ventilation is strongly influenced by wind speed and direction, which in turn are affected by three-dimensional urban morphology (Skote et al., 2005; Yang et al., 2013). As a combination of the individual shapes and dimensions of buildings and their arrangement in the city, urban density can be described by geometric parameters in planning like ground coverage ratio ($\lambda_p$), frontal area density ($\lambda_f$), and plot ratio (P). So-called parametric studies, which simplify complex actual urban geometries into simple morphological models, are widely applied in urban ventilation studies for their advantages of linking specific geometric parameters to air ventilation performance (Hang et al., 2012; Lin et al., 2014; Ho et al., 2015; Ramponi et al., 2015; Nazarian and Kleissl, 2016).

Associated with investigations of ventilation in idealized urban models, computational fluid dynamics (CFD) techniques are needed. Reynolds-averaged Navier-Stokes (RANS) models have commonly been used in previous CFD studies, mainly due to their low computational cost. However, there is debate regarding the performance of different kinds of RANS models (Yuan and Ng, 2012; Hang et al., 2013). Large-eddy simulation (LES) overcomes the deficiencies of RANS by explicitly resolving large, energy-containing turbulent eddies and parameterizing only small (subgrid) scale turbulence (Tamura, 2008). What affects pedestrian comfort directly is the wind flow within cities, and the local turbulence level in particular (Britter and Hanna, 2003). LES provides not only mean flow fields but also instantaneous turbulences, which are especially important for human comfort at the pedestrian level in the urban canopy layer. We therefore use an LES model to produce CFD simulations of air flow and ventilation performance in a set of comprehensive parametric urban scenarios in this study.

2. The Parallelized LES Model (PALM)

The LES model used in this study is the Parallelized LES Model (PALM), which was developed in 1997 (Raasch and Schröter, 2001). PALM has been validated for simulating flows and turbulence characteristics at the street-canyon and neighbourhood scale (Letzel et al., 2008) and has been widely used in studies of urban street-canyon flows in recent years (Letzel et al., 2012; Kanda et al., 2013; Keck et al., 2014; Park and Baik, 2014). The code used in this study is PALM version 4.0 (Maronga et al., 2015).

2.1. Output indicator and simulation setup

In air ventilation assessment (AVA) studies, we are especially interested in pedestrian-level wind velocity. The wind velocity ratio is used as an indicator. It is calculated by $V_p / V_\infty$, where $V_p$ is the wind velocity at the pedestrian level (2m above ground), and $V_\infty$ is the wind velocity at the top of the wind boundary layer not affected by ground roughness. A commonly used top boundary layer height of 500m in AVA (Ng, 2009) is adopted in this study. Winds are assumed to come from the left in all LES experiments, as the calculation of frontal area density $\lambda_f$, which will be discussed later, is also based on this assumption. A velocity of 1.5 m/s is prescribed.

Horizontal grid sizes are equidistantly 2m. The vertical grid spacing is 2m below 300m and stretched with a stretch factor of 1.04 above. Scalar variables are defined at the grid centers in APLM, while velocity components are shifted by half of the grid spacing. Therefore, horizontal velocity output from the 1m and 3m levels is linearly interpolated to obtain $V_p$ at 2m above the ground. The total simulation time is 6 hours. The first 4 hours are excluded in the analysis of the results, as the turbulences need this time to spin-up (Letzel et al., 2008). The simulated results from the 5th to the 6th hours are averaged for analysis. Cyclic (periodic) boundary conditions are adopted in both the streamwise and spanwise directions. The simulations are restricted to neutral atmospheric stratification.
2.2. Model validation

We use the CFD guidelines proposed by a working group from the Architectural Institute of Japan (AIJ) to verify the PALM codes. To calibrate CFD simulations of air ventilation, the AIJ group conducted a series of cross-comparisons of wind data from CFD and wind tunnel tests (Tominaga et al., 2008). We conducted a LES experiment of the 2:1:1 shape building model that complies with the AIJ guidelines (Mochida et al., 2002). The horizontal computational domain size is 172m × 108m. An equidistant grid size of 0.5m is used. In the vertical direction, a grid size of 0.5m is adopted below 24m and a stretch with a stretch factor of 1.05 is applied above. With 90 vertical levels, the domain height is about 100m. The inlet mean wind profile is the same as that given in the guidelines. It is noteworthy that for this simulation of a single building, a noncyclic boundary condition in the streamwise direction is adopted. Otherwise, it will become a simulation of an infinite row of buildings.

![Figure 1: Cross-comparison between Architectural Institute of Japan (AIJ) experimental data and PALM results: (a) Vertical wind profiles in the windward (red lines) and leeward (blue lines) position at 2m from the building; the inflow is shown by the black profile. (b) Linear regression between AIJ and PALM results in the test points at 1m above the ground](image)

Figure 1: Cross-comparison between Architectural Institute of Japan (AIJ) experimental data and PALM results: (a) Vertical wind profiles in the windward (red lines) and leeward (blue lines) position at 2m from the building; the inflow is shown by the black profile. (b) Linear regression between AIJ and PALM results in the test points at 1m above the ground

Figure 1a compares velocity profiles at 2m away from the single building to windward (red lines) and leeward (blue lines) and Figure 1b is a scatter plot of PALM-computed velocity and AIJ experimental data at 60 test points. Stronger rooftop vortex and velocity fluctuation compared to AIJ data can be observed in Figure 1a, but overall good agreement between the two suggests that PALM can capture the wind profile features around the building. As this study focuses on pedestrian-level ventilation, the computational performance of PALM in reproducing near-surface velocity may be more important. Cross-comparison with Figure 1b gives substantial confidence to using PALM in this study.

3. Parametric urban scenarios

Parametric scenarios of generic urban configurations are defined in a practical way. The plot ratio P, the ground coverage ratio λ_p, and the frontal area density λ_f are prescribed (Table 1) and to be investigated. To give finite solutions, the site area is assumed to be 1km^2, the floor height is assumed to be 3m, and the floor area (A) is approximately assumed to be 2000m^2 or 4000m^2, depending on the value of the plot ratio (P). Given the prescribed and assumed parameters, other geometric parameters including building
height (H), building number and building size (frontal size L and perpendicular size D) can be calculated by the definitions of prescribed parameters. In addition, row and column numbers of the building matrix have to be fitted to the 1km² site area. Parallel and perpendicular street widths are herein obtained. The Schematic diagram in Figure 2 elucidates the meanings of the involved geometric parameters. All computed values are coerced to the closest even-integral numbers, as the horizontal resolution in the PALM setup is 2m.

Table 1: Parametric scenarios of various urban morphologies and PALM-computed velocity ratios.

<table>
<thead>
<tr>
<th>Scenario ID</th>
<th>Plot ratio (P)</th>
<th>Frontal area density (λ_f)</th>
<th>Ground coverage ratio (λ_p)</th>
<th>Frontal area (A)</th>
<th>Building height (H)</th>
<th>Frontal building size (L)</th>
<th>Perpendicular building size (D)</th>
<th>Velocity ratio of HM</th>
<th>Velocity ratio of IM</th>
</tr>
</thead>
<tbody>
<tr>
<td>HM/IM01</td>
<td>3.0</td>
<td>0.1</td>
<td>25%</td>
<td>2160</td>
<td>36</td>
<td>24</td>
<td>90</td>
<td>0.196</td>
<td>0.147</td>
</tr>
<tr>
<td>HM/IM02</td>
<td>3.0</td>
<td>0.1</td>
<td>50%</td>
<td>2160</td>
<td>18</td>
<td>24</td>
<td>90</td>
<td>0.073</td>
<td>0.090</td>
</tr>
<tr>
<td>HM/IM03</td>
<td>3.0</td>
<td>0.1</td>
<td>75%</td>
<td>2160</td>
<td>12</td>
<td>24</td>
<td>90</td>
<td>0.050</td>
<td>0.058</td>
</tr>
<tr>
<td>HM/IM04</td>
<td>3.0</td>
<td>0.25</td>
<td>25%</td>
<td>2128</td>
<td>36</td>
<td>56</td>
<td>38</td>
<td>0.098</td>
<td>0.118</td>
</tr>
<tr>
<td>HM/IM05</td>
<td>3.0</td>
<td>0.25</td>
<td>50%</td>
<td>2128</td>
<td>18</td>
<td>56</td>
<td>38</td>
<td>0.083</td>
<td>0.092</td>
</tr>
<tr>
<td>HM/IM06</td>
<td>3.0</td>
<td>0.25</td>
<td>75%</td>
<td>2128</td>
<td>12</td>
<td>56</td>
<td>38</td>
<td>0.036</td>
<td>0.065</td>
</tr>
<tr>
<td>HM/IM07</td>
<td>3.0</td>
<td>0.4</td>
<td>25%</td>
<td>2160</td>
<td>36</td>
<td>90</td>
<td>24</td>
<td>0.109</td>
<td>0.142</td>
</tr>
<tr>
<td>HM/IM08</td>
<td>3.0</td>
<td>0.4</td>
<td>50%</td>
<td>2160</td>
<td>18</td>
<td>90</td>
<td>24</td>
<td>0.128</td>
<td>0.105</td>
</tr>
<tr>
<td>HM/IM09</td>
<td>3.0</td>
<td>0.4</td>
<td>75%</td>
<td>2160</td>
<td>12</td>
<td>90</td>
<td>24</td>
<td>0.057</td>
<td>0.064</td>
</tr>
<tr>
<td>HM/IM10</td>
<td>5.0</td>
<td>0.1</td>
<td>25%</td>
<td>4200</td>
<td>60</td>
<td>28</td>
<td>150</td>
<td>0.138</td>
<td>0.124</td>
</tr>
<tr>
<td>HM/IM11</td>
<td>5.0</td>
<td>0.1</td>
<td>50%</td>
<td>4200</td>
<td>30</td>
<td>28</td>
<td>150</td>
<td>0.130</td>
<td>0.104</td>
</tr>
<tr>
<td>HM/IM12</td>
<td>5.0</td>
<td>0.1</td>
<td>75%</td>
<td>4200</td>
<td>20</td>
<td>28</td>
<td>150</td>
<td>0.036</td>
<td>0.075</td>
</tr>
<tr>
<td>HM/IM13</td>
<td>5.0</td>
<td>0.25</td>
<td>25%</td>
<td>2160</td>
<td>60</td>
<td>36</td>
<td>60</td>
<td>0.130</td>
<td>0.094</td>
</tr>
<tr>
<td>HM/IM14</td>
<td>5.0</td>
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<td>50%</td>
<td>2160</td>
<td>30</td>
<td>36</td>
<td>60</td>
<td>0.149</td>
<td>0.093</td>
</tr>
<tr>
<td>HM/IM15</td>
<td>5.0</td>
<td>0.25</td>
<td>75%</td>
<td>2160</td>
<td>20</td>
<td>36</td>
<td>60</td>
<td>0.059</td>
<td>0.066</td>
</tr>
<tr>
<td>HM/IM16</td>
<td>5.0</td>
<td>0.4</td>
<td>25%</td>
<td>2160</td>
<td>60</td>
<td>54</td>
<td>40</td>
<td>0.084</td>
<td>0.095</td>
</tr>
<tr>
<td>HM/IM17</td>
<td>5.0</td>
<td>0.4</td>
<td>50%</td>
<td>2160</td>
<td>30</td>
<td>54</td>
<td>40</td>
<td>0.059</td>
<td>0.096</td>
</tr>
<tr>
<td>HM/IM18</td>
<td>5.0</td>
<td>0.4</td>
<td>75%</td>
<td>2160</td>
<td>20</td>
<td>54</td>
<td>40</td>
<td>0.049</td>
<td>0.071</td>
</tr>
<tr>
<td>HM/IM19</td>
<td>8.0</td>
<td>0.25</td>
<td>25%</td>
<td>4032</td>
<td>96</td>
<td>42</td>
<td>96</td>
<td>0.132</td>
<td>0.097</td>
</tr>
<tr>
<td>HM/IM20</td>
<td>8.0</td>
<td>0.25</td>
<td>50%</td>
<td>4032</td>
<td>48</td>
<td>42</td>
<td>96</td>
<td>0.061</td>
<td>0.102</td>
</tr>
<tr>
<td>HM/IM21</td>
<td>8.0</td>
<td>0.25</td>
<td>75%</td>
<td>4032</td>
<td>32</td>
<td>42</td>
<td>96</td>
<td>0.025</td>
<td>0.080</td>
</tr>
<tr>
<td>HM/IM22</td>
<td>8.0</td>
<td>0.4</td>
<td>25%</td>
<td>3960</td>
<td>96</td>
<td>66</td>
<td>60</td>
<td>0.096</td>
<td>0.097</td>
</tr>
<tr>
<td>HM/IM23</td>
<td>8.0</td>
<td>0.4</td>
<td>50%</td>
<td>3960</td>
<td>48</td>
<td>66</td>
<td>60</td>
<td>0.079</td>
<td>0.098</td>
</tr>
<tr>
<td>HM/IM24</td>
<td>8.0</td>
<td>0.4</td>
<td>75%</td>
<td>3960</td>
<td>32</td>
<td>66</td>
<td>60</td>
<td>0.049</td>
<td>0.084</td>
</tr>
</tbody>
</table>

A total of 24 scenarios for homogeneous (HM) building heights are presented (Table 1). For inhomogeneous (IM) scenarios, building heights are generated by a normally distributed random series, which is given a mean of the corresponding homogeneous building height (H) and a standard deviation of H/4. Moreover, to avoid wind blowing directly into street canyons, normalized blocks with sizes of 40m × 40m × 10m are set around every model. The block height is 10m so as to be lower than the
smallest building height of 12m in the parametric scenarios. As the site area $S$ is assumed to be $1\text{km}^2$, the actual computational domain is $1.2\text{km} \times 1.2\text{km}$.

![Figure 2: Schematic diagram showing definitions of geometric parameters.](image)

### 4. Results and discussion

#### 4.1. Identification of the most important factor

Site-averaged velocity ratios of all scenarios in the assessment area ($200\text{m}$ away from the lateral boundary in all horizontal directions) are listed in the last two columns of Table 1. To statistically capture the spatial differences in the velocity ratios, the distributions of velocity ratios taken from random test points are shown in Figure 3. In this analytical procedure, 1000 test points are randomly taken from each scenario. In each panel of Figure 3, the plot ratio $P$ and frontal area density $\lambda_f$ are fixed. Different lines represent changes in $\lambda_p$ as well as building height differential. Velocity ratio distributions of parametric models with $\lambda_p = 0.25$ are shown in blue, $\lambda_p = 0.5$ are shown in green, and $\lambda_p = 0.75$ are shown in red. Homogeneous scenarios are given in solid lines, while inhomogeneous scenarios are given in dashed lines.

Figure 3 demonstrates the significance of $\lambda_p$ in affecting the performance of pedestrian-level ventilation. In most cases, blues lines give the best ventilation performance compared with the other two, while red lines are generally the worst. This is the case for both homogeneous (solid lines) and inhomogeneous (dashed lines) parametric scenarios. For scenarios of homogeneous building height, there is only one exception, that is, ventilation performance of HM14 is better than that of HM13 (Figure 3e). A potential cause for these exceptions is the building height. Homogeneous scenario HM14 with $H = 30\text{m}$ has better ventilation performance than HM13 with $H = 60\text{m}$. The effects of building heights and their differentials will be further discussed in the following section. For scenarios of inhomogeneous building height, the effect of $\lambda_p$ is also essential. The ventilation performance in cases of
\(\lambda_p = 0.25\) and 0.5 are very close. They are IM13 and 14, IM16 and 17, IM19 and 20, and IM22 and 23. From Figure 3, we can suggest that a possible cause of what makes the velocity ratios in cases of \(\lambda_p = 0.5\) close to those in cases of \(\lambda_p = 0.25\) is again the building heights and their differentials. When it comes to the other two prescribed parameters, it is difficult to identify a substantial effect on the pedestrian-level velocity ratio when the focus is on the single parameter \(P\) or \(\lambda_f\).
4.2. Height differential and turbulent momentum

Inhomogeneous building heights present enhanced spatial differences in velocity ratio. Relative high-rise buildings are generated from the normally distributed random series generator in inhomogeneous parametric scenarios. On the windward side of high-rise buildings, pedestrian-level wind velocities are enhanced significantly (figures not shown). Overall ventilation performance is thereby affected by building differentials, which can be examined in Figure 3. We compare the solid (HM) and dashed (IM) line in each pair of scenarios and summarize the results in Table 2.

Table 2 provides a cross-comparison of the influences of urban density and building height differentials on air ventilation. One point that can be identified from Table 2 is that in cases of either $\lambda_p = 75\%$ or $\lambda_f = 0.4$, inhomogeneous building heights have better ventilation performance than homogeneous building heights. In cases of “HM is better,” both low $\lambda_p$ (25\%) and low $\lambda_f$ (0.1) may be necessary. With medium values of $\lambda_p$ (50\%) or $\lambda_f$ (0.25) in combination, the influences of building height differentials are case-dependent. Dynamical potentials for these impacts of building height differentials on ventilation performances are of scientific merit. From the viewpoint of energy transport in the urban canopy, horizontally averaged profiles of total turbulent momentum are herein investigated (Figure 4).

Figure 4: Horizontally averaged total turbulent momentum flux profiles of all 48 scenarios. Blue lines denote scenarios with a $\lambda_p$ value of 25\%, green lines denote scenarios with a $\lambda_p$ value of 50\%, and red lines denote scenarios with a $\lambda_p$ value of 75\%.
Table 2: Influences of building height differential on ventilation performance.

<table>
<thead>
<tr>
<th>(\lambda_f)</th>
<th>0.1</th>
<th>0.25</th>
<th>0.4</th>
<th>0.1</th>
<th>0.25</th>
<th>0.4</th>
<th>0.25</th>
<th>0.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>HM is better</td>
<td>01</td>
<td>10</td>
<td>13</td>
<td>19</td>
<td>25%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IM is better</td>
<td>02</td>
<td>04</td>
<td>07</td>
<td>16</td>
<td>22</td>
<td>25%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>05</td>
<td>08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>03</td>
<td>06</td>
<td>09</td>
<td>12</td>
<td>15</td>
<td>18</td>
<td>21</td>
<td>24</td>
</tr>
<tr>
<td>P</td>
<td>3</td>
<td>5</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Negative values of momentum fluxes in Figure 4 indicate downward propagation of kinetic energy. Maximum momentum fluxes occur at around the heights of the building top in each scenario. Downward-propagated turbulent momentum fluxes are generally stronger in IM scenarios than in HM scenarios when profiles in Figure 4c–d are compared with profiles in Figure 4a–b. However, more turbulent momentum fluxes in street canyons do not always mean more wind loads at the pedestrian level. Higher turbulent momentum means higher ventilation, which is the case for high-density scenarios. This can be recognized when comparing high-density parametric models (e.g., \(\lambda_p = 75%\)) in HM scenarios with IM scenarios in Figure 3. But higher turbulent momentum may cause lower ventilation in low-density parametric scenarios. An evident example is HM01 and IM01 in Figure 3a. In a wind tunnel study of scalar (e.g., air mass) transfer efficiency, Ikegaya et al. (2012) has pointed out that the transfer coefficients for arrays with blocks of inhomogeneous heights were smaller than for arrays with blocks of homogeneous heights under low \(\lambda_p\) conditions, but the opposite tendency was observed as \(\lambda_p\) increased. Dynamically, the decrease in the transfer coefficient in low \(\lambda_p\) conditions is due to the decrease in advection effects and deficits in momentum, which can be estimated from the larger values of drag coefficients for inhomogeneous arrays when compared with those of homogeneous arrays (Hagishima et al., 2009). In contrast, high-rise blocks in inhomogeneous arrays introduce more flow momentum into the canopy under high \(\lambda_p\) conditions (Ikegaya et al., 2012). We can derive similar conclusions for pedestrian-level ventilation from our simulations in and over generic urban configurations here. Turbulence level can be a factor in “balancing” ventilation: inhomogeneous building heights generate more turbulence in street canyons by capturing more downward-propagated momentum, and they have a negative (positive) effect on the pedestrian-level velocity of low-density (high-density) idealized urban fabrics. The application of this point is that homogeneous building heights are recommended when low density is present, and inhomogeneous building heights may be better in cases of high density.

7. Conclusions

This study investigates ventilation performance in parametric urban scenarios using an LES model—PALM. The PALM codes used in this study are first validated using the AIJ guidelines for CFD building simulations before being utilized in simulations of parametric scenarios. Four morphological parameters in urban design and planning, including ground coverage ratio (\(\lambda_p\)), frontal area density (\(\lambda_f\)), plot ratio (P), and building height differential, are used to construct the parametric scenarios. Three values are set for each of these parameters except building height differential: 25%, 50%, and 75% for \(\lambda_p\); 0.1, 0.25, and 0.4 for \(\lambda_f\); and 3.0, 5.0, and 8.0 for P. For building height differential, we propose two situations: homogeneous and inhomogeneous. Homogeneous means all buildings are of the same height, while for
inhomogeneous, building heights are generated by a normally distributed random series. With fixed site area, floor height and floor area, a total of 48 scenarios are investigated.

PALM-computed velocity ratios at 2m above the ground and horizontally averaged turbulent momentum profiles in all scenarios are analyzed. The key findings and recommendations for urban planning deduced from this study are: First, among all four investigated parameters, $\lambda_p$ is found to be the most important for good pedestrian-level ventilation. Second, the effects of building height differential on urban ventilation are connected with urban density: In relatively low-density scenarios, inhomogeneous building heights give worse ventilation performance compared to homogeneous cases; in a few medium- to high-density scenarios, ventilation performances of homogeneous and inhomogeneous building heights are close and complex; and in high-density scenarios, inhomogeneous building heights result in better ventilation performance than homogeneous cases. Turbulence level can be a factor in “balancing” ventilation: inhomogeneous building heights generate more turbulence in street canyons and have a negative (positive) effect on velocity ratios of low-density (very high-density) morphological scenarios. The application of this point is that homogeneous building heights are recommended when low density ($\lambda_p$ and $\lambda_f$) is present, and inhomogeneous building heights may be better in cases of high density.

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Abstract: This paper examines new towns constructed for the Mahaweli Development Project (MDP)—a mega project—which involved a comprehensive resettlement program in Sri Lanka. Only a handful of studies examine the new towns designed by the Mahaweli Architectural Unit (MAU), from the perspective of architecture and urban design. This paper analyses the design of these new towns with regard to the MDP resettlement goals articulated in socio-cultural assessment reports which made recommendations about physical planning principles. This critical analysis is informed by drawings and documents examined at the Mahaweli Archives, Colombo, and field work in Mahaweli towns. The paper argues that the MAU embraced the MDP initiative to build sustainable new towns, inspired by vernacular architecture, with a certain degree of success. However, with the advantage of hindsight, notable shortcomings are evident which can be attributed to an apparent disregard for the socio-cultural recommendations. Given the escalating number of large scale infrastructure projects in developing countries—which force displacement, resettlement and redistribution of people—this paper renews emphasis on the importance of sociological concerns as a key dimension of architectural interventions for sustainable development.

Keywords: Sustainable; urban design; vernacular; re-settlement.

1. Introduction

Major multi-purpose hydro-electric projects were a common development strategy during the mid to late 20th century. Known as mega projects, they made unprecedented impacts on the environmental, economic and socio-cultural conditions of their respective contexts. These expensive projects were built to cater for increasing demands for resources (water, food and power) and the targets were closely related to further goals to stimulate new industries, to develop rural settlements in regional areas and to generate exponential improvements in living standards (Scudder, 2005, 20). Large scale population displacement has been an unavoidable consequence of these initiatives (the World Commission on Dams, 2000, 102-104) and concomitant issues have often compromised the overall success in many
cases (the World Bank, 2004, 321-323).  Sustainable resettlement—a major responsibility of planning authorities—is the key to the success of mega-projects (Roy, 1999, 20-22). One of these mega projects—the Mahaweli Development Project (MDP), initiated in the 1960s—is the most ambitious multi-purpose infrastructure project ever attempted in Sri Lanka. Under the MDP, a comprehensive resettlement programme was implemented in the Dry Zone (DZ), that is estimated to have affected approximately 1 million people (nearly 7% of the population in 1981), which consisted of re-settlers (compulsory and voluntary), and traditional inhabitants (Scudder, 2005, 135). These Mahaweli resettlements aimed to redistribute the population through rural infrastructure development. The settlements were socially engineered to redefine the rural territory and in turn have instigated a new paradigm of regional planning and urban design practice in Sri Lanka (Rajapakse, 2007, 220). This paper investigates the role of architects and planners in this process and considers potential lessons from the MDP in Sri Lanka.

With its commendable goals and long-term vision of reform (Mendis, 1973, 6-7), the MDP has received substantial scholarly attention, by individual scholars as well as sponsored studies, particularly in the discipline of economics. It has also been subject to much criticism, especially since the Accelerated Mahaweli Project (AMP), ushered in with a change of government economic policy, commenced (Karunatilake, 1988, 155-172; Ponnambalam, 1981, 155; Scudder, 2005, 138, 161). However, only a handful of studies focus on the architectural and urban design aspects of the resettlements. The Mahaweli Architectural Unit (MAU)—a government initiative under the AMP—has played an important role in designing and constructing Mahaweli towns and buildings (Rajapakse, 2007, 220-222). The MAU was unable to conduct a post-occupancy evaluation due to its abrupt cessation of works (Perera, 2016). Therefore, this paper aims to fill the gap in knowledge through an examination of the original MDP goals for creating sustainable settlements within the socio-cultural context and to critically analyse the MAU’s contribution to the design of these settlements. The intent is to inform discussion about sustainable and effective architectural models with a view to future resettlement projects.

Independent researchers argue that the MAU towns have not progressed to their anticipated potential (Rajapakse, 2007, 230-232; Udumulla, 1999/2000, 45). Observations in the field visits support this argument. Thus, the present research project stems from the hypothesis that, despite the many admirable goals of the MDP and the positive impact on the economic development of Sri Lanka, the present day settlements, created as a part of the AMP, do not meet the stipulated goals, particularly those of the MAU. Forty years after the inception of the MDP, this hypothesis is tested through a critical examination of archival materials documenting the implementation of the mega-project, and field work in Mahaweli towns that has sought to observe and reflect on the outcomes. The research was primarily archival based; the primary and secondary archival materials were sourced from the Archives of the Mahaweli Authority of Sri Lanka (MASL), in which the original Master Plans, Proposals and Recommendations and the relatively few drawings that are still preserved were critically examined. This comparative analysis is also informed by a critical review of the retrospective writings by the key MAU architects, Nihal Perera and Ulrik Plesner. Perera was also interviewed in order to better understand the MAU’s design approach, its operation within the MDP, and its contribution to the Mahaweli towns (2016). Through this combination of methods, the project has sought to cross-examine the original concept and policies of the MDP, in relation to resettlement, settlers’ socio-cultural wellbeing and the urban design of new settlements. To assess the success of the MAU’s design approach as a strategy to achieve the goals of the MDP, the research has examined, in particular, the experience and design philosophy of the design team (led by the Sri Lankan architect, Perera, and his Danish counterpart, Plesner), their critical response to the design principles of the initial Mahaweli towns implemented

previously, and the architectural language of the dwellings. The realization of the original MDP settlement goals through the design and construction of the MAU towns is discussed critically. The paper concludes with a critical reflection on the lessons that can be learnt to achieve sustainable and integrated development within the mega-dam context in relation to urban design and planning.

The following section of this paper explores the conceptual framework, with emphasis on the sociological recommendations, for the MDP settlements. This is followed by an investigation of the formation of the MAU and the principles adopted for designing ‘unique’ Mahaweli towns and buildings. The next section evaluates the towns and buildings designed by the MAU in the light of a comparative analysis with the original sociological recommendations of the MDP. The outcomes of the MAU are subsequently identified as a very important phase in the context of Sri Lankan urban design. Finally, the retrospective architectural lessons that can be learnt from the MDP are discussed.

2. Mahaweli settlements: a conceptual framework

2.1. MDP impact assessments

Sustainable development and improved standards of living are the key objectives of resettlement related to large infrastructure projects. These economic objectives are inextricable from social and environmental concerns. In theory, then, careful plans coupled with initiatives to attract new services and industries, strengthened by adequate funds and the institutional capacity to empower re-settlers, to restore resiliency and encourage independence are imperative measures for a ‘win-win scenario’, in which resettled communities can become project beneficiaries (Scudder, 2005, 20, 43, 87). However, there are many barriers to success, including complicated planning, legal, administrative and management processes and vagaries of political agendas and policies. Moreover, re-settlers have diverse backgrounds which can lead to conflict. Recognition of these issues in relation to the broader agendas of economic reform has led to the emergence of Environmental and Social Impact Assessments (EIAs and SIAs). These are increasingly common, if not mandatory, evaluation processes in the current global mega-project context that assign equal importance to the environmental and social costs of economic growth and change, with the primary goal of attaining integrated economic and socio-cultural development that is both sustainable and equitable, with minimal adverse consequences for the environment (Vanclay, 2000, 2).

A number of comprehensive assessment reports were prepared for the MDP. Several of these were directly related to resettlement and, in turn, urban design. The main sociological reports examined in this paper (herewith referred to as the ‘Mahaweli Reports’), provide a sound understanding about the nature of the resettlement process as it unfolded in Sri Lanka. The reports stressed that the settlements were to be ‘designed for people’. Thus, they described the overall goals of the settlements including sociological concerns relating to the aspirations of the re-settlers, basic standards of the settlements, detailed physical plans ad proposals for services, and ‘good’ design principles to guide the development of new settlements. They were comprehensive for their time, but are inadequate and incomplete compared to present day standards for this type of project. Therefore, developing a strong theoretical framework on this basis was challenging. As such, the Mahaweli Reports have been used in this study as a benchmark for analysis.
2.2. Traditional Sri Lankan settlements and the MDP model

The rural development instigated as part of the new MDP resettlement schemes represented a distinct change from the socio-cultural structure of traditional villages. The most important socio-cultural impact was the transformation of small isolated traditional village communities into production oriented colonisation schemes (TAMS, 1980, 12). In this type of setting, small townships play an indispensable role, as anywhere, as commercial, social, and recreational hubs. They create wealth and provide alternative modes of employment to balance the farming economy and opportunities for future generations, such as vocational training. They are fundamental for regional economic growth (King, 1984, 9-11). Such towns in the rural context provide a higher quality of living, disseminate innovations, and more importantly they represent a modern way of life for the rural inhabitants (Sogreah, 1972, 7). Thus, in relation to rural development, the Mahaweli towns were crucial elements in the overall success of the MDP.

The physical planning model for the Mahaweli settlements was largely based on Central Place Theory (CPT) which was gradually developed and fine-tuned in the consecutive Mahaweli reports. This settlement framework represents territories divided into a hierarchical order of service centres. It consists of ‘Blocks’, the smallest unit, of 100-125 households, ‘Hamlets’ comprise a couple of blocks, ‘Village Centres’ group 4-5 hamlets, ‘Area Centres’ serve a couple of village centres and ‘Townships’ cover 2-4 area centres. Townships are the primary service centres and the major unit that reconfigured the underdeveloped Sri Lankan rural interior into an urban landscape. A system consisted of several townships and the MDP area was divided into several systems (Jayewardena, 1988, 34; Rajapakse, 2007, 222; Perera, 2010, 153) (Figure 1).

![Figure 1: The ‘Systems’ (A, B, C...) of the Mahaweli Development Project (source: MASL Archives) and schematic model of the Mahaweli settlements based on the CPT. (source: Jayewardena 1988, 35)](image)

3. Mahaweli Architectural Unit (MAU): an architectural venture in MDP

Resettlement in the sparsely populated DZ, based on irrigation projects, began in the latter part of the British colonial regime (1815-1948). These endeavours carried a cultural significance—restoration of the ‘lost’ glory of the DZ—which was vigorously promoted after Independence (1948). The MDP continued to champion this significance and it was aligned with the increasingly popular nationalist vision whereby the DZ was celebrated as the home for a ‘Sinhala’ civilization which thrived for over a millennia before

the 12th Century due to the advanced cascade irrigation systems which relied primarily on the Mahaweli River (Hennayake, 2006, Moore, 1996, 325-356; 108-110, Sorensen, 1996, 70-73). This ‘colonization’ of the DZ, then, was state-sponsored through agricultural, irrigation and land policies (Sanderatne, 2004, 196-207).

The MDP, the culmination of these projects, was convened in 1963. Like mega-projects worldwide, the MDP was funded by western capital and operated with western expertise (Gunatillake, 1999, 196). In the process of implementing the AMP (1977), the formation of the MAU (1982), by a ‘ministerial decision’ under the umbrella of the MASL (1980), was a timely intervention which enabled the new town construction (with appropriate expertise) to match the engineering works (Plesner, 2010, 376). Moreover, this unit comprising primarily architects was a response to the recommendation of the TAMS report to align the settlements with the “human side of planning” (TAMS, 1980, 25). As Perera argues, the planning approach of the pre-MAU planning body was engineering-dominated and relied extensively on physical data without adequate consideration of the socio-cultural conditions and the ways these could be addressed through architecture and urban design (Perera, 2016). Plesner, an influential figure in post-colonial Sri Lankan architectural practice, who “co-developed a hybrid architecture (with Geoffrey Bawa),” referred to as a “critical vernacular” style by Perera, was appointed as the Consultant Architect, while Perera was appointed as the Chief Architect-Planner of the MAU (2010, 159). This combination of local and foreign expertise was a complementary strength (Perera, 2010, 158-160).

The buildings designed by the MAU differed significantly from the pre-MAU designs. The MAU employed a large number of small scale village contractors and purchased equipment locally in order to strengthen the local economy, as well as to give them ownership through participation (Plesner, 1986, 86). In keeping with this sense of agency, the design of buildings in the vernacular style was compatible with the technical skills of local carpenters and builders. Given these considerations, the MAU aimed to develop simple and rational low-cost buildings and self-help housing types. Rammed earth techniques were developed to a technically satisfactory state and applied to the design of schools and health centres, as well as houses, with the intent to establish better building practices for towns to develop on their own, one of the key dimensions of sustainable settlements (Figure 2).

![Figure 2: Examples of MAU building designs: administrative building, shop-house and model low-cost core house for farmers (source: Plesner, 1986, 86-87) and the MAU design for the Dehiattakandiya Township. (source: MASL archives)](image)

The vernacular language, nurtured by both the Portuguese and the Dutch, and which mitigated the Sri Lankan hot and humid tropical climate, is prominent not only in these Mahaweli towns, but it is an important trend in the Sri Lankan built environment, embraced in particular, by wealthy, educated, elite
families. Mahaweli buildings expressed the traditional ‘spirit of the place’ and they were arranged around internal courtyards as in the case of the ancient mansions; they are further characterised by pitched roofs with low eaves providing cool shade; colonnades covering wide, deep, open verandas, as in buildings in southern Sri Lanka where colonial influences were prominent; long vistas, as in Buddhist Temples; trellis windows, enabling cross-ventilation whilst affording privacy and security as in the Moorish houses in Colombo and useful and beautiful details including integrated sleeping and seating platforms evident in old traders’ houses in Jaffna (Plesner, 2010, 195-197).

The MAU designed and built mainly two types of town buildings, shop-houses and administrative buildings. These “linear system of buildings”, concentrated along streets and squares are open on two sides to allow cross-ventilation in response to mitigate the hot-humid conditions (Rajapakse, 2007, 228). They could be adapted with new ceilings, windows or special equipment, and connected to nearby buildings with a covered walkway (Plesner, 1986, 86). Shops were built with an upper floor for living or storing goods. This “shop house typology ... built wall to wall” along the main road is a very common element in rural Sri Lankan towns (Rajapakse, 2007, 227). Perera claims, the MAU just built the shells, allowing the owners to customise their interior (2010, 164), and in particular, the provision of sidewalks was intended to create opportunities for individual expression whilst breaking the monotony that might result from repeated building types (Perera, 2010, 166). Rajapakse rightly observes that the “covered walkway in the shop house is a key element in tying the buildings within a common theme” (2007, 229).

The MAU built 12 new towns between 1983 and 1989. The MAU work encompassed a vast scale from territorial considerations through to small buildings within the townships (Rajapakse, 2007, 222). The scope of the MAU included, planning new towns and settlements, design and construction of individual buildings, environmental planning and landscaping (Plesner, 86; Jayewardene, 34). Plesner envisioned the Mahaweli towns as recreations of “traditional qualities in new circumstances”, solving the typical problems such as “traffic, parking, shanty development and unknown future growth” (Plesner, 2010, 384). The MAU employed a “people centred” design approach, to generate an “adaptable plan” or a “loose-fit design”, to construct “good towns” that were intended to respond positively to the climate and the culture. The towns are characterised by a “by-pass concept”, and incorporated “Sri Lankan sensibilities” such as “compact and mixed-use cores”. There are plenty of open public spaces. A unique identity was achieved through the “vernacular style” buildings, which used local materials and expertise, and a simple colour code (Perera, 2010, 160-166), thus giving them their special ‘Mahaweli Town’ characteristics. They responded to the natural environment through the protection of existing trees and the planting of new trees, with the intent to furnish the towns with ‘character’ and to provide ‘shade’. The towns were created for the present rather than for the future and were expected to provide a framework for future development. (Perera, 2010, 168). The MAU’s towns were planned (Figure 2), unlike typical Sri Lankan towns, and they employed a vernacular architectural language, unlike the pre-MAU towns. In doing so, the design of the Mahaweli new towns precipitated a new paradigm of regional planning and urban design in Sri Lanka.

4. Mahaweli buildings and new towns: performance in retrospect

Many interesting features of the townships can still be observed. The covered walkway is functional and humanises the scale of the street and the shop houses, materialising the ‘people centred approach’ advocated by the architects. These transitional spaces also create opportunities for social interaction. However, given the time that has passed since the towns were originally built, it is possible to observe the successes and shortcomings of these unprecedented urban experiments. The key architects
themselves were critical about the MAU towns in hindsight (Perera, 2010, 143, 166; Plesner, 2010, 411). The by-pass concept or loop road of the MAU towns has had positive and negative results. While providing safety within the town centre, the distance from the main arterial road has hindered the growth of the town. Meanwhile, unauthorized and temporary commercial structures are flourishing along the main roads or at transit nodes in the MAU towns. It was also observed that the prime places in the MAU towns are underused or completely unused. Thus, the towns are empty in contrast to crowded, lively and busy typical towns. Traditional building ‘types’ and spaces were not integrated in productive ways. A key example of this is the incorporation of the traditional ambalama or rest house. It does not function like a wayside stop. It is too distant from the main circulation routes. Moreover, the centrally planned market squares are not being used, a planning feature which does not match the tendency for people to gather at a specific place of business activity. Not least, the buildings which are inspired by vernacular architecture, which maintain continuity with the past, do not seem to be appreciated by the new settlers who have built modern structures and amenities when the opportunity to do so has arisen (Figure 3).

Figure 3: Abandoned Ambalama: Girandurukotte, unplanned commercial activities: Digana and new shop building in a row of shop-houses: Dehiattakandiya. (photos: author 14-16.6.2015)

The outcomes and the conclusions of the research can be outlined as follows. It is evident that the MAU attempted to create cohesive physical environments and functional towns, while maintaining a simple and rational scale and style in the built entities which integrated well with the natural environment. At the same time, the design of the new towns created a distinctive Mahaweli identity. However, it is not entirely clear how the designs for the new towns addressed the recommendations presented in the Mahaweli Reports (such as the FAO Survey, the Sogreah or the Hunting Feasibility Reports) which offered substantial guidelines for the detailed physical planning of the Mahaweli settlements, including the Mahaweli towns. In these reports, particular emphasis is placed on the ‘modern’ point of view of the re-settlers and their progressive aspirations. It would seem that the re-settlers did not embrace the critical vernacular approach to the design of the new towns. While the same Mahaweli Reports placed emphasis on the importance of local leadership channels, it is not clear how these were embraced in the structure of the settlements and such channels might have been better understood through the engagement of a rural sociologist; consultation opportunities that could and should have been provided by the MDP given the emphasis placed on socio-cultural concerns raised prior to the appointment of the MAU. Without these mechanisms in place, the new towns lack vitality, or a lively character. They have not precipitated growth – the primary purpose of the proposed towns in the rural context – and they have not promoted economic and social development, or provided opportunities for youth, or for ethnic integration. However, it is acknowledged here that external factors and systemic faults may also have had a significant impact on the present state of the Mahaweli towns,
such as, lack of economic development, low population growth, poor transport and poor maintenance; inherent problems in a developing country; as well as long-term ethnic conflict that could not have been anticipated to the degree that it affected Sri Lanka.

5. MAU within the Sri Lankan architectural discourse

Plesner’s pioneering work was significant in the revival of traditional architecture. Similarly, the MAU work led by Plesner was significant in the urban design discourse in Sri Lanka. The concept of the MAU was “radically new in Mahaweli” and the MAU created towns with “a unique physical identity and character, new to this previously rural area” that aimed to serve the community and promote growth at an appropriate rural scale (Perera, 2010, 161). Towns created by the MAU can be considered significant in the discourse about urbanism and development in Sri Lanka, not only in terms of what was expected as an outcome, but as a paradigm of post-independence spatial planning and design in which the state, through population redistribution and master planning formulated development projects that resulted in structural transformations in environmental, ecological, socio-cultural, economic and design context for a new urbanism.

Mahaweli towns and buildings have shifted perceptions, positively and negatively, about the role of architecture in development projects in Sri Lanka, both within the planning community and by the general public. It is evident that some aspirations were not met, showing the mismatch between the design and the context. For example, continuity of tradition was not always valued by the “pluralistic” inhabitants with ‘modern’ and ‘progressive’ views, or within the changing socio-cultural context of the traditional villages (Barnabas, 1967, 67). Thus the sentimentality attached to traditional architecture was not embraced by rural people as it was by the elite in urban areas. Moreover, as anticipated by the MAU architects, utilizing the MAU towns as a ‘framework’ for future development did not happen and the present state of the Mahaweli towns are the result of administrative, planning and design negligence. However, the MAU towns did influence the Sri Lankan urban design discourse to a certain degree. Some of the main MAU concepts were directly adopted in contemporary urban design. For example, even though the by-pass concept had specific drawbacks in the Mahaweli context, it was adopted in the recent designs for Kegalle and Mawanella.

In any case, these Mahaweli towns are the outcomes of an intensive regional scale architectural experiment by the MAU architects, who tried to create good towns with sensible and sustainable building designs. As such, they are the pioneering products of a revival of traditional vernacular architecture on a large scale. They are key examples of a different urban design perspective in Sri Lanka with positive lessons. The MAU, as the author of the Mahaweli towns, formed a foundation based on its ‘people centred approach’ to facilitate a noteworthy epoch of the Mahaweli scheme. Not least, by drawing on a glorious and energetic past the MAU played a significant role in the architectural and urban design discourse of Sri Lanka with their emphasis on the specificity of place in social, environmental and architectural terms.

6. Lessons learnt from the MAU

The inspiration that can be drawn from the MAU in the global mega dam context particularly related to architectural design, is not yet recognised nor sufficiently acknowledged. The MDP is not explicitly an architectural project; or an urban design project (Rajapakse, 2007, 220). Nevertheless, for the first time in post-colonial Sri Lanka, urban design and landscape design were considered as integral parts of a resettlement project, and great value was placed on the transformative possibilities of architecture by
the Mahaweli authorities. The formation of a state sponsored but largely autonomous unit, the MAU, comprising architects dedicated to the design of entirely new settlements, was rare in the Sri Lankan urban design context, and unprecedented in the context of mega dams. This distinguishes the unit considered in relation to other resettlement projects of a similar scale, even worldwide. The design philosophy of the MAU, which advocated a people centre approach and the application of a critical vernacular architectural language should be applauded. However, it is evident from this research that the project, comprising the design of 12 new towns in a vast territory forever changed by a mega-infrastructure project, and which displaced hundreds of thousands of people (often against their will), would have benefitted from more rigorous sociological expertise to address the socio-cultural concerns anticipated in the Mahaweli Reports. This sociological expertise was understandably beyond the professional expertise of the MAU. Furthermore, it raises questions about the responsibilities of the MDP in resourcing the MAU and enabling a rigorous process of sociological analysis to best inform the design process given the complexity of the settlers’ ethnic diversity, their progressive needs and aspirations, and the sheer number of people involved in the exercise. Hence, the research re-emphasises the importance of sociological considerations in sustainable architectural ventures.

Furthermore, a critical understanding and analysis of the preconditions and structures adopted by the MAU, highlighted the need for constantly evolving new paradigms and practices to accommodate, support or reject change. The MAU fits within the modernist paradigm where the major social and physical structural changes reflect the political ideology of the time. Planning sponsored a new way of living by establishing rationalized, formal principles in space and functions that forced people to live, work and recreate in a predetermined way. The project bears all the hallmarks of a top down, rational and formal approach (Rajapakse 2007, 220), typical of such projects. Most importantly, the research points out the dearth of scholarship of this type of architectural project at the ground level and the need for critical evaluation of the post occupancy sustainability of the settlements, from the point of view of the very occupants, which should necessarily inform similar architectural interventions in the future. The outcomes of the planning principles adopted and the applicability of them in the MDP, can be used to better understand the paradigms, as well as the necessary consultation processes, that architects and designers could take in projects of a similar nature in the future.

Unprecedented numbers of people today are forced to relocate not only due to mega-projects, but for a host of issues including civil conflict, was, and the looming effects of climate change. Creation of sustainable resettlements is of utmost importance and urgency. Where there is an opportunity for design thinking and planning to make a difference, one of the most important questions to ask is whether, according to De Wet, settlers have ‘actually upgraded their lives relative to their original setting?’ (1995, 1-2). Resettlement is a process of evolution; the entire process takes at least two generations (Sorenson, 1996, 4). Therefore this research on the towns of the MDP – a ‘mature’ project with more than 40 years of history and spanning at least three consecutive generations – teaches a lesson; that major new planning and design efforts necessarily demand sociological expertise to address the complexities of human needs and may fail to address the fundamental needs of the re-settlers for whom such new settlements are built, and on whom they depend to be sustainable, not just in economic or environmental terms, but in inherently complex social terms.

Acknowledgements

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References


Outdoor activity and spatial choices of citizens during heat stress conditions: a case study of Adelaide, South Australia

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Abstract: During summer heatwaves, public spaces are frequently warmer than human thermal comfort preferences in a majority of Australian Cities. Citizens’ preferences of public space elements and supportive features during heat-stress conditions are under particular focus in this paper. Outdoor activity choices in different thermal environments were surveyed in Adelaide from September 2013 to April 2014. This post-activity survey indicates that necessary, optional and social activities decreased during outdoor heat-stress more than any other thermal conditions. Outdoor activities were chosen the most in neutral and warm thermal environments. Outdoor activity choices were affected significantly by the magnitude of solar radiation. Tree canopy, shading (from buildings or temporary elements) and water features were the most attractive public space features for outdoor participants during heat-stress conditions in Adelaide. Meanwhile, essential shopping and dining facilities and social events affect citizens’ outdoor activity choices during heat-stress conditions. Thus, increased green infrastructures and supportive land uses are a prerequisite of urban transformation for climate change adaptation.

Keywords: Heat-stress; outdoor activity preferences; public space features; thermal comfort.

1. Introduction

Australia is expecting a likely increase of 2-5°C in its surface temperature by 2070 (Ricketts and Hennessy, 2009). The number of days with maximum temperature above 35°C increases from 15.3 in 30-year average to 18.3 in 3-years average in Adelaide. During summer, public spaces are frequently warmer than human thermal comfort standards in a majority of Australian Cities (BOM, 2008; Ricketts and Hennessy, 2009). The excess heat-stress can reach up to 10°C in urban settings compared to their peri-urban surroundings and is well known as the urban heat island effect (Oke, 2006; Gartland, 2008;
Erell et al., 2011). In response to such substantial extra heat load in cities, citizens increasingly move into air-conditioned buildings to benefit from the indoor thermal comfort. However, exhausted heat - generated from indoor air-conditioning - causes an ever-increasing outdoor temperature.

Urban heat-stress affects citizens’ health, especially in regards to more vulnerable groups such as the elderly and children. Amplified heat-stress during summer heatwaves causes more than 1000 extra annual deaths and contributes significantly to heat-related morbidity in Australia (McMichael et al., 2003; SoAC, 2013; Steffen et al., 2014). In this context, this paper examines the outdoor activity choices of citizens during heat-stress conditions through an exploratory survey in Adelaide, South Australia.

2. Outdoor activities and urban microclimates

The built environment can significantly affect outdoor activities; Meanwhile, it is impacted by people’s social norms and activities (Lang, 2005). The concept of ‘public space and public life’ describes that vibrant public life is the result of quality public spaces and is a significant contributor in shaping such quality (Gehl, 1987; Bosselmann, 2008). While a comfortable thermal environment can enhance the usage of outdoor space, heat-stress can cause significant discomfort, altering the frequency and patterns of outdoor activities. Gehl (1987, p. 11) argues that optional activities (in which there is a strong factor of choice) are the only ones that are influenced (notably) by urban microclimates. However, Gehl’s studies on quality of public space and public life considered climate (long-term) and weather (short-term) as controlled (relaxed) variables and investigate public life in ideal weather conditions (respective case studies are done on sunny days in spring and autumn).

Thermal comfort is defined as the state of mind that expresses satisfaction with the thermal environment (ASHRAE-55, 2013). The built environment can justify the primary microclimate conditions for thermal comfort; However, it is the human’s perception that justifies if the body is thermally comfortable or it is under stress. Thermal comfort studies result in the development of a number of steady state thermal comfort (SSTC) models, in which thermal comfort is predicted based on microclimate factors of air temperature, humidity, airflow and radiation in addition to human’s metabolic rate and clothing isolation (Stathopoulos et al., 2004; Walton et al., 2007).

Advanced thermal comfort investigations indicate that the state of adaptation to outdoor microclimates is an influential factor in comfort sensations (Nikolopoulou and Steemers, 2003; Lin, 2009). Despite the SSTC models, which considers people as passive occupants of the space exposed to external microclimates, the adaptive thermal comfort argues that thermal comfort contributing factors are beyond the physical environment. Accordingly, thermal comfort is perceptual and varies depending on the psychological condition of participants, their expectations and adaptation level, their physiological conditions and the microclimate of the space in which they are placed (Nicol, 1993; Nikolopoulou, 2004; Szokolay, 2008).

People adapt themselves to microclimate conditions by selective activities such as clothing and sunlight exposure-prevention (Spagnolo and de Dear, 2003), while the level of social activities can also influence the outdoor thermal comfort sensation. The adaptive thermal comfort (ATC) concept is multi-variable and complex and discusses thermal comfort not only dependent on microclimate physical factors but also dependent on demographic characteristics such as gender and age, health, psychological states such as happiness and stress (Szokolay, 2008), adaptive actions (e.g. clothing), and general expectations of the climate (de Dear et al., 1991; Candido, 2011).

In this context, the questions for this paper are: what outdoor activities are sensitive to heat-stress in public space? Furthermore, what public space features can attract outdoor activities during heat-stress?
conditions. Such heat-activity investigation supports vitality and usability enhancement of public spaces, and provides guidelines to increase the adaptive capacity of public spaces to heat-stress.

3. Materials and methods

A self-completion questionnaire has been used to survey choices of outdoor activities during a year concludes to the data of survey completion (January to August 2014) in Adelaide. The questionnaire aimed to test and validate activity observation findings (see: Sharifi et al., 2016) via ten multiple-choice questions and one optional open question. Participants answer the questions by selecting their activity and space choices during one year ending on the date of survey completion. Participants were accessed through two separate channels of postal addresses and online social network.

- A package including cover letter, research information sheet, a copy of the questionnaire and a prepaid return envelope were distributed to postal addresses in the City of Adelaide. As the minimum acceptable response number had been set to 100, the hard-copies will be distributed to 500 postal addresses (assumed response rate of 20%). The questionnaire was designed to take approximately 15 minutes to be completed (simple random sampling).

- An online copy of the survey was provided to broaden the surveyed population to the Adelaide metropolitan area. Direct recipients of the survey were asked not to fill, but to nominate potential participants and redistribute the online survey. The questionnaire is prepared in Google Forms identical to the hard-copy questionnaire. The second layer of recipients browsed through the online survey via the provided link (http://goo.gl/forms/9EHlqhMedv). The expected return rate for the online questionnaire was set to 100 (snowball sampling).

3.1. Survey design and response rate

The questionnaire was designed in a brief format to address the required criteria exclusively through close questions and multiple choice activity preferences with the option to add comments at the end of each question. The questionnaire included an information sheet, a question on frequency of public space usage, four questions on outdoor activity choices during last year in different thermal conditions, a question on weather information, a question on other microclimate parameters affecting outdoor activity choices, a question on spatial preferences during heat-stress conditions, a question on heat-health awareness, a data monitoring question on age-range and an open question on participants further suggestions. A choice of “none of above” and a choice of “other” were designed for a majority of questions, in which respondents were able to enter their additional comments. Respondents were not identifiable in the design of the questionnaire. They are asked for their city of living (Adelaide) for data monitoring and age group for data separation and analysis. Name, address, and gender were not recorded since they are not relevant to the project scope. No follow-up questions were envisaged in research scope. At the end of the survey, there was an option for the respondents to contact the researcher via email address to be forwarded the research outcomes.

3.2. Response rate

Baurch (1999, p. 434) suggests that it is acceptable to have the response rate of 36% ± 13 for social research of general population. Though, the response rate may be affected by presentation style, population demographics, control rate, required time and seasonal climate at the time of distribution.
The initial response rate of 20% had been set at the time of questionnaire distribution. From the 500 hard-copy questionnaires, the total number of 108 were returned. Thus, the actual response rate is 21.6%. The actual response rate of 21.6% is marginally higher than the expected response rate of 20%. Also, it is very close to the suggested 23% for the lower limit of response rate for general population social research. Total 159 online questionnaires were received from January to August 2014 (One questionnaire was taken out from the data set due to the age of respondent being less than 18). This led to the actual response rate of 31.8%. The actual response rate of 31.8% is higher than the expected response rate of 20%. It is in very close to the average ideal response rate of 36% for general population social research. In total 1000 surveys were distributed, of which 267 were returned. Therefore, the overall response rate equals to 26.7%, which is in the range of ideal response rate of 36% ± 13 for general population social research.

3.3. Chi-square test

The chi-square test is used to test whether there are differences in the data distribution in two or more categorical data groups. A chi-square test assumes that data of the two groups are independent and normally distributed. When $p$-value $\geq 0.05$, then the data does not suggest that the two discrete data groups have statistically significant differences. The chi-square test is performed using the MS Excel data analysis tool for questionnaire survey data in this paper. It is used to test and discuss outdoor heat-activity choices of citizens of Adelaide via online and hard copy self-completion questionnaire surveys.

4. Results

Citizens of Adelaide were asked to choose their outdoor activities during a year concluded to the completion of the questionnaire. Based on the adopted theory of ‘public space and public life’, outdoor activities are coded as follows (Gehl and Svarre, 2013):

- Walking and working are coded into necessary activity category
- Standing, sitting, eating, drinking, laying down, jogging, cycling, and other individual exercises are coded into optional activity category
- Playing (children), group sports, meeting others and attending social or cultural activities are coded into social activity category

The Chi-square test reveals that there is no meaningful statistical differences between the two data collection methods regarding public space usage ($p = 0.076$). Nearly 80% of respondents reported that they had used public space at least once a week (see Table 1). Therefore, the randomly selected sample population does present public space users in Adelaide. Meanwhile, 83% of the respondents check the weather predictions at least once a day. Adding the population who check the weather when going outdoors increase weather awareness rate of the respondents to 89%. Therefore, the survey respondents are assumed to have proper weather information before attending outdoors.

Table 1: Annual outdoor attendance rate of questionnaire survey participants in Adelaide

<table>
<thead>
<tr>
<th></th>
<th>Online</th>
<th>Hard-copy</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>At least once a week</td>
<td>79.9%</td>
<td>80.6%</td>
<td>80.2%</td>
</tr>
<tr>
<td>At least once a month</td>
<td>94.3%</td>
<td>99.1%</td>
<td>96.7%</td>
</tr>
<tr>
<td>Rarely</td>
<td>5.7%</td>
<td>0.9%</td>
<td>3.3%</td>
</tr>
</tbody>
</table>
### 4.2. Comparison of online and hard-copy heat-activity choices

Outdoor activity choices of respondents were collected in four ordinal thermal environments (see Figure 2). Such ordinal thermal environments are based on how respondents felt outdoors and were divided into hot, warmer than preferred, thermally comfortable and cooler than preferred categories (The fifth scale – cold - was not included in the questionnaire due to the research scope and focus on the heat-stress). A reference temperature range was given on the questionnaire for each thermal sensation category, and the participants were asked to note their thermal preferences if different from the given range.

The chi-square test confirms that there is no statistical significance between online and hard-copy responses regarding activity preferences in different thermal conditions ($p=0.088$). Therefore, the responses can be grouped for heat-activity analysis. Descriptive charts of outdoor activity choices are presented in Figure 1 and reveal that online and hard-copy responses have less than 15% variation in each category.

![Figure 1: Descriptive charts of outdoor activity choices in four sensible thermal environments](image)

As expected, a higher number of outdoor activities occurred in neutral temperatures, when respondents felt thermally comfortable compared with hot, warm and cool conditions. The total number of activity choices are calculated based on declared choices that respondents had made in a year concluding to the questionnaire survey. As such, results do not reflect the total number of outdoor activities for each respondent, but the choices of outdoor activities. For example, despite probable multiple outdoor walking activities in the past year, only one walking score could be recorded for an
identical respondent in hot weather conditions. The hot thermal environment was avoided by citizens with the considerable decline rate of 45% compared with the neutral thermal conditions.

![Figure 2: Outdoor activity choices in hot, warm, neutral and cool outdoor thermal conditions in Adelaide (N=267)](image)

### 4.3. Heat sensitivity of necessary activity choices

Necessary activities tend to be the highest during neutral thermal conditions. Necessary activity choices in warm and cold thermal environment have marginal differences to neutral thermal conditions (less than 10%). However, necessary activity choices have a significant 41% decrease in sensible heat-stress conditions. Meanwhile, 40 respondents expressed that they had not done any outdoor activities during heat-stress conditions (15% of the whole sample population).

The rate of no outdoor activity (during a year) in hot thermal conditions is even more significant. Some 13.9% of the studied population revealed that they had no outdoor activities during heat-stress conditions while such critical zero-activity situation occurs only for 2.6% of the population in cool and 1.9% of the population in warm outdoor thermal conditions. No outdoor zero-activity was chosen by the participants during neutral (comfortable) thermal conditions. As such, necessary activity choices decrease during outdoor heat-stress more than any other thermal conditions and are sensitive to heat-stress in public space.

### 4.4. Heat sensitivity of optional activity choices

Optional activity choices tend to be the most favourite during neutral thermal conditions. Optional activities in warm and cool environments have a higher decrease rate compared with necessary activities. Such outdoor activity decrease rate is 29% for warm, 51% for cool and 64% for hot outdoor thermal conditions. Therefore, optional activities were the least favourite in cool and heat-stress conditions. Three participants (1.89% of the population) did outdoor swimming during heat-stress conditions that are classified in optional activity category.

Laying down had the least activity choice rate among other optional activities and reached its lowest rate in cool outdoor environments (7.9%). However, the hierarchy of optional activity choices shifts in the favour of cool thermal environments for individual physical activities. Individual physical activity choice rate of 57.7% in neutral thermal environment decreases to 41.6% in cool thermal conditions, 35.2% in warm thermal conditions and 14.2% during heat-stress conditions. Such popularity of physical activities in cooler thermal environments can be justified by the physiological need of the human body to generate internal heat in cool thermal conditions. As such, a majority of optional activity choices
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(excluding laying down outdoors) decrease during outdoor heat-stress more than any other thermal conditions and are sensitive to heat-stress in public space.

4.5. Heat sensitivity of social activity choices

Social activities tend to be the highest during neutral thermal conditions. Social activity choices in warm and cold thermal environment have less than 10% differences to each other (25% and 34% respectively). However, social activities had a significant 53% decrease in heat-stress conditions compared with neutral thermal environments.

Group physical activities had the least popularity among other social activities in Adelaide. The corresponding ideal rate of 44.6% in neutral thermal environment decreased to 31.8% in cool thermal conditions, 26.6% in warm thermal conditions and 16.1% during heat-stress conditions. Similar to individual physical activities (sub-class of optional activities), group physical activity choices were more favourite in neutral and cool thermal environments due to the physiological characteristics of human participants. As such, social activity choices decrease during outdoor heat-stress more than any other thermal conditions and are sensitive to heat-stress in public space.

4.6. Spatial preferences during heat-stress

Spatial preferences of citizens are analysed in two parts: influential microclimate parameters and spatial preferences during heat-stress. Respondents were asked to indicate climate factors that can affect their decision for outdoor attendance. Figure 3 reveals that urban microclimate parameters of sunshine intensity, wind speed and humidity have almost similar effect on outdoor attendance as rainfall (temperature was excluded in this question because thermal preferences of participants were asked in other questions).

![Figure 3: Effective climate factors in outdoor attendance of survey respondents in Adelaide (N=270)](image_url)

Randomly selected citizens of Adelaide were asked to choose their outdoor spatial preferences during heat-stress conditions in the questionnaire survey. The chi-square test of online (N=159) and hard-copy (N=108) data reveals that there are no statistically significant differences between the mean values ($p = 0.068$). Figure 4 presents the merged results of spatial feature preferences during heat-stress conditions in Adelaide. Tree canopy was the most attractive public space feature for outdoor participants. With the preference rate of 62.9%, tree canopies were chosen by more citizens compared with any other public space features. With 13.8% less popularity, water features had the preference rate of 49.1%. Such preference rate was 37.1% for temporary shading, 32.2% for grass coverage and 30.7% for buildings’ shading (in land cover feature class). In public space supportive feature class, shopping facilities had the preference rate of 33%. The preference rate was 27% for dining facilities and 21% for swimming facilities. Regarding public space management, social and cultural events had the preference rate of 27% during heat-stress conditions.
Outdoor air-conditioning attracted 16.1% of survey respondents. Landmarks and vista were among the attractive features of public space for 11.6% of respondents and playing facilities attracted 9.4% of surveyed population. However, hard landscapes were highly avoided by citizens and had the lowest preference rate of 2.2% during heat-stress conditions. Meanwhile, 6.4% of respondents expressed that no spatial feature can attract them to attend outdoors during heat-stress conditions. Comparing this preference rate with the expressed 13.9% zero-activity rate in hot thermal environments underlines that, regardless of public space features and facilities, there are some citizens who avoid outdoor heat-stress. The difference between no-preference rate (6.4%) and zero-activity rate (13.9%) during heat-stress condition highlights the freedom and complexity of outdoor activity choices among citizens.

![Figure 4: Merged results of spatial feature popularity during heat-stress conditions in Adelaide (N=267)](image)

5. Further discussion

Necessary, optional and social activities were more chosen during thermally comfortable and slightly warm conditions. Table 2 reveals that except individual and group physical activities, the least activity decrease rate occurred in warm thermal environments (less than 30% decrease rate). Sedentary activities such as standing, sitting, laying down, eating, drinking and attending social or cultural events are less favourite during cool conditions, when more active outdoor activities such as walking, working, individual exercise and group sport are preferred by respondents.

Hot environments were avoided by citizens especially when there was a strong factor of choice such as optional activities with 63.8% activity decrease compared with the neutral thermal environment. Necessary activities including walking and working had the least decrease average rate of 40.6% in hot thermal environments. Planned optional and social activities such as eating, drinking, meeting and attending social or cultural events have the second lowest decrease rate during heat-stress conditions (average rate of 50.2%). However, optional and social activities which could be easily relocated indoors or postponed such as individual exercise, sport, laying down, standing and sitting are highly sensitive to heat-stress.

Outdoor activity choices have the highest quantities in neutral and warm thermal environments where optional and social activities are as favourite as necessary activities and contribute more to the vitality of public spaces. Patterns and frequency of outdoor activities are affected by increased outdoor temperatures. Such negative effect of high temperatures on outdoor activities is more resilient to warm conditions than cool temperatures. However, after reaching the extremely uncomfortable outdoor
temperatures, outdoor activities would be limited to obligatory activities such as walking to work or home and attending planned activities, yet with lower rates than business as usual.

Table 2: Decrease rate in necessary, optional and social activities in different thermal conditions compared with neutral environment

<table>
<thead>
<tr>
<th>Classification</th>
<th>Decrease rate</th>
<th>Cool</th>
<th>Neutral</th>
<th>Warm</th>
<th>Hot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Necessary</td>
<td>Walking through</td>
<td>7.6%</td>
<td>11.4%</td>
<td>40.8%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Working</td>
<td>10.3%</td>
<td>5.7%</td>
<td>40.2%</td>
<td></td>
</tr>
<tr>
<td>Optional</td>
<td>Standing or sitting</td>
<td>61.0%</td>
<td>25.2%</td>
<td>61.6%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Laying down</td>
<td>80.2%</td>
<td>34.0%</td>
<td>69.8%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eating or drinking</td>
<td>44.0%</td>
<td>21.1%</td>
<td>51.2%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Individual exercises</td>
<td>27.9%</td>
<td>39.0%</td>
<td>75.3%</td>
<td></td>
</tr>
<tr>
<td>Social</td>
<td>Group physical activity</td>
<td>28.6%</td>
<td>N/A</td>
<td>40.3%</td>
<td>63.9%</td>
</tr>
<tr>
<td></td>
<td>Meeting others</td>
<td>31.4%</td>
<td>18.6%</td>
<td>51.6%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Social or cultural event</td>
<td>41.5%</td>
<td>20.8%</td>
<td>47.8%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Necessary</td>
<td>8.4%</td>
<td>9.7%</td>
<td>40.6%</td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>Optional</td>
<td>50.9%</td>
<td>29.2%</td>
<td>63.8%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Social</td>
<td>34.1%</td>
<td>24.9%</td>
<td>53.4%</td>
<td></td>
</tr>
</tbody>
</table>

6. Conclusions

Heat-activity survey findings reveal that necessary, optional and social activities are heat-sensitive. Outdoor activities decrease significantly in hot temperatures compared with neutral (comfortable) thermal conditions. Optional activities have the highest heat-sensitivity rate to temperatures above 35°C (hot conditions). Tree canopies are the most attractive public space features during heat-stress conditions in Adelaide. Shading, soft landscapes, and water features are reasonably popular in hot microclimates. However, hard landscapes are highly unattractive and are likely to be avoided by citizens. Nevertheless, public space supportive features and management can extend the attractiveness of public space under heat-stress conditions. In the context of climate change, public space can support more vibrant, healthy and safer urban environments in cities. Such heat resilient public spaces support the usability of outdoor spaces by local communities in hot scenarios.

Public spaces in city centres are different from suburban setting; Large open spaces have a different feel in comparison to small spaces. Such variations in typology, size and location of public spaces were not included in this study. These variables are vital to generalise findings and are covered in a separate research (see: Sharifi et al., 2016).

Acknowledgements

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Optimization of Hong Kong residential building design guidelines to improve urban air ventilation

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Abstract: Stagnant ventilation levels below 2 m/s is a common phenomenon in most urban areas in Hong Kong. Increasing urban development has demonstrated impacts on pedestrian wind environments. ‘Hyper podium & tower’ typology that consists of a 15 m high podium has further impacted on pedestrian zone wind speed. This study investigates impacts created by the ‘hyper podium & tower’ typology on pedestrian wind speed and the contribution from proposed design modifications in improving wind speed. Using computational fluid dynamics ANSYS Fluent, this study developed ten-year interval wind profiles from 1960 to 2015 and three-year interval wind profiles from 1997-2015. Findings indicate, 0.7 m/s reduction in wind velocity from 1960-1990 in relation to the reduction in urban porosity from 51% to 6.1%. A drastic drop of 0.4 m/s in the wind speed is noticeable from 1990-2000, which may be attributed to the ‘hyper podium & tower’ developments introduced in the mid 1990s. Improvements in the pedestrian wind velocity was evident with the of 30% void and individual tower options compared to other design modifications. Building geometries such as individual towers and large podiums reported significant differences in wind behaviour around these developments. Findings from wind behaviour around 55m and 110m tall towers advocate the sustainability of taller towers with more urban porosity. Findings from this study calls for a review of ‘hyper podium & tower’ typology.

Keywords: pedestrian wind; urban porosity; urban ventilation; building typologies.

1. New town developments in Hong Kong

Hong Kong is one of the most densely populated cities on the Planet with average population density around 6,700 persons/km$^2$ with some areas exceeding 57,000 persons/km$^2$. Hong Kong population increased by 135% since 1960 to 2015 from 3.1 million people to 7.3 million people with a projected population of 8.72 million in 2031 (Trading Economics; Census and Statistics Department). Hong Kong ranked as the most unaffordable housing market in the world sixth time in a row according to annual housing affordability surveys by Demographia International (Demographia, 2015).

New town development programme was emerged as a response to the fire in 1953 in an informal settlement in Shek Kip Mei which left 53,000 Mainland Chinese refugees homeless and the rapidly
escalating population growth. New towns developed in early 1970s accommodated public and private housing supported by infrastructure and community facilities, with connectivity to other adjacent urban areas. New towns were developed as self-sufficient entities consisting of mixed land uses: infrastructure, residential, industrial, educational, healthcare, and recreational facilities etc. To date, Hong Kong has developed nine new towns accommodating about 3.47 million population which is expected to rise up to 3.63 million in 2021, out of 7.8 million national population.

1.1. Recent transformation of the first generation of new towns

The first generation of new towns namely, Tsuen Wan, Sha Tin and Tuen Mun provided housing for about 1.8 million out of 4.2 million overall population in the early 1970s. The second generation new towns were developed in the late 1970s followed by the third generation towns in the 1980s and 1990s.

With China’s Open-door policy initiated in the mid 1980s, most Hong Kong light industries were relocated their production facilities to mainland China, minimizing the scale of Hong Kong operations. Since then Hong Kong has been transforming from manufacturing sector to service sector reducing job opportunities in the manufacturing sector. Vacant industrial buildings in these new towns were gradually transformed into residential estates with urban areas becoming magnets for employment opportunities.

1.2. Residential Building Typologies in new towns

Over the past fifteen years, Tsuen Wan experienced a rapid regeneration of the industrial buildings and old buildings built in the 1950s. With modified zoning requirements, stand-alone developments were progressively replaced by mixed-use large scale developments under the ‘Comprehensive Development Areas (CDA)’ policy. Old narrow street blocks were amalgamated and transformed into large blocks with development Plot Ratio of 5 to 6 reducing the urban porosity in these new towns. Hyper podium & tower developments that consist of a 15 m mixed-use podium and residential towers above were introduced in mid 1990s. Figure 1 presents the chronology of development typologies in Hong Kong from 1950s to year 2000.

Figure 1: Development trends & typologies in Hong Kong from 1950s-2000 (source: adapted from Kirchhoff et al. 2011)

2. Urban ventilation challenges

Increasing density in Hong Kong has resulted in lack of urban porosity leading to a series of adverse impacts such as stagnant urban ventilation, air pollution concentration, high humidity, urban heat island effect and health impacts.
Increasing urban roughness as a consequence of urban density reports a declining trend in the wind speed. Figure 2 presents a comparison in wind speed between an undeveloped island and an urban area reporting a 4 m/s lower wind speed in the urban area. On average wind speed in most urban areas in Hong Kong is less than 2 m/s.

Figure 2: Comparison of annual average of 12 hourly 10 minutes mean wind speed in an urban area with the monitoring station in Waglan Island. (Source: Hong Kong Observatory, 2015)

2.1 Mitigation strategies

Realizing the urgent need to mitigate these impacts arising from high density, Hong Kong development authorities have initiated two key design guidelines: Sustainable Building Design (SBD) guidelines in 2011 and Air Ventilation Assessment guidelines in 2006. SBD guidelines have established three key design elements to promote urban environmental quality by improving pedestrian level ventilation, increasing greenery, and mitigating urban heat island effect. SBD guidelines are voluntary, yet incentive based guidelines leading up to 10% of additional Gross Floor Area concession. BEAM Plus green building rating scheme initiated in Hong Kong also has incorporated credit requirements within the scheme to facilitate desirable air ventilation levels by minimizing wind amplification at pedestrian level.

2.1.1 Sustainable Building Design (SBD) guidelines

The three key design elements established by SBD guidelines are building separation, building setback and site coverage of greenery. ‘Building separation’ requirement applies to sites that are over two hectares or having a continuous frontage exceeding 60 meters. Building separation guideline aims at improving permeability at site level, through a provision of 20% - 33.3% voids at <60 m & 60 m> height zones along each plane.

The second SBD guideline ‘building setback’ aims at improving environmental quality at pedestrian level and mitigating urban heat island effect caused by narrow street canyons that are less than 15 meter wide. Buildings fronting a street less than 15 m in width are required to maintain a 15 m x 15 m ventilation corridor with no part of the building protruding within 7.5m from the centreline of the street.

Site coverage of greenery aims at improving quality of the urban environment and mitigating heat island effect. Sites that exceed 1,000 m² are required to provide greenery areas equivalent to 10% - 30% at primary zones and overall depending on the site extent. Primary zone is the 15m vertical zone abutting the concerned street.
2.1.2. **Air Ventilation Assessment framework**

Air Ventilation Assessment (AVA) is mandatory for all major government projects that exceed certain critical parameters stipulated in the AVA technical circular. AVA aims at reducing significant negative impacts caused by developments on existing wind speed at pedestrian zones. Since the AVA framework doesn’t provide any benchmark standards, the main objective is to avoid potential impacts on air ventilation by evaluating design options at the planning stage. Planning studies for new towns, development sites over two hectares, podium coverage exceeding one hectare, development with Gross Floor Area exceeding 100,000 m², developments of waterfront sites with lot frontage exceeding 100 m and building height exceeding 15 m within a public open space are some of the projects that require air ventilation assessment (Development Bureau, 2006).

2.1.3. **BEAM Plus green building rating scheme**

Since the establishment of SBD guidelines and AVA framework and also realizing the importance of curbing adverse impacts created by new developments, BEAM Plus which is the national green building rating scheme, has incorporated air ventilation related credit requirements within the scheme leading up to two credit points. BEAM Plus Version 1.1 (2010) under ‘microclimate climate around buildings category’ required demonstration of two wind related performances: no wind amplification and no stagnant areas which has a wind speed of less than 1.5 m/s. Realizing air ventilation challenges in Hong Kong with regards to maintaining sufficient air ventilation levels, minimum wind speed requirement has been excluded from BEAM Plus Version 1.2 (2012).

### 3. Methodology

#### 3.1. Development of historical wind profiles

This study investigates changes in the wind profiles in relation to development chronology. Considering the development pace in Tsuen Wan, digital models were developed to represent major changes in the urban fabric and hence changes in the wind profile at ten-year intervals. Results were further validated with three-year interval analysis of the wind patterns from 1997 to 2015 as a result of ‘hyper podium’ residential typology introduced in mid 1990s. Digital models were developed from two dimensional survey maps and were verified with aerial images taken with a fly camera and Google satellite maps.

#### 3.2. Establishing model parameters and simulation procedure

Selection of an appropriate turbulence model is important in simulation studies. Based on literature reviews on turbulence models adopted by Franke *et al.* 2004 and Shih *et al.* 1995, pilot studies were conducted adopting commonly practiced RANS k-ε family steady turbulence model. Out of the three variations of RANS k-ε models, this study adopted ‘Realizable k-ε model’ proposed by Shih *et al.* (1995) due to its ability to ensure more realistic turbulence properties and the ability to modify the turbulent dissipation rate with a varying model coefficient of $C_\mu$.

Developments in purple, blue, pink and yellow zones represent different typologies of residential mixed-use developments whilst orange zones representing old factory buildings. As per Hong Kong AVA framework, the ‘Assessment Area’ of the project is delineated by drawing a circle with a radius equivalent to the height of the tallest building (H) within the project boundary. In addition a ‘Surrounding Area’ equivalent up to 2H of the tallest building within the project boundary also shall be
included in the study to capture effects on wind environment in the surrounding. As this study is not limited to a particular project site, the entire developed area surrounded by the peripheral road was considered as the assessment area which is beyond 2H of the typical buildings within the boundary. Approximately 320m tall Nina tower which was completed in 2007 is the only exception within the assessment area which is located away from the two experimental zones. Assessment area was limited to Tsuen Wan city centre and periphery areas as shown in the CAD model in the Figure 3 below.

![Figure 3: CAD model representing the assessment area (red dash line) and experimental areas (yellow dash line) (source: Authors et al. 2016)]](image)

### 3.2.1. Boundary condition

Air Ventilation studies are often done for site scale analysis; therefore it is important to derive wind simulation parameters suitable for urban scale analysis. Observing reasonably consistent wind patterns in Tsuen Wan over the years, infinity level wind velocity was based on 2015 wind data for developing historical profiles. Infinity wind data were obtained from Hong Kong Planning department. Following the recommendations in CFD guidelines (Franke, 2007; Tominaga, et al. 2008; Mochida et al., 2002), the study adopted a rectangular computational domain with symmetric boundary conditions at the two side boundaries and the upper boundary. For computation purpose, the inflow boundary condition is set as the velocity inlet and the outflow boundary as the zero gradient condition. Unstructured tetrahedral cells of approximately 8-15 million with maximum expansion ratio were created in the mesh strictly following the COST Action C14 (Franke et al., 2011) and the Architectural Institute of Japan (AIJ) guidelines (Tominaga et al., 2008; AIJ, 2007). Inflow wind profiles are adopted from RAMS data from Hong Kong Planning Department. Inflow turbulent kinetic energy profile and corresponding dissipation rate profiles are estimated using the following equations where \( u^* \) is the frictional velocity, \( C_\mu =0.09 \) and \( \kappa=0.4 \).

\[
\begin{align*}
  k &= \frac{u^*}{\sqrt{C_\mu}} \\
  \varepsilon &= \frac{u^*}{\kappa(z+z_0)}
\end{align*}
\]

ANSYS Fluent programme was used for wind simulation adhering to the parameters described in Hong Kong AVA framework. Seven major wind directions that represent over 75% of annual wind
frequency in a typical year were considered. Results were obtained from fifty strategically placed test points encompassing street nodes, large scale developments and street centres etc. and were analysed using weighted average scoring method.

3.3. Design case testing

Considering prospective redevelopment plans for two existing factory estates in Tsuen Wan, following speculative design scenarios were tested replacing old factory buildings with typical ‘hyper podium and tower’ developments and the following design options (Table 1). Currently existing street network and the ratio of open areas within these estates were maintained in all scenarios whilst adopting the currently governing development plot ratio of 6.5.

<table>
<thead>
<tr>
<th>Case</th>
<th>Permeability ratio &amp; design option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>Wind performance in existing factory estates</td>
</tr>
<tr>
<td>Case 2</td>
<td>Replacing factory buildings with new residential buildings that consists of a 15 m tall podium and towers above</td>
</tr>
<tr>
<td>Case 3</td>
<td>6 m high, 20% void area was introduced to the podium block in Case 2</td>
</tr>
<tr>
<td>Case 4</td>
<td>6 m high, 30% void area was introduced to the podium block in Case 2</td>
</tr>
<tr>
<td>Case 5</td>
<td>6 m off ground elevated podium with commercial element at the ground level creating a 3.5 m void in between</td>
</tr>
<tr>
<td>Case 6</td>
<td>Individual tower residential developments with a 3 m link podium</td>
</tr>
</tbody>
</table>

3.4. Data normalization

Site A and Site B are located within 1km from each other; however Site A and Site B inherited different wind profiles attributed by the site boundary condition for wind simulation (Figure 4).

![Figure 4: Comparison between Site A and Site B wind profiles (source: Authors et al. 2016)](image-url)
Site A indicated lower wind speed due to increased urban roughness imposed by the development surrounding the site. Site B indicated relatively higher wind speed as one of the experiment boundaries borders the Site B eliminating the surrounding development. In order to normalize these data variations, only the core area of Site B was selected for placing data sensor points, that provided a similar conditions to Site A in terms of urban roughness.

4. Findings

4.1. Correlations between development trends and pedestrian zone wind speed

Ten-year interval analysis from 1960 to 2015 was conducted, further validated by a three-year interval analysis capturing impacts from the evolution of building typologies such as low-rise buildings, wide plot developments, individual tower developments and large podium type developments. Findings from 3-year interval study did not indicate significant changes in the wind patterns compared to 10-year interval study. This comparison indicates the adequacy of ten-year interval study for city scale wind analysis (Figure 4).

Weighted average scores from fifty strategically placed test points within the study area indicate a decline in pedestrian wind speed in parallel to declining unbuilt areas. Evolution of building typologies and progressive developments in Tsuen Wan new town resulted in the reduction in urban porosity from 51% unbuilt area in 1960 to 6.1 unbuilt area in 1990 negatively impacting on the pedestrian zone wind speed. However the reduction in wind speed was 0.7 m/s from 1960 to 1990 in parallel with approximately 45% reduction in urban porosity and evolution of larger developments, compared to the sharp drop in the wind speed from mid 1990s onwards (Table 2).

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Undeveloped area in km²</td>
<td>1.02</td>
<td>0.73</td>
<td>0.59</td>
<td>0.17</td>
<td>0.23</td>
<td>0.24</td>
</tr>
<tr>
<td>% of undeveloped land</td>
<td>51%</td>
<td>29.8%</td>
<td>22.3%</td>
<td>6.1%</td>
<td>8.2%</td>
<td>8.3%</td>
</tr>
<tr>
<td>average wind speed</td>
<td>2.97</td>
<td>2.50</td>
<td>2.28</td>
<td>2.27</td>
<td>1.88</td>
<td>1.88</td>
</tr>
</tbody>
</table>
Two significant development typologies attributed to this noticeable decline in the wind speed; a decline from 2.97 m/s to 2.5 m/s with the introduction of ‘hyper factory blocks’ in the 1970s followed by another sharp decline from 2.27 m/s to 1.88 m/s with the introduction of ‘hyper podium & tower’ developments in mid 1990s. Approximately 1.1 m/s reduction in the wind speed can be observed in the year 2000 compared to 1960s (Figure 5). Considering fairly stagnant wind speed in Hong Kong, even a 0.5 m/s can be considered a significant change in the pedestrian wind environment.

4.2. Correlations between void ratio and wind speed

Replacement of factory estates with hyper podium & tower development indicate a reduction in wind speed from 1.21 m/s to 1.24 m/s. Findings from the six design scenarios established the importance of urban porosity at the pedestrian wind zone. Introduction of 30% void and individual tower developments contributed to better wind performance compared to other design options. Current factory estates and the introduction of 20% void in the podium presented equal wind performance concluding the importance of voids for wind penetration. Elevated podiums with voids over 20% did not indicate improvements at the pedestrian level wind environment; one possibility could be due to wind obstruction by the built element at the ground level (Figure 7).

Figure 5: Correlation between pedestrian level wind speed and reduction in urban porosity (source: Authors et al. 2016)

Figure 7: Improvement in wind velocity with the introduction of varying proportions of voids to the ‘hyper podium’ residential typology (source: Authors et al. 2016)
4.3. Correlations between building geometries and wind behaviour

An analysis was conducted to observe correlations between various building geometries and building heights of the same geometry selecting the hyper podium & tower geometry and currently existing building typologies in Tsuen Wan. Findings reported distinct patterns of wind behaviour around certain building geometries. Large podiums reported wind amplification above a factor of 2 on the windward side of the podium and individual tower developments and existing factory estates indicated acceptable level wind speed in situations where there is adequate distance between buildings (Figure 6). Majority of hyper podium residential towers in Hong Kong are of cruciform geometries in order to increase number of flat units per floor that have daylight access. Cruciform geometries increase urban roughness thereby reducing wind speed. These findings are supported by a study conducted by Montazeri, H. et al. (2013) which experimented with staggered second skin façade to equalize wind pressure in balconies.

![Figure 6: Wind behaviour around different building typologies in Tsuen Wan new town (source: Authors et al. 2016)](image)

The experiment between 55m and 100m tall towers didn’t report any significant impact on the wind profile concluding that the height of towers does not have any significant impact compared to the impact created by the porosity within developments. A majority of Hong Kong developments are designed with flat roofs and sharp geometries; a study conducted by Perèn, J. et al. (2015) reports a 22% improvements in wind flow with the introduction of inclined roofs and more so when the angle is increased. Yuan & Ng (2012) reports the friction created by shape-edged geometries on the boundary layer air flow. Predominance of flat roofs and sharp geometries in Hong Kong may also be some of the factors that adversely impact on wind speed besides the lack of urban porosity; however these assumptions are yet to be validated.

5. Conclusions & recommendations

This study contributed to the advancement in built environment knowledge by developing historical wind profiles from 1960-2015 and identifying the effect of development trends and building typologies on urban ventilation. Results from 3 year interval analysis and 10 year interval analysis confirm the adequacy of 10 year interval analysis for development of historical wind profiles at city scale.

Although improvements to the pedestrian wind environment are marginal 30% void in the podiums and individual tower developments show promising directions for future developments. Adverse impacts are notable around hyper podium developments due to wind amplification on the windward side. Similarities in wind behavior around shorter and taller towers advocate the sustainability of tall towers facilitating more urban porosity compared to the currently adopted hyper podium & tower developments that create wall effect curbing urban ventilation.
Findings call for review of design modifications to the currently adopted podium typology in Hong Kong in order to create desirable air ventilation levels at pedestrian zones. These findings are generalizable for most new towns in Hong Kong and also to other dense cities.

Acknowledgements

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Assessment of outdoor space’s ventilation efficiency around residential building: Effects of building dimension, separation and orientation

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Abstract: This paper probes into the influence of varying lateral spacing and serial lengths in residential buildings on ventilation efficiency in various typical outdoor spaces. To assess ventilation efficiency around residential buildings, purging flow rate (PFR), visitation frequency (VF) and air residence time (TR) are calculated with the computational fluid dynamics (CFD) method. The calculation tool is ANSYS-Fluent. Simulation results show that in comparison with length and lateral spacing, building orientation exerts relatively more effect on ventilation efficiency of outdoor spaces. When the angle between the long facade orientation and wind direction exceeds 30 degrees, the ventilation performance of different domains sees great improvement. Building length has certain influence on ventilation efficiency of outdoor space, especially for the buildings located in the middle of the residential area. The varying range of PFR could reach 16%. Lateral spacing in varying has a relative limited effect on the ventilation efficiency of various outdoor spaces, among which those closer to the varying area generally receive higher effect this way, in the meanwhile dependent on the layout pattern of surrounding buildings.

Keywords: Residential building; Layout design; Ventilation efficiency; CFD simulation.

1. Introduction

Ventilation efficiency of outdoor space is very important for both interior and exterior air qualities. Good ventilation condition around buildings means effective pollutant dilution and highly exterior air quality, which again affects the interior air quality by mechanical or natural ventilation. As most people spend most of their daytime and all nighttime indoors, a good ventilation condition around residential buildings proves importance for residents’ health. But how to create good ventilation conditions through appropriate building layout poses a challenge for architects. On the other hand, although research has revealed the effect of design variables on air flow pattern around buildings, the wind environment still remains beyond control of the architect as with the sunlight in deciding the orientation, length and spacing [Sanaieian et.al 2014]. It is partially because of the complexity of forms and design. So the trial-and-error method is adopted primarily at present during layout design of residential
buildings to improve the exterior wind environment of residential area. In order to help designers in effective decision-making for ventilation design of exterior spaces, the relationship between design parameters and exterior ventilation efficiency requires intensive research in an operable level.

Factors such as the size, spacing, orientation and location of residential buildings are important in the layout design. Effect of such design factors on ventilation and pollutants dispersion of exterior space has been discussed extensively in many studies in the field of urban forms and street canyon. For studies on urban forms, for example, Mfula et al. (2005) discussed the effect of spacing variation between buildings on diffusion of pollutants at different locations within urban space through wind tunnel tests. Buccolieri et al. (2010) employed numerical modelling to examine the spacing variation as to air exchange rate. These studies are mostly focussed on influence of building density on overall urban wind flows, choosing the square building arrays equally spaced in longitudinal and lateral directions in uniform variation as the simulation object. Buccolieri et al. (2015) also chose square arrays while respectively investigating the influence of the longitudinal and lateral spacing. Hang et al. (2015) conducted similar researches on street widths and building height studies. In the field of street canyon study, Oke et al. (1988) identified three characteristic flow field types on the basis of width / length (w/h) ratio of street section as early as in 1988. Then, Sini et al. (1996) discussed different characteristics of wind field with and without heating of walls for street canyon of infinite length with the technique of numerical modelling and studied street canyon simulation under different w/h ratios of street section, confirming the conclusion of Oke et al. again and finding the change of wind field characteristics when windward facade walls were heated. Similar studies also include that of Simoens and Wallace (2008) on diffusion of pollutants. Besides w/h ratio of street section, Chan et al. (2001) also studied the effects respectively of different w/h ratios of building facade and change of building height on diffusion of pollutants at different locations, and results showed the facilitation of non-uniform building heights to urban ventilation and a maximum of building facade w/h ratio recommended to control within the range of 5. With most studies concerned with proposing an evolution method, the guidance value for practice in term of design operation is relatively limited. Most studies of urban form are restricted in discussing overall effect on ideal urban form with models of homogeneous fabric. In the street canyon field, long-strip buildings with w/h ratio of building facade over 7 were applied in most calculation models, and sections of street of infinite length were investigated even with 2D calculation model, which differed considerably from the design of residential buildings.

In addition, a number of studies related to residential building layout design have been carried out in recent years. For example, Hong and Lin (2015) simulated and compared 6 layout patterns of multilayer residential buildings under same density and coverage, and results showed that the building layout and orientation had significant effect on outdoor wind environment at pedestrian level. Yang et al. (Yang et al. 2015) analysed the effect of standard and staggered layout of roadside multi-floor buildings on diffusion of pollutants with numerical modelling. Ying (Ying et al. 2013) and Iqbal (Iqbal and Chan 2016) also conducted comparisons of high-rise residential building layout patterns. However, most of them performed simulation by simply combining several individual buildings without considering the blocking effect of surrounding buildings. What’s more, very few systematic studies have been conducted to characterize the effects of serial design changes.

In the last decade, evaluation method on urban ventilation has developed rapidly. Different parameters have been proposed and applied to assess ventilation efficiency of urban areas. Most of those parameters were developed from indoor ventilation studies (Bady et.al 2008, Hang et.al 2015, Buccolieri 2010, 2015), such as mean age of air (MAA), purging flow rate (PFR), visitation frequency (VF) and air residence time (TR). MAA in urban area can be defined as the time it takes for the urban external
“fresh” air to reach a given location. PFR is defined as the effective airflow rate required to purge the air pollutants from the domain. TR means the time a pollutant takes from once entering or being generated in the domain until leaving it. A high value of MMA or AR implies a poorly ventilated domain. And a low PFR means that the domain is weakly ventilated. VF represents the number of times a particle enters the domain and passes through it. A high VF indicates poor removal efficiency of the pollutants. These parameters provide effective analysis methods for this study.

This research is attempted to probe into the correlation between varying design parameters and various spaces’ ventilation performances for design in operative level, so as to facilitate the designer in terms of ventilation design of outdoor space around residential buildings. This paper is focused on the influence of varying lateral spacing and serial lengths in residential buildings on ventilation efficiency at various typical positions within the outdoor space. In consideration of the likely impacts from blocking effect of surrounding buildings, the cases were all set with similar surrounding conditions, namely residential districts with similar layouts. As for the residential district types, the slab-type and multi-story buildings are mainly paid attention to as accounting for the largest proportion in current China. To assess the influence of varying designs on ventilation efficiency of outdoor spaces, computational fluid dynamics (CFD) simulation method is adopted, and the calculation tool is ANSYS-Fluent, an extensively used commercial calculation software. As for the evaluation parameters of ventilation efficiency, there are some limitations with layout design researches of partial residential districts due to the fact that MMA is meant for fresh air areas. PFR, VF and TR are employed as indicators to evaluate the ventilation efficiency, which fully reflect air flow features of the calculated domain.

2. Simulation method

2.1. CFD model setting

For the setup of CFD model, the study refers to the guidelines of Architectural Institute of Japan (AIJ) as well as some similar studies (Tominaga et.al 2008, Hang et.al 2015). The computational domain is $5H$ ($H$ is the building height) in lateral spacing and $6H$ in vertical direction. The distances are respectively $5H$ between inlet boundary and buildings and $20H$ between outlet boundary and buildings. Hexahedral elements are applied in the computational domain (about 3 million). The minimum grids in vertical and horizontal directions and maximum expansion factor between grids are respectively $0.022H$, $0.044H$ and $1.15$. The boundaries of air inlet and outlet are respectively velocity-inlet and pressure-outlet. Lateral sides and top are symmetrical boundaries while floor and building walls are non-slipping walls. Inlet vertical wind speed and turbulence distribution are determined according to formula (1) - (3).

\[
U(z) = \frac{U_H(z/H)^{\alpha}}{H} \\
\frac{k(z)}{\mu} = \frac{U_f^2}{C_{\mu}} \\
\frac{\varepsilon(z)}{\mu} = \frac{C_{\varepsilon}^{3/4}k(z)^{3/2}}{\kappa z} 
\]

According to AIJ standard wind tunnel test (Tominaga et.al 2008), in the formula $\alpha=0.25$, thickness of atmospheric boundary layer $\delta=1m$, ground roughness $Z_0=4.8\times10^{-4}h$ ($h$ is the building height), which indicates that thickness of atmospheric boundary layer under actual conditions is $250m$, (scale 1:250), reference wind speed $U_{H}=7.8m/s$, thickness at atmospheric boundary layer $H=\delta$, $C_{\mu}=0.09$, $U_f=0.33$, $K_v$ is Karman constant, which is determined as 0.4.
For selection turbulence model, large eddy simulation (LES) is relatively accurate for simulating wind field characteristics around buildings according to literatures. In consideration of the higher complicatedness and time-consumption of the LES, the more stable RANS model is introduced. Turbulent model is the standard k-ε model [Santiago et.al 2010]. All transport equations are discretized by the second order upwind scheme. The SIMPLE scheme is used for the pressure and velocity coupling. CFD simulations are run until all residuals become constant (equal to or below 1e-05).

2.2. Calculation of ventilation parameters

For calculation of ventilation efficiency parameters, a “homogeneous emission method” is introduced into numerical simulation (Hang et.al 2009). The homogeneous emission method means that pollutant source, such as carbonic oxide (CO) with uniformly distributed emission rate, is set in the studied domain, and the ventilation parameters of the studied domain can be calculated from the local pollutant concentration in certain wind field. As the air flow is not influenced by diffusion of pollutants, the flow field can be firstly calculated and then utilized in estimating the ventilation parameters. So the calculation of ventilation efficiency parameters consists of three steps: First, calculate and obtain flow field within the distribution area; secondly, determine the pollution source of overall or local area according to demand of parameter calculation, and calculate the concentration distribution of pollutants within flow field with mass transfer equation; and thirdly, calculate the parameters of ventilation efficiency via various calculation formulas.

The calculation formulas of PFR (m³/s), VF and TR (s) are as follows [Bady et.al 2008]:

\[ PFR = \frac{q_p}{(C_p \cdot \rho)} \] (4)
\[ VF = 1 + \frac{\Delta q_p}{q_p} \] (5)
\[ TR = \frac{Vol}{(PFR \cdot VF)} \] (6)

Where \( q_p \) denotes pollutant generation rate (kg/s), \( C_p \) stands for domain’s average concentration (kg/kg), \( \rho \) the air density (kg/m³), \( \Delta q_p \) the inflow flux of pollutants into the domain (kg/s) and Vol the domain volume (m³).

As the research deals with ventilation efficiency parameter calculations of different cases in various investigated regions, setting of pollution sources and calculation of ventilation parameters are quite complicated and time-consuming. To improve the calculation efficiency, the user-defined- function (UDF) of ANSYS-Fluent is applied here to help set the pollution sources and post-process the data.

3. Residential building configurations

3.1. Living units and combination

Configuration of residential buildings sizes (width L, depth D and Height H in Fig. 1a) involves the selection of living unit and their combination. Liu and Ding (2012) had made a systematic summary of different types of living units in newly built residential region in China (Liu and Ding 2012). According to their study, three common used living units are selected to compose the multi-floor residential buildings, as shown in Figure 1b. They represent two-bedroom (U1), three-bedroom (U3), and four-bedroom (U3) units. The living unit depth D is namely that of the residential units (D=12m). Building width L is subject to the unit composition. The unit composition types include single-unit composition and multi-unit
composition. The pattern of single-unit composition determines the minimum width of residential units, and residential units with greater width are configured with multi-unit grouping, as shown in Fig. 2c. To simplify the modeling, the partial undulations are excluded from consideration while plane of residential buildings is determined as rectangular, the floors as six in number and 2.8m in height and totaling in 18m in addition of the parapets and height difference between the interior and exterior heights.

<p>| | | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>U1</td>
<td>U2</td>
<td>U3</td>
</tr>
<tr>
<td>Br</td>
<td>Ki</td>
<td>Dr</td>
</tr>
<tr>
<td>M-Br</td>
<td>Ti</td>
<td>Lr</td>
</tr>
<tr>
<td>W=7.2, D=11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W=10.8, D=11</td>
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<td></td>
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<tr>
<td>W=14.4, D=11</td>
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</tbody>
</table>

Note: Br=bedroom, Ki=kitchen, Li=living room, Dr=Dining room, Ti= Toilet

(a) Building size (b) Living unit type and size (c) Unit composition

Figure 1: Living unit and units composition (unit: m)

3.2. Calculated residential buildings group setup

The latest residential districts in China share a noticeable fabric characteristic as shown in Figure 2a. The configuration derives from the designer’s initiative responses to the site shape, functions, sunshine and fire control requirements. Based on the striped fabric, residential building groups arrayed in 3*3 is assumed as the calculation object. The middle group serves as the studied area for the residential building length and varying spacing while the surrounding groups take part too, only as the surrounding conditions. To conveniently divide the grid to attune to the Fluent model, the surrounding groups are all arrayed in 2*3, each building sized 72x11m, with 3~4 units, duly oriented southward, spaced laterally (s1) in 7.2m and longitudinally (s2) in 24m particularly to meet the very sunshine spacing coefficient from the national specification. The road widths around and within the groups (r1 and r2) are set respectively as 24m and 10.8m precisely according to the national specification (GB50180-93 2002).

(a) Residential district fabric in Nanjing (b) Calculated model of residential buildings group

Figure 2: Calculated model setup (unit: m)
3.3. Building lateral spacing and length variation

To investigate the influence of varying building lateral spacing and lengths on the ventilation in outdoor space, two steps are adopted in this study. First, a common used design case is simulated under different wind direction to decide the typical wind directions. Then different cases with varying lateral spacing and lengths are performed in these typical wind directions. As shown in Figure 3, Case A denotes the varying lateral spacing while Case B stands for the varying lengths. The longitudinal spacing is restricted by the sunshine conditions and land use economy, therefore fixed in 24m. To examine the effect of design variables on ventilation efficiency in different domain, some typical areas are selected for comparison. A-R1 and A-R3 represent outdoor space of outer and inner side living units in Case A, B-R2 represent outdoor space of central living units in Case B.

4. Simulation results and analysis

4.1. Influence of wind direction changes

To assess the influence of wind direction on space ventilation, Case A2 is taken as the simulation object with a building size and spacing commonly used in the residential layout design. The wind direction variation is set from south direction ($\theta$=0°) to east ($\theta$=90°), with an interval of 30 degrees. Figure 8 shows the MMA, VF and TR of different domains all through the wind direction variation. It is noticeable that as the wind angle increases, these indices change evidently. VF and TR in all domains decrease while PFR rises rapidly. It implies the ventilation ability improves as the wind direction gradually tends to parallel to the building’s long facade. This is mainly due to the strip-shaped spatial structure with a duly north-south directed ventilation corridor as a result of the sunlight requirement. As the wind direction turns parallel to the ventilation corridor from being perpendicular, the wind flow entering the space between residential buildings increases greatly. However, effect on ventilation efficiency caused by wind direction variation does not show the rule of linear variation. When the angle between building facade orientation and wind direction exceeds 30 degrees, amplitude of variation of ventilation parameters decreases gradually, especially obvious in term of visitation frequency and air resistance time. Taking A-R1 for an example as well, when wind direction turns from south to 30 degrees of southeast, VF and TR reduce by 32% and 79% respectively, while when wind direction turns from 30 degrees of southeast to east, the change range of VF and TR are all blow 1%. What’s more, the ventilation efficiencies of different domains also vary greatly, especially when wind direction is perpendicular to the long facade of buildings. The variation range of VF and TR can respectively reach more than 23% and 32%.
It can be concluded from the simulation that building orientation is an important factor for improving outdoor ventilation of multilayer residential buildings. In the design process the local prevailing wind direction should be seriously considered, and when the angle between the main facade orientation and wind direction exceeds 30 degrees, the ventilation efficiency of different domains improves greatly. So in the following studies, the cases are all calculated in the wind directions of south and southeast 30°.

4.2. Lateral spacing change

Lateral spacing variation (S) also has a certain influence on ventilation efficiency of outdoor space between the buildings, but the influence range varies greatly in different domains. As the study cases are symmetrical in the southward wind direction, three typical domains between the western two buildings are calculated, as shown in Figure 5a-c. The results reveal that the outdoor space of inner side living units (A-R3), which is adjacent to the changing middle space, is more affected by lateral spacing variation. The change range of A-R3 on PFR, VF and TR can exceed 50%, 25% and 35%. However, the outdoor space ventilation of outer side living units (A-R1) and central living units (A-R2), which are far away from the changing middle space, are less affected by the lateral spacing variation. The change range of A-R1 on PFR, VF and TR are 9%, 4%, and 7%, and that of A-R2 are 17%, 1% and 18%. As the lateral spacing increases, the PFR of A-R3 rises gradually. These simulation results show that an increasing lateral spacing can improve the ventilation in limited areas. Besides, when the lateral spacing goes beyond 10.8 meter, the range decreases evidently perhaps as a result of the lateral spacing of the surrounding buildings, which is located in the south of the target area.

In southeast wind direction (30°), the influence of lateral spacing variation on outdoor ventilation of different domains also varies (Figure 5d-f). As the lateral spacing increases, PFR of the domain between buildings at the west end decreases, while that of the east keeps constant. Take the outdoor space of the living units on the inner side (A-R3 and A-R4) for an example, PFR of the west-end domain A-R4 decreases by 20% while that of the east-end domain A-R5 decreases only by 5%. This is mainly because that the wind flow enters from the west side into the in-between space of the south-oriented buildings. And as the lateral spacing increases, more wind flows hit the east interface of the western building, bringing about eddy flows at the building corner, which decreases the wind speed in the very domain.
Figure 5 Influence of Lateral spacing changes on local pollutant purging flow rate, visitation frequency and air resistance time at different domains under (a-c) south and (d-f) southeast 30° wind directions.

4.3. Building length change

Figure 6a–c shows the effects of building length (L) variation on ventilation efficiency in different domains in the south wind direction. As the study cases are also symmetrical in the south wind direction, two typical domains (B-R1 and B-R2) between the two middle buildings are calculated. The simulation results show that as the building length increases, PFR of the outdoor space of middle living units (B-R2) decreases evidently, with variation amplitude of 16%. PFR of the outdoor space of outer side living units (B-R1) initially keeps nearly constant, but when building length reaches more than 50 meters, it increases greatly. The change range reaches as much as 60%. The main reason might be that as the building length increases, domain B-R1 gradually approximates the edge of the study area, which leads to acceleration of wind speed in this domain. Meanwhile, the vortex flow weakens as shown in Figure 6b. As building length increases, VF decreases slightly. So it can be concluded that increasing building length will not benefit the improvement of space ventilation when wind direction is perpendicular to the main building facade, especially for the middle located buildings.

Figure 6d–f shows the effects of building length variation on ventilation efficiency of different domains in southeast wind direction. As building length increases, PFR of the domain B-R3 decreases, while the other two domains B-R3 and B-R4 remain constant. The reason might be the same as that of the building lateral spacing variation. As the domain B-R3 approaches the east side of studied area, more wind flows hit the east side wall of the middle south and north buildings, which leads to more rotation in vortex flow at domain B-R4 as clearly shown in Figure 6e.
5. Conclusion and discussion

This paper discusses the effect of design variables such as orientation, length and lateral spacing on ventilation efficiency of outdoor spaces under the conditions of blocking effect from surrounding buildings. Based on CFD simulation, the pollutant purging flow rate, visitation frequency and air resistance time of different domains are calculated for serial design variation under typical wind directions. These indices show relatively favorable effect of design variables on the ventilation in outdoor space. The findings are concluded as follows.

- Building orientation exerts relatively more effect on ventilation efficiency of outdoor spaces. In the design process, local prevailing wind direction should be considered seriously, and when the angle between building main facade orientation and wind direction exceeds 30 degrees, the ventilation performance of different domains improves greatly.

- Building length has a certain influence on ventilation efficiency of outdoor space. It is especially true for the buildings which are located in the middle of the residential area. Decreasing building length will benefit the ventilation performance of outdoor space around the middle living units when the wind direction is perpendicular to the main building facade, and the improvement of purging flow rate could reach 16%.

- Lateral spacing variation have a relatively limited effect on ventilation efficiency of outdoor spaces and a certain effect on that of two adjacent domains. Besides, the improvements are restricted by lateral spacing of the surrounding buildings, which is located in the windward direction of the studied area.

This research preliminary analyses the influence of several design changes on outside space’s ventilation. Due to urban form complexity, the conclusions are constrained to these studied patterns. In further research, more numerical simulations should be carried out to check whether the conclusions
drawn above changed or not. For example, housing blocks with staggered layout buildings and trees arrangement should be considered in both studied area and surrounding conditions. Building heights variation and leisure square design will also be discussed in the following studies. What’s more, only the predominant wind characteristics are discussed in this study. In subsequent research, local wind rose data should be considered to discuss the influence of annual wind direction and speed variation.

Acknowledgements

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References


Limits of thermal adaptation in cities: a case study of Darling Harbour, Sydney

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Abstract: Climate change projections indicate a likely 3.8°C increase in the average temperature in Australia by 2090. During summer, outdoor heat-stress causes significant thermal discomfort, altering outdoor living preferences. This paper aims to explore the neutral and critical thresholds for outdoor thermal adaptation. The paper reports on outdoor activity change during different outdoor microclimates in Darling Harbour, Sydney. Results indicate that outdoor participants adjust their insulation and activity rate by an outdoor neutral thermal threshold of 28-30°C. For the thermal environments hotter than this neutral threshold, the pattern of adaptation shifts towards modification and dismissal of optional, social and ultimately necessary activities. Such thermal adaptation continues to occur by an outdoor critical thermal threshold of 28-48°C. After the critical thermal threshold, outdoor activity prevention becomes the major thermal adaptation strategy. Therefore, to support usability of public spaces during summer heat-stress conditions, public spaces are required to provide thermal environments closer to neutral and no hotter than critical thermal thresholds.

Keywords: Outdoor activities; public space vitality; thermal adaptation; critical thermal threshold.

1. Introduction

Australia will face a likely 3.8°C increase in surface temperature by 2090 (the worst scenario: A1F1) (CSIRO, 2007). Such an increase in temperature will have a severe impact on regional and local climate systems, natural ecosystems, and human life in cities. Heat stress can reach up to 10°C in urban settings compared to their peri-urban surroundings and is well known as the urban heat island effect (Erell et al., 2011). In response to such substantial extra heat load in cities, people increasingly move into air-conditioned buildings to benefit from the indoor thermal comfort. However, anthropogenic heat –
generated from indoor air-conditioning – causes an ever-increasing outdoor temperature. In this context, this paper aims to examine the limits of thermal adaptation in cities via outdoor activity observation and urban microclimate measurement in Sydney. The questions are: when thermal adaptation starts and what are the neutral and critical thresholds for outdoor thermal adaptation? Such heat-activity investigation informs public space vitality enhancement in the context of warming climate.

2. Thermal adaptation and outdoor activities

Thermal comfort is defined as the state of mind that expresses satisfaction with the thermal environment (ASHRAE-55, 2013). Outdoor heat-stress can cause significant discomfort, altering the frequency and patterns of outdoor activities. While the surrounding built environment can justify the primary microclimate conditions for thermal comfort, it is the human’s perception that justifies if the body is thermally comfortable or it is under stress. Extensive research reveals that microclimate factors of air temperature, humidity, airflow and radiation in addition to human’s metabolic rate and clothing isolation affect thermal comfort in steady state conditions (Stathopoulos et al., 2004; Walton et al., 2007).

The state of adaptation to outdoor microclimates is an influential factor in thermal comfort (Nikolopoulou and Steemers, 2003). Accordingly, thermal comfort is perceptual and alters depending on participants’ physiological and psychological conditions, in addition to physical characteristics of the built thermal environment (Nicol, 1993). People may adapt themselves to microclimate conditions by selective activities such as clothing and sunlight exposure or prevention (Spagnolo and de Dear, 2003). The adaptive thermal comfort concept is multi-variable and complex and discuss thermal comfort not only dependent on microclimate physical factors but also dependent on demographic characteristics such as gender and age, health, psychological states such as happiness and stress (Szokolay, 2008), adaptive actions (e.g. clothing), and general expectations of the climate (de Dear et al., 1991; Candido, 2011).

3. Thermal thresholds of outdoor activities

Outdoor thermal comfort is an emerging field of research. Outdoor environments can not be controlled with ease and accuracy and therefore, outdoor thermal comfort studies are always accompanied by complexity and uncertainty. Extensive thermal comfort research indicates that there are temperature ranges, in which the need for thermal adjustment is perceived to be neutral by more than 80% of the space participants (ASHRAE-55, 2013). In such thermal environments, occupants feel neither warm nor cold, and therefore, the ambient thermal conditions are perceived as ‘neutral’ (Nikolopoulou and Steemers, 2003, p. 98).

The threshold for thermal neutrality – measured by standard effective temperature (SET) – is suggested to be 24.1°C for indoor steady state conditions (Höppe, 2002, p. 661). However, research in European context reveals up to 10°C variation in outdoors thermal neutrality in different European cities (Nikolopoulou and Lykoudis, 2006). A thermal comfort investigation in Sydney suggests that neutral temperature threshold in semi-outdoor environments (naturally ventilated buildings) is OUT_SET=26.2°C (Spagnolo and de Dear, 2003). Another Australian outdoor thermal comfort research reports comfortable outdoor temperature in summer varies between the minimum of 19.9°C (in Melbourne) and the maximum of 30.6°C (Adelaide in) (Loughnan et al., 2012). Outdoor thermal environments change more rapidly compared with indoors. There is also limited chance to control the
participants in outdoor environments. Heat sensitivity of outdoor activities may include changes in outdoor activity patterns, activity locations and in extreme conditions activity elimination.

3.1. Outdoor neutral thermal threshold (NTT_{out})

Heat sensitivity of outdoor activities starts after a determinable neutral thermal threshold (Spagnolo and de Dear, 2003; ASHRAE-55, 2013), and is referred to as the outdoor neutral thermal threshold (NTT_{out}) in this paper. The NTT_{out} can be effectively determined based on the observation of thermal sensitivity of participants’ activities (Nikolopoulou and Lykoudis, 2007). Progressive outdoor activity-comfort research suggests that thermal adaptation occurs more frequently and significantly outdoors (Lin et al., 2011; Chen and Ng, 2012). Such thermal adaptation can be highly complex and occurs due to a higher degree of freedom, choices and flexible climate expectations compared with what may be experienced indoors (Nikolopoulou et al., 2001).

The NTT_{out} indicates the equivalent temperature threshold, after which significant decrease in outdoor activities occurs (the causes of such outdoor activity decline are not focused in this research). The NTT_{out} may be identified as the breakpoint in the temperature-activity regression model. Segmented regression analysis (also known as piecewise regression) is the mathematical method to distinguish the breakpoints in the temperature-activity model. The breakpoint of the best-fit model is the most accurate value to indicate the NTT_{out}.

3.2. Outdoor critical thermal threshold (CTT_{out})

Public spaces may experience zero-activity condition after a critical thermal threshold. This critical zero-activity condition may be determined via experiment or projected data. The possible zero-activity condition is expected to occur after a certain outdoor thermal thresholds. Nevertheless, such critical zero-activity situations have uncertainty, due to the unpredictability of human behaviours. If the NTT_{out} is assumed as the first thermal environment measure, the outdoor critical thermal threshold (CTT_{out}) is its complementary measure. The CTT_{out} explains the limits of outdoor thermal adaptation.

4. Materials and methods

This paper investigates outdoor neutral thermal thresholds in sample public spaces of Sydney. Cities with temperate climate represent useful examples to study outdoor thermal discomfort and its social consequences in Australia. More than 60% of Australian population live in cities with temperate climate including Sydney, Melbourne and Adelaide (BOM, 2008). Furthermore, outdoor thermal comfort investigation in climate conditions, where people experience diverse outdoor thermal environments, can give more accurate results compared with more static climate conditions such as tropical and cold climates (still contextual investigations are required for less diverse climates).

The City of Sydney is selected as urban context for case study public spaces. The city of Sydney experienced record temperature of 45.8°C in 2013. As Table 1 shows, the January-February maximum mean temperature in Sydney was above 27°C between 2010 and 2015. The number of days with the maximum temperature above 27°C reveals that the summer temperature in Sydney frequently passes the outdoor thermal comfort threshold of 26.2°C, as claimed by Spagnolo and de Dear (2003, p. 721).
Table 1: The climate profiles of Sydney in summer (BOM, 2008, p. 42, 43)

<table>
<thead>
<tr>
<th></th>
<th>Latitude (d°)</th>
<th>Longitude (d°)</th>
<th>Record temp. max. (°C)</th>
<th>Days with max. temp. &gt; 27°C</th>
<th>Climate 2010-2015</th>
</tr>
</thead>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Temp. January-February (°C)</td>
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<tr>
<td>Sydney</td>
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<td>151.20</td>
<td>45.3</td>
<td>502</td>
<td>Mean min. 20.3</td>
</tr>
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<td>Standard deviation 1.9</td>
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<td></td>
<td></td>
<td>Mean max. 27.6</td>
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<td></td>
<td></td>
<td>Standard deviation 3.9</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Annual mean 19.0</td>
</tr>
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</table>

4.1. Case study public spaces

Darling Harbour is selected as a multi-functional and contemporary public space complex for this outdoor heat-activity study. Data were collected in three observation points. The observation points in Darling Harbour were Friendship Plaza, Darling Quarter and Darling Harbourside. These public spaces present three contemporary multi-functional public spaces with microclimates and activity diversity (see Figure 1). Selected data collection sites also vary in their spatial configurations. All of them provide public sitting facilities, wide walkways and supporting land uses. Each site covers an approximate area of 5000m² and is a major outdoor activity hub in Darling Harbour. One researcher observed all outdoor activity patterns, inserted results manually on paper, coded activities and recorded microclimate measures in all public spaces.

Case study public spaces were monitored from February 2013 to April 2014. The long duration of data collection facilitated a well-distributed activity observation in a wide range of thermal conditions and different seasons (temperature between 18°C and 42°C). Data were collected in five-minute intervals during hourly periods in daily working hours. Observation data were collected via fixed station (for walking activities) and mobile traverse (for stationary activities) methods. Changes in outdoor activities in each public space in different thermal environments are focused (rather than comparing public spaces) to minimise the effect of space design and public facilities on the results.

Figure 1: Friendship Plaza, Daring Quarter and Harbourside are three public spaces of Darling Harbour. and have diverse space configurations, and supportive land uses (Photos: Author, November 2014)
Observations were limited to working hours between 9am to 5pm during weekdays to ensure data consistency. The patterns of outdoor activities vary during weekends and after working hours. Activity patterns and users of the public spaces change significantly during weekends (weekend activities can still inform some aspects of the public life but are out of the scope of this study). Therefore, weekends and public holidays are not included in the final data. Rainy and stormy days were also excluded.

4.2. Outdoor activity classification

Gehl classifies outdoor activities into three major types of necessary, optional and social (Gehl and Svarre, 2013). Necessary activities are related to unavoidable occasions in daily life. Optional activities take place only if the physical environment and time conditions are optimal for humans, and social activities (or resultant activities) occur due to the presence of a group of people in public space. Gehl (1987, p. 11) argues that optional activities are the only ones that are influenced (notably) by urban microclimates. Gehl’s studies on quality of public space and public life do not consider climate (long-term) and weather (short-term) as effective variables (respective case studies are done on sunny days in spring and autumn) (Gehl, 2007).

Observed outdoor activities are documented in walking, working, standing, sitting, eating, reclining, jogging, cycling, children playing, sports and group games, music play and other cultural activity subgroups. The location and quantity of each activity were printed on data collection sheets and summarised in activity frequency charts. Observed outdoor activities were then coded into necessary, optional and social activities and printed on data collection sheets.

4.2. Universal thermal comfort index

The universal thermal comfort index (UTCI) is an advanced outdoor thermal discomfort indicator - based on multi-node effect of the thermal environment on human’s thermoregulatory system which is developed exclusively for outdoor application and is increasingly used in experimental outdoor thermal comfort research (Höppe, 2002; Bröde et al., 2012). The UTCI is defined as the air temperature of the reference environment that provides a similar physiological response to the complex outdoor thermal environment. Effective parameters are air temperature, humidity, wind speed, radiant temperature, and adaptive clothing (Bröde et al., 2012, p. 483). A complete adaptive UTCI model considers details such as individual’s weight, body surface area, and exposure time that are not focused in this paper due to the large scale of the study and limited time frame. Therefore, the simplified UTCI values are used in this paper which are calculated at http://www.utci.org/.

5. Results and discussion

Distribution of outdoor activities in Friendship Plaza, Darling Quarter and Harbourside is presented in Figure 2. As shown, necessary activities are dominant in Darling Harbour particularly in Friendship Plaza at the rate of 78%. Optional and social activities combined almost equals to necessary activities in Darling Quarter. The dominance of necessary activities in Friendship Plaza and Darling Harbour may be due to the high volume of pedestrians who use these public spaces for their daily home-education and home-work journeys. Darling Harbour is a tourist attraction in the City of Sydney and has a considerable number of daily tourists including urban and state-wide and interstate visitors. However, public space visitors are commonly looking for optional and social activity opportunities. Except Darling Quarter such optional and social activity opportunities are mainly provided indoors in Darling Harbour.
The correlation coefficient analysis of necessary, optional and social activities in Darling Harbour reveals that necessary and social activities in Friendship Plaza and Harbourside have a weak correlation to increased UTCI in Darling Harbour ($r$-values $< 0.3$). The quantity of necessary, optional and social activities has a positive correlation (weak to medium) to increased UTCI in Darling Quarter. Weak positive correlation also exists for necessary activities in Harbourside.

**Table 2: heat-activity correlation coefficient ($r$) values in Darling Harbour, Sydney (UTCI > 18°C)**

<table>
<thead>
<tr>
<th>Heat-activity r-value</th>
<th>Necessary activities</th>
<th>Optional activities</th>
<th>Social activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friendship Plaza</td>
<td>-0.05</td>
<td>-0.56</td>
<td>-0.18</td>
</tr>
<tr>
<td></td>
<td>Neutral</td>
<td>Strong negative</td>
<td>Weak negative</td>
</tr>
<tr>
<td>Darling Quarter</td>
<td>0.46</td>
<td>0.34</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>Medium negative</td>
<td>Weak positive</td>
<td>Medium negative</td>
</tr>
<tr>
<td>Harbourside</td>
<td>0.11</td>
<td>-0.15</td>
<td>-0.05</td>
</tr>
<tr>
<td></td>
<td>Neutral</td>
<td>Weak negative</td>
<td>Neutral</td>
</tr>
</tbody>
</table>

The distribution of outdoor activities in UTCI thermal spectrum in Friendship Plaza, Darling Quarter and Harbourside is presented in Figure 3. None of the initial regression models has reliable heat-activity $R$-squared scores for the total thermal spectrum. Darling Quarter had its maximum activities between 30°C and 35°C, whereas other case studies that experienced their peak activity conditions between 25°C and 30°C. Necessary, optional and social activities show positive regression with increased temperature in Darling Quarter (15°C < UTCI < 38°C). This might be due to the lack of outdoor activities in lower temperatures or being attractive at higher temperatures. Low $R$-squared scores make this statement uncertain. More accurate segmented regression models can give more reliable approximations in Darling Harbour. Nevertheless, any generalisation of the models requires similarity in climate, spatial and social context.
5.1. The effect of UTCI on necessary activities

Friendship Plaza had the average 84.2 necessary activities in every 5 minutes for 18°C<UTCI<30°C, which decreased to 64.9 for UTCI>30°C. In a similar pattern, average 120.7 necessary activities occurred (every 5min) in Harbourside for 18°C<UTCI<30°C, which decreased to 96.4 for UTCI>30°C. However, the average necessary activities (every 5min) had a slight increase for UTCI>30°C in Darling Quarter (162.4 before 30°C and 166.7 after 30°C). Maximum necessary activities in Friendship Plaza and Harbourside start to decrease constantly from NTT\textsubscript{out} = 28°C. The best fit segmented regression model extends such thermal neutrality in Darling Quarter by additional 2°C (NTT\textsubscript{out}=30°C). However, it does not provide a reliable R-squared score for future predictions (R-squared = 0.35). Full spectrum heat-activity model of Darling Quarter indicates uncertain positive regression, while segmented regression model shows uncertain negative dependency for UTCI < 28°C. None of these models can provide statistically reliable predictions for necessary activities in Darling Quarter (the later model suggests CTT\textsubscript{out}=48°C).

Friendship Plaza loses 2.4% of its necessary activities for each 1°C of temperature increase for UTCI > 28°C. In similar thermal conditions, Harbourside loses 2.5% of its necessary activities for each 1°C increase in UTCI. Both Friendship Plaza and Harbourside are expected to experience their critical zero-activity condition at CTT\textsubscript{out}=40°C. In segregated linear regression models of the number of necessary...
activities and UTCI in Friendship Plaza and Harbourside, p-values are less than 0.001 and R-squared values are greater than 0.5 (see Table 3 and Figure 3). Therefore, the models can be considered reliable to predict future scenarios. To address the likely 2.4°C overall warming in Australia by 2030 (CSIRO 2007) and the highest record temperature of 45.3 in Sydney (in 1939) the value of 48°C is used as the NTT_{out} and CTT_{out} for highly heat-resilient public spaces with unknown neutral and critical thermal thresholds in this study.

5.2. The effect of UTCI on optional activities

Friendship Plaza had the average 25.5 optional activities (every 5min) for 18°C<UTCI<30°C, which decreased to 13.9 for UTCI>30°C. In a similar pattern, average 66.4 optional activities occurred (every 5min) in Darling Harbourside for 18°C<UTCI<30°C, which decreased to 32.3 for UTCI>30°C; and an average of 104.0 optional activities for 18°C<UTCI<30°C decreased to 87.0 for UTCI>30°C in Darling Quarter. The distribution of optional activities in Darling Quarter is similar to necessary activities. They peak at 30°C < UTCI < 35°C (5°C higher than other public spaces), have uncertain positive regression to increased temperature (15°C < UTCI < 38°C) and uncertain negative dependency to heat-stress. However, optional activity decreases constantly after NTT_{out}=28°C in Friendship Plaza and Harbourside.

Regression models of optional activities for UTCI > NTT_{out} indicate that the decrease in optional activities for each 1°C decrease in UTCI varies between 2.5% in Friendship Plaza to 2.8% in Harbourside (Darling Quarter does not show any meaningful decrease). The CTT_{out}=38°C in Friendship Plaza and 36°C in Harbourside (see Table 3). However, no reliable indication of NTT_{out} and CTT_{out} is identifiable from this observation for Darling Quarter. It means that optional activities in Darling Quarter are less heat sensitive than the other two public spaces of Darling Harbour.

5.3 The effect of UTCI on social activities

Not many social activities occurred in Friendship Plaza and Harbourside during the observations. The very limited social activities in Friendship Plaza (average=1.1 in 5min) and Harbourside (average=0.2 in 5min) for 18°C<UTCI<30°C completely dismissed for UTCI>30°C. However, social activities remained almost constant in Darling Quarter with the average of 41.1 for 18°C<UTCI<30°C, and 36.8 for UTCI>30°C. Many zero-activity conditions in Friendship Plaza and Harbourside indicate existing critical conditions in these two open spaces even during ideal climate conditions. Such critical zero-activity conditions frequently occurred after CTT_{out} = 28°C in Friendship Plaza and CTT_{out} = 30°C in Harbourside.

Table 3: Statistical significance (p-value) and coefficient of determination (R2) of activities to universal thermal comfort index (UTCI) after the outdoor neutral thermal threshold (NTT_{out}) in Darling Harbour

<table>
<thead>
<tr>
<th></th>
<th>Necessary activities</th>
<th>Optional activities</th>
<th>Social activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NTT_{out}</td>
<td>CTT_{out}</td>
<td>NTT_{out}</td>
</tr>
<tr>
<td>Friendship Plaza</td>
<td>28°C</td>
<td>p&lt;0.001</td>
<td>40°C</td>
</tr>
<tr>
<td></td>
<td>R²=0.60</td>
<td></td>
<td>R²=0.60</td>
</tr>
<tr>
<td>Darling Quarter</td>
<td>30°C</td>
<td>p=0.015</td>
<td>48°C</td>
</tr>
<tr>
<td></td>
<td>R²=0.35</td>
<td></td>
<td>R²=0.42</td>
</tr>
<tr>
<td>Harbourside</td>
<td>28°C</td>
<td>p&lt;0.001</td>
<td>42°C</td>
</tr>
<tr>
<td></td>
<td>R²=0.59</td>
<td></td>
<td>R²=0.55</td>
</tr>
</tbody>
</table>
There is an uncertain negative regression between social activities and UTCI in Darling Quarter in UTCI > 30°C (R-squared = 0.30). However, full spectrum heat-activity model in Darling Quarter indicates an uncertain positive regression (R-squared = 0.21). Similar to necessary and optional models, social heat-activity model does not provide enough confidence for CTT_{out} projections in Darling Quarter. Meanwhile, social activities were observed to increase during heat-stress conditions in Darling Quarter, when it experienced 30°C < UTCI < 38°C. As such, social activities are sensitive to heat-stress in Darling Quarter, but not in the expected direction. Therefore, Darling Quarter may be assumed as a social activity hub during heat-stress conditions.

5.4. Limitations in the projection of NTT_{out} and CTT_{out}

Projected outdoor heat-activity critical limits and thermal thresholds (CTT_{out}) depend on the assumption that the form of relationship is maintained at higher temperatures than observed. The estimation of future heat-activity patterns may experience another step change. Since the thermal environment becomes extremely uncomfortable for humans in UTCI > 45°C, sudden step changes (new breakpoints) at higher temperatures are probable (Bradshaw, 2010).

A possible step change in activities during extreme heat-stress conditions could make Darling Harbour very hard to access. Such probable (and experienced) step change refers to the prominent avoidance of outdoor activities resulting from the extreme heat-stress in public space. In such circumstances, people may not participate outdoors at all; and to access entertainment, recreation or shopping attractions people are required to walk over extremely hot urban surfaces for a distance. Nevertheless, any generalisation of the models requires similarity in climate, spatial and social context.

6. Conclusions

Outdoor activities are sensitive to heat-stress and start to dismiss from the public space after a determinable neutral thermal threshold, denoted the NTT_{out}. A range of 28-30°C is identified for NTT_{out} in Darling Harbour, Sydney. Necessary and social activities have higher neutral thermal thresholds compared with optional activities. While changes in outdoor activity patterns are noticeable after the NTT_{out}, significant changes in public space vitality take place after a critical zero-activity threshold, denoted the CTT_{out}. The CTT_{out} can have more variations between 28°C and 48°C. Spatial configurations and supportive land uses can extend the CTT_{out}. The NTT_{out} and CTT_{out} are highlighted as two key measures for public life vitality assessment during heat-stress. They indicate the extent of public life resilience to outdoor heat-stress. In the context of climate change, heat-resilience in public space can support more vibrant and healthy urban environments in cities. Such spatial heat-resilience supports the usability of outdoor spaces by local communities in warmer scenarios.

Acknowledgements

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References


Street Networks and Finite Boundaries: Modelling the unique evolution of Malé

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Abstract: The paper provides a quantitative assessment of the historic evolution of street networks based on a unique case-study, the street networks of Malé. The street network is Male is a result of the geographic limits of the island city and currently supports an extraordinary population density of 41,000 per sq km, the highest in the world. This paper revisits the role of architectural science in the design and practice of urban modelling through the spatio-temporal investigation of the street network. Street formation is an indirect measure of the intensity of land-use and development. By tracing the formation of street networks, the paper presents quantitative results on the intensification of the finite space over time. Street networks are represented as a graph, whose edges represent edges and nodes represent junctions. The findings of the study provide a quantitative signature of the temporal evolution of the street system reveals the existence of two dynamic mechanisms that drive the evolution of the road network over time, namely plot subdivision (intensification) and reclamation (exploration). A summary of the street network metrics shows a continuous change in the growth of the road network between 1920 and 2011.

Keywords: City modelling; Street Networks; Computational Urban Dynamics; Connectivity Analysis.

1. Introduction

The classical role of architectural science has been the investigation of the relationship of human comfort to the built environment. The primary methodologies have evolved from the domain of building physics and environmental studies. More recently, attention has been drawn to urban microclimates and larger scale phenomena such as Urban Heat Island effects. Streets play a central role in the spatial organisation of urban settlements (Shouri et al, 2009). The networks formed by streets are an important contributor to the evolution of urban systems (Pitts et al, 2013). Like all urban processes, streets are continually subject to the forces of change and transformation. Empirical investigations of the dynamics of urban change can provide quantitative measures of the basic mechanisms governing the formation of street networks (Mimi et al, 2010).
The paper provides a quantitative assessment of the historic evolution of road networks based on a single case-study, the unique street networks of Malé. The city of Malé, the capital of the Maldives, is a unique settlement for understanding urban evolution. Malé occupies a 2 sq km island about 2m above sea level and is continuously growing inside a very small and finite boundary. The combination of the geographic limits of the island city and urban growth currently supports an extraordinary population density of 41,000 per sq km.

This paper examines the development of urban form based on the spatio-temporal analysis of street networks. Street formation is an indirect measure of the intensity of land-use and development. The paper presents quantitative results on the intensification of existing space over time through the formation of street networks. An urban environment can be topologically represented as a connectivity graph or space-space topology by mapping the line segments to nodes and the intersections to links. Street networks are represented as a graph, whose edges represent edges and nodes represent junctions.

A large number of studies have established that streets, like urban form, are subject to the forces of change and transformation (Doxiadis, 1970). The analytical tools of network science (Newman, 2003) can be applied for the quantitative characterization of street patterns. For example, Strano et al (2012) study the evolution of street networks over two centuries in a large urban area in Northern Italy. They suggest that the evolution of road networks is governed by two simple spatial mechanisms, namely, densification and exploration. Street patterns and their evolution in traditional cities have also been empirically studied using network models. Karimi et al (2003) investigate “grid dynamics” in the world heritage city of Isfahan through a comparative study of the city in the 17th and 20th centuries. Shpuza (2009) reports on the evolution of street networks in Adriatic and Ionian coastal settlements between 1769 and 2007. Furthermore, contemporary street networks have also been the subject of analysis by these same methods (Al-Sayed, 2014).

Axial maps (Turner et al, 2004) are a visual and formal description of street connectivity to understand and compute measures that characterize the spatial layout of street networks. The representation and analysis of axial maps using tools of space syntax, provide an evidence-based approach to analyzing spatial layouts of buildings and cities through the study of connectivity of places (Hillier, 2007; Griffiths, 2014). A street can be represented as a number of longest visibility line segments or axial lines. Axial lines are basically the ‘longest visibility lines for representing individual linear spaces in urban environments’ (Liu and Jiang 2011, 1) or ‘the longest line that can be drawn through an arbitrary point in the spatial configuration’ (Turner et al, 2004, 426). The collection of these line segments form an axial map. There are numerous measures generated by an analysis in DepthMap. From an analysis of axial maps, measures of node, depth, integration and connectivity (described in the following section) can be extracted from the data and the comparative analysis of these measures are presented as tabulated graphs.

2. Urban Dynamics and Street Networks

The network approach, describing a set of nodes connected by links, is a very useful framework to represent physical, biological and social systems. This methodology is well-established in the literature of network analysis and has been recently applied to spatial networks (Strano et al, 2012; Davis et al, 2014). A street network is the collection of streets, roads and paths within an urban area. Followed by the division of Male’ as explained above, axial maps for all division of the 6 stages were produced. Taking each individual street and space as an axial line generates the Male Axial Map. This map provides
a skeletal approximation of the street network. i.e. a connectivity graph where the nodes represent streets and the links correspond to street intersections. The Analysis Framework for modelling street network data as a series of time slices and generating network graphs where streets are represented by nodes and their intersections by edges. Each slice is processed for network connectivity, accessibility and degree of integration. The network representation and its topological metrics represent the toolbox of urban dynamics (Figure 1).

The following metrics are used for the street network analysis.

2.1. Node Connectivity

Connectivity of a street (node) measures the number of immediate neighboring streets that are physically connected to the street. The graph representation provides a measure of the degree of connectedness of a space to another. This measure depends on the node count, the approximate number of streets in a given layout. Mean Connectivity measures the average number of connections any given street has to other streets in the network. Max Connectivity measures the highest number of connections any given street has to other streets in the network. For example, connectivity is equivalent to local depth when s=1 (neighboring street intersections).

2.2. Depth and Access

For any given pair of streets (nodes in the connectivity graph), depth is defined as the number of shortest number of steps needed to reach one from the other. Depth measures the shortest distance s, (steps) to the neighboring streets. Mean Depth measures the average depth between any two streets in a given network. This measure captures the spatial depth of a street network and is an indicator of accessibility.
2.3. Global and Local Integration

Integration is a measure that describes the average depth of a street to all other streets in the network. It was originally defined in Hillier and Hanson (1984) as a normalization of the mean depth measure. Integration allows all streets to be ranked from the most integrated to the most segregated. Mean Integration (Global-$R_n$) and Mean Integration (Local-$R_3$) are two measures that quantify how a street relates to its local neighbourhood to a depth of 3 and then to the whole network (max depth).

3. Street Evolution of Malé 1922-2011

In this section, Male’s urban growth is mapped using the above framework approach to measure the depth, connectivity, integration and in turn efficiency of street layouts. The approach here is to analyse the spatial structure of Male’ over time, as a basis of understanding its growth. A longitudinal study of Male's street network and block structure over a 90 year period is undertaken in six time slices between 1922-2011 (Figure 2). The street network data and analysis of Male has been developed on the basis of a collection of historical aerial images, historical maps and planning data.

Male' has an organic core or the Old City, which was the only part of the city that was existing in 1922. The New City has been built around this old core, mostly to the South and West of the Old City.
Male’ urban growth occurred in the later part of this period. The analysis is applied on three divisions to all six stages:

Old City – Because Male’ has gone through land reclamation quite rigorously in relation to the size of the island, any other urban growth process could be falsely be assumed as associated with land reclamation. To overcome this problem, the Old City area is extracted from the city map in all of the six stages to analyse the changes or growth within the Old City.

New City – Extracting the New City for analysis can reveal characteristics that belonged to either the Old City or the New City. This would be difficult to achieve in a Whole City analysis alone.

Whole City – This considers the whole island at all of the six stages.

3.1 Street Network Evolution 1922-1960

In 1922, the street network (188 nodes) comprises a single relatively well integrated (Rn=1.77 and R3=2.09) street with a max connectivity measure of 38 and mean connectivity of 3.97. By 1960, the node count has increased to 220. Smaller crossing streets have appeared. These changes serve to better integrate the network with slight increases in all network metrics and the structure of the network remains stable (Figure 3).

![Street Network Evolution: Comparison of Old City](1922.png)

Figure 3: Street Network Evolution: Comparison of Old City, showing the visual network map with parameters at two time slices, 1922 and 1960.

3.2 Street Network Evolution 1979-1986

In the case of Male, this period marks a radical departure from the previous 70 years of continuous expansion towards a new type of configuration (Figure 4). The most significant changes in the street network of Male are seen in the two decades between 1979 and 1999. The New City has grown substantially on land reclaimed from the sea. Two significant East-West streets running the whole length of the island have appeared in parallel to the Central Street in the Old City. The new street network, following on from the active land reclamation, is a rectilinear grid. During this period, the street count...
climbs dramatically, almost doubling in a 25 year period from 225 (1960) to 415 (1986). The depth of the network increases to 7.2 with network integration dropping slightly (Rn=1.84 and R3=2.19). Max connectivity increases to 46 while mean connectivity also drops slightly to 3.96 (Figure 4).

Figure 4: Street Network Evolution: Comparison of the visual network map with parameters at two time slices, Old City (1979) and Whole City (1986).

3.3 Street Network Evolution 1999-2011

The most central streets in the network in 2011 largely coincide with the oldest ones (Figure 5). As shown in the study of Strano et al (2012), the oldest central road of Male appears to constitute a persistent backbone that increases in importance over time. The evolution of the core road system, with the addition of 51 nodes is a continuous expansion and reinforcement of old and new structures (Figure 5).
4. Urban Dynamics Analysis

By reconstructing the historical topographical and mapping data into a computational environment, we constructed the detailed road system (including minor streets) at six different points in time, \( t = 1, 2, \ldots, 6 \), respectively corresponding to years: 1922, 1960, 1979, 1986, 1999 and 2011. For each time, \( t \), an associated axial map is constructed. The geographical information sources used to construct the primal graphs. They were then imported into DepthMap to generate the topological measures tabulated for ease of analysis as shown in Table 1.

The findings of the study provide a quantitative signature of the evolution of the street network in Male, the capital city of the Maldives. The quantitative analysis of the temporal evolution of the system reveals the existence of two dynamic mechanisms that drive the evolution of the road network over time, namely plot subdivision (densification) and reclamation (exploration) dynamics. A summary of the street network metrics shows a continuous change in the growth of the road network between 1920 and 2011 (Table 1). It was identified in the 1922 map of Male’ that there were only about 168 streets in contrast to 329 streets in 2011. In a span of about 90 years the number of streets has almost doubled. This may seem like a reasonable increase when the land area of Male’ too has almost double in those 90 years. Most changes within the Old City area in terms of street count have occurred from 1960 – 1979. While the city exhibits a relatively consistent set of metrics showing stability of the street evolution, a different picture emerges when the relative contributions of each of the components are analysed. A comparison of Old and New street networks to the Whole of Male is shown in Figure 6. Interestingly, node creation climbs dramatically in a relatively short period of time between 1979 and 1986. The new streets introduced that appear in time slice \( t=4 \), are planned on a grid unlike the organic character of the older street network. The number of nodes on the network almost doubles (220 to 415). The snapshot of the network in 2011 shows increasing node count (466), almost unchanged depth and max
connectivity and slightly decreased mean connectivity to 3.78. The integration of the street network changes marginally (Rn=1.86 and R3=2.21).

Table 1: Street Network metrics, Whole City of Male 1922-2011.

<table>
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<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Node Count</td>
<td>188</td>
<td>220</td>
<td>295</td>
<td>415</td>
<td>415</td>
<td>466</td>
</tr>
<tr>
<td>Mean Depth</td>
<td>6</td>
<td>6.4</td>
<td>6.6</td>
<td>7.2</td>
<td>7.2</td>
<td>7.2</td>
</tr>
<tr>
<td>Max Connectivity</td>
<td>38</td>
<td>41</td>
<td>47</td>
<td>46</td>
<td>47</td>
<td>47</td>
</tr>
<tr>
<td>Mean Connectivity</td>
<td>3.9681</td>
<td>4.2273</td>
<td>4.0407</td>
<td>3.9614</td>
<td>3.8182</td>
<td>3.7897</td>
</tr>
<tr>
<td>Integration (Global-Rn)</td>
<td>1.7722</td>
<td>1.9542</td>
<td>1.9252</td>
<td>1.8427</td>
<td>1.8580</td>
<td>1.8650</td>
</tr>
<tr>
<td>Integration (Local-R3)</td>
<td>2.0986</td>
<td>2.2669</td>
<td>2.2709</td>
<td>2.1964</td>
<td>2.2062</td>
<td>2.2135</td>
</tr>
</tbody>
</table>

The spatial depth of the city is almost entirely contributed by the Old City. The connectivity of the new city is better and contributes to the relative stability of the network connectivity. The integration of the new city is high while the integration of the old city drops significantly over the study period. In conclusion, the network metrics track the continuously changing urban street characteristics as they dynamically evolve over time.

Figure 6: Evolution of the Street Network of Male, 1922-2011 showing the Old City (red), New City (green) and the Whole City (blue).

5. Discussion

Using network measures, we characterise the dynamic structure of street networks over time. The continuous change that we have reported in Male’s streets reflects the radical changes in urban form
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that have occurred during its transition from a tropical island settlement to a modern city. Male is an example of street evolution that builds at each step on the characteristics of older streets by a process of expansion, sometimes radically, such as the introduction of main streets and the urban grid. More importantly, Male also is an example of a network structure that tends to change through a process of intensification where new streets are carved out within the existing structure. At this stage, these results cannot be generalized to the larger processes of urbanisation. The results from Male are highly specific. Our findings support the hypothesis that street networks undergo fine-grained local dynamics of change, continuously expanding upon a stable backbone of structures (Strano, 2012). They include the persistence of older streets, the formation of a “stable backbone” of highly integrated (central) streets, the formation of a grid network on the land reclamation areas and finally the densification of streets through subdivision of land parcels.

First, the findings are limited by assumptions such as the definition of the streets as a graph representation of streets (node) and their connections (edges). Additional network and topology measures (e.g. centrality), better integration of street dimensions such as lengths, widths and volumes are necessary to improve and tune the representation. Finally, the validation of data and models with other spatial network models and empirical measures are needed. For example, the correlation of urban micro-climate effects with street form, size and composition; thermal variation across streets and the role of the spatial characteristics of streets in the mitigation of Urban Heat Island (UHI) effects can be developed. The development of predictive models will significantly increase the applicability of computational urban dynamics to the problems of urban growth, density and sprawl. The establishment of the physical limits of urban land-use and density is an important criterion for the development of compact settlements. While a vast variation in settlement size and density can be observed in studies of settlement form, relatively few studies have been undertaken on how cities grow within finite boundaries. The city of Male provides an opportunity for understanding the effect of finite boundary metrics in the growth of human settlements. Computational methods such as those presented here can assist in the development of metrics that permit the study of urban growth within finite boundaries.

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References


Form follows food: an examination of architecture’s role in urban farming

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Abstract: With rising global urban populations, existing food infrastructure systems are rapidly becoming unsustainable. Increasing distances between rural food production and urban residents extends to a conceptual divide and misguided understanding of what activities ought to be classed as ‘rural’ versus ‘urban’. Some of those looking for alternative solutions note food’s potential to act as an organiser of urban systems and catalyst for change. Tapping into this potential, architects and designers have been using urban farming as a vehicle to speculate about “green” futures. However, sustainability is often sidelined in photorealistic renders where designs are ‘decorated’ with organic matter, designs that are unlikely to be viable. The paper critiques current practices in relation to this important social, economic and ecological infrastructure. Historic and contemporary precedents at various stages of the food cycle, from how it is produced to where it is consumed, are introduced. The paper goes on to discuss the potential for urban farming, trading and consumption to contribute to a sense of place through architectural interpretation. While widening the discussions of food and the city, architecture provides the built accommodation for both plants and people, so that the ‘urban future’ can be revaluated.

Keywords: urban food production; diversifying food space; architecture’s role in urban farming; food system visibility

1. Introduction

Food can be considered a universal language, a form of dialogue. But this language of food is not always understood or accepted in urbanised areas because of preconceptions around those activities considered either rural and urban. Steel’s Hungry City speaks of an ‘urban paradox’ in drawing attention to the failure of cities to recognize that they remain reliant on the land for their sustenance. Conversations around food and the city often centre on consumption – the buying and eating of food at tempting new stores, along with the fashionable ‘foodie’ culture that has emerged. Seldom discussed are the production or waste stages of the food cycle. On the one hand, food is glamourized and celebrated as it is being consumed while on the other, its full cycle is discussed in some kind of “shock horror exposé” (Steel, 2008, p. 4). The framing of contemporary urban food culture suggests that some activities are less worthy for discussion, possibly because of the near invisibility of a sustainable food system in the urban environment altogether.
Dining out can be a pleasurable experience, evidence in most cultures of a prosperous lifestyle and helping to foster streetlife. The presence of food can often generate a feeling of intimacy between people (Franck, 2002, p. 5) and helping link people to public spaces. Public eateries are important urban ‘third’ places; semi-public places of refreshment where one can visit regularly to linger and socialize (Oldenburg, 1999). It seems that public eateries have grown to become expected in all urban settings, whether for gathering socially or for convenience.

The idea of bringing a complete food system into cities – from its production to the way it is ultimately disposed – has begun to emerge as a common theme across multiple disciplines. In architecture for example, the design and planning of urban systems has begun to see food as a potent element. Urban farming is often seen as the foundation for such design constructs, though many projects remain speculative due to lack of financial feasibility. On the other hand, urban farming that has been established is often utilitarian in nature, placing little emphasis on architectural design examples include commercial rooftop greenhouses, which are designed to create optimal growing conditions but which generally contribute little to the surrounding cityscape. The relationship between urban farms and urban centres is consequently undervalued, a missed opportunity to enrich cities with an identity of a local sustainable food culture.

This paper takes the form of a literature review and speculative exploration of the potential for farming activities to enrich our experience of urban places. It examines the economic and psychological gaps that currently exist between producer and consumer. In addressing this, the current and speculative practices of urban farming are examined. Finally, the development of place identity through food in the city is discussed. The scope for a solution springs from architecture’s role in assimilating urban farms into the city fabric. The functional programmes of farm + market + building is laid out for ongoing investigation. The paper acknowledges that the topic is extremely broad and narrows the scope by asking the question how can architecture contribute to diversifying food space through the introduction of urban farms, breaking down the conceptual divide between urban versus rural?

2. Food Space

While consumption is critical for a city’s social and local economic viability, what is often reflected in mainstream ‘food + architecture’ publications are designs confined to eating venues as ‘spaces of food’ (Figure 1). That is, coffee-table books featuring the trendiest restaurant/café designs of the season (Castle, 2002, p. 4). These are often seen to promote a self-indulgent lifestyle and do little to educate urbanites about the physical and psychological distances between food production and the city. ‘Food space’ is a broad system that includes all stages of the food cycle; from production to distribution, preparation to consumption and finally waste. The breadth of this system is largely underrepresented in architectural thinking due to the invisibility of activities taking place beyond the urban limit. Until there is also a food space living and breathing within the city fabric, conveying its diversity beyond consumerism, interest amongst urban residents will likely remain low. The obsession with consuming results in reduced opportunities as viewing food as an urban system.

The gastro-culture of restaurants and food stores are well chronicled in the press while other life-sustaining aspects of food remain nearly invisible – in education, urban design, planning and architecture (Franck, 2005, p. 36).

Similarly, Steel observes the minimal efforts of the media in way of educating the real effects of food, which has instead given rise to a veneer of the foodie culture,
...where we are happy to let food take a back seat...while most of us probably suspect, deep down, that our eating habits are having nasty consequences somewhere on the planet, those consequences are sufficiently out of sight to be ignored (2008, p. 5).

Visibility of the food system in the urban construct is lower than that of other systems such as transportation, housing, employment and the environment, a fact highlighted in Pothukuchi and Kaufman’s 1999 publication Placing the Food System on the Urban Agenda. The paper underlines the four key reasons for this as: 1) urbanities take food for granted where few see serious problems related to food access, availability, or affordability; 2) the definition of specific issues as being either rural or urban, this separation in thinking results in food not being considered an urban issue in the same magnitude as are housing, crime or transportation; 3) technological advances in transportation, food preservation and processing since the industrial revolution have rendered an acceptance to sweep away rural land to make way for new suburbs, what is offered in place of local farmland that historically served cities is the grocery store; 4) the persistent contradictions between policy departments (authors refer to the US) such as the Department of Housing and Urban Development which rarely addresses food issues and the Department of Agriculture which pertain mostly to farms and agriculture, yet their policies significantly impact cities (1999, p. 214).

None of these factors are currently at the forefront of the agendas in developed cities. The full potential of food in the urban system is far from being realised because of the top-down false sense of security about its ongoing availability and overshadowing by more immediate demands. The sharp and powerful dichotomy between what is considered urban versus rural conceals the many interconnected activities that make up a food system from urban residents and professionals. With agricultural food production assumed to take place in rural areas, it becomes a matter of rural policy, treated independently from urban policy and problems (Franck, 2005, p. 37). Modern zoning controls as set out by urban authorities do little to help and are instead instrumental in creating a segmented and sterile environment. It becomes quickly evident that opportunities lay with policymakers to make changes about the urban food system, beginning with a need for more flexible land use policies. Making progress in this regard will by necessity call into question what it means to be urban.

The path to truly viable food cities would seem to be obstructed by many peripheral issues when in fact, the it is it all boils down to one; without farmers and farmland, cities could no longer exist. Emerging
out of this realisation, one architectural thinker has begun to give shape to manifestos that explore future ‘foodsapes’. In *Smartcities + Eco-warriors* (2010) and *Food City* (2014) Lim examines the potential for food to become fully re-integrated with urban environments — how the creation, storage and distribution of food can once again become a construct for everyday life. With the realities of achieving such a condition seemingly beyond reach in contemporary socio-political conditions, radical constructions such as Lim’s Food Parliament set in London brings these issues to the forefront. Food cultivation becomes reinstated at the core of national and local governance in this proposal and is the essential driver for restructuring aspects of everyday life (Lim, 2014). Here, food space is truly realized in all its diversity, where consumers are also growers. Though Lim presents fictional fabrications, his message is precise and clear, raising serious questions about the priorities of governing bodies. Similarly, in the final chapter of *Hungry City* Steel speaks of a ‘sitopia’ (from the Greek sitos, meaning food, and topos, meaning place) as a practical alternative to the unattainable utopia (2008, p. 291).

In an era of unrelenting urbanism, it is appropriate for cities to adopt a more holistic outlook on food, to encourage projects and experimentations that embrace the complete food cycle. Authorities could reprioritize their agendas to engage residents to real and palpable ‘food spaces’ in all its forms. Quite possibly, it is only through a built reality experienced by residents themselves that they will begin to recognize any effective outcomes, in the hope that it can change the ways people think about the cities they live in.

**3. Urban + farming + architecture**

The current world population of 7.3 billion has just over half of its inhabitants (54%) living in urban areas and by 2050 some 66% of the then 9 billion people will be urbanised (United Nations, 2016). The cheap and ongoing availability of food to meet the needs of many urbanised people, and in particular those who make decisions on infrastructure development, ensures that few city dwellers are aware of emerging problems with the linear metabolism of its production and consumption. Nevertheless, some are beginning to see the potential benefits of a closed-loop food system in cities and urban farming has been revisited across several disciplines to address the opportunities. Architecture is one of those disciplines.

It is commonly assumed that urban farming is a recent phenomenon, brought on by sustainable initiatives. Although it has gained traction in recent years, urban farming has been practiced since the origin of village settlements. Jacobs argued that the act of growing food amid dense settlements likely dates back to the origin of cities. When organized agriculture began to be recognized as a system for tradable commodity, cities grew dramatically, relocating agricultural activities to surrounding land and thus creating the urban/rural divide. “Rural work is city work transplanted” (Jacobs, 1969, p. 16).

Before the modern world overcame difficulties of failing produce and means of distribution, cities had to produce enough food to sustain themselves. It is only with developments such as chemical fertilizers, refrigeration and mass transportation, among other technologies, that the current global food system is possible (George, 2015). It is also heavily reliant upon non-renewable resources. In the recent past it was concern about food shortages that saw urban farming revisited. Many cities across the United States and Britain for example had flourishing ‘Victory Gardens’ during both world wars in response to the threat of shortages created by blockades. After the wars however, many garden allotments were returned to their original uses or lost to developers (Doron, 2005, p. 53). Similarly, a food crisis in Cuba in 1989 forced the government to innovate, to introduce food production and agricultural initiatives into the existing urban fabric. This resulted in a successful city farming model where, by 1998, there were more than 8000 urban farms infused into Havana’s urban landscapes and producing nearly half of the country’s vegetables.
(Clouse, 2014). Cuba’s government continues to promote and even finance urban farming practices today. Perhaps it is this history that can teach the modern world of its potential; “sometimes to move forward, we must look back. Our past can inform our present (Smith, 2014, p. 5).”

Today, many urban farming efforts seen around cities appear to have been distilled down to light-hearted amenity to consolidate harsh urban environments or to provide for the recreation of those who tend to them. A few planter boxes distributed around the city will have little effect in activating anyone’s way of thinking about their food. The problem with some examples of ‘pocket’ size urban farming in modern metropolises is that they are merely inserted into undesirable leftover spaces to increase attractiveness, but with inadequate consideration of how they connect with surrounding amenities, activities and landscapes. Furthermore, community gardens (the most common form of urban farming) are often hidden away between suburban plots and run by volunteers, without a strict work schedule (Figure 2 left image). This can only function with small scale, low yield and low maintenance farms. For city residents to truly start taking the practice seriously, it needs to operate at a larger scale. And most importantly of all to break down conceptual barriers, its processes need to be as transparent as possible to the public eye.

![Figure 2: A community garden between suburban plots in Wellington, New Zealand (left) (source: Author, 2016) and a rendering of Paris’ future smart city by architect Vincent Callebaut (right) (source: Bhansali, 2015)](image)

In the contemporary architectural discipline, strategies addressing food are surfacing through the incorporation, at various scales, of agriculture into designed urban spaces. This includes farms established within/on/around buildings, though many of the projects have to date been speculative. Recently, urban farming has gained attention from architects as it is being commercialized into an emerging industry. Some of these proposals have, unfortunately, been taken out of context with concepts of sustainability being overstated and clichéd. Many lush photo-realistic landscapes are no more than backdrops for the main architectural proposal and plants are often brushed onto buildings to pass as a sustainable design contribution (Figure 2 right image).

In his essay titled Post-Sustainability, Jarzombek criticizes recently designed eco-cities, noting how they demonstrate that any approach could be taken to make a project look green,

...but has anything really changed?...the tendency to drip green ivy on buildings or plant grass or trees on roofs makes a parody of what needs to be done...this is not about the need for local produce, but about the destruction of the conceptual barrier between city and farm (Jarzombek, 2010, p. 249).
One can argue the need for both local produce and a better conceptual understanding of a food system. Jarzombek’s statement applies equally to the minimal efforts of urban authorities in the way small community gardens, a few scattered trees and open areas are used to market ‘green cities.’ His point is valid—little has changed in the preconceptions of food for the majority of city residents, and if anything, the barrier is wider thanks to a thriving consumerist culture.

Recent technological developments such as high efficiency LED grow lights and automatic control systems have aided hydroponic urban farming. The indoor controlled environment agriculture (CEA) model is efficient, does not rely on weather conditions and makes it more viable to grow in city centers as demonstrated by recent examples such as Gotham Greens in New York and Lufa Farms in Montreal (Figure 3). It has raised the topic of urban farming to new levels of interest amongst professionals such as growers, urban designers, planners and architects. The desire for maximum yield while being close to urban centers has sparked a contemporary urban agriculture movement across many disciplines as the realisation of interrelated city patterns is triggered by food, along with their commercial value. This growing interest is also extending to consumers, who want a closer connection to their producers in seeking to be more conscious of food origins. With urban farming now identified as an opportunity for a viable food production system, rather than as a result through fear of war or economic hardship, it is important that appropriate time and energy resources can be dedicated to experimentation.

Figure 3: Lufa Farms grows their produce inside controlled environments in their rooftop greenhouses.
(source: Lufa Farms Inc, 2014)

While some projects only touch upon the tip of urban farming principles, others can be found at the extreme end of a totalitarian city run by the food system. Without question, these proposals are utopian and ideological and have yet to prove their feasibility beyond a rendered landscape. Nevertheless, it is these idealists who push the discourse, in the hope that one day, the visions can be realized, or at least come close (e.g. Despommier’s *The Vertical Farm*). However, there would appear to be time for innovation between now and then and this gap needs addressing through the combined efforts of science, technology, architecture and planning. Pilot projects are underway as seen in the proposal of ReGen Villages (Figure 4), an off-grid, self-sustaining village featuring at this year’s Venice Biennale (Dezeem Magazine, 2016). The first of its high-tech farming villages where food and energy is produced in a closed-loop system is expected to be completed in 2017. This village model is designed for a greenfield site west of Almere, Netherlands, and therefore skirts around issues of integrating such a system into an existing city, where the majority of consumers live. As such it can be seen as a continuation of current practices.
To date, architecture has not been integrated with urban farming proposals and it has instead been used to depict a backdrop to show how urban the farming proposal is, or the farming takes place inside a standard commercial greenhouse, no different to what is being used on the outskirts of the city. At times these greenhouses are constructed on rooftops in urban centers, but they do not capitalise on the opportunity to innovate nor to engage with the surrounding environment. Architecture’s contribution has resultantly been underutilized in the relationship between farms, residents and the cityscape.

Across many developed cities, conditions such as largely unused surfaces (such as rooftops) indicate that there are a plethora of vacant space available for urban farming. Other environments, such as vacant building interiors and unused land present different opportunities for urban farming that falls outside the scope of this research. Creating rooftop greenhouses has, in recent years, begun to emerge at a commercial scale in cities across North America and Canada (Figure 3) but their practical requirements tend to outweigh design possibilities that engage with their context, and hence the people of the city. Urban farming, in the context of a strong design focus, could help make food systems more visible, adding to the definition of urban ‘food space’. Architecture’s role could operate beyond simply designing functional growing environments for farms, as rooftop constructions (in this case rooftop greenhouses) have the potential to shape cities by operating symbiotically in their urban settings (Melet & Vreedenburgh, 2005), adding to the complexity and dynamism of urban life.

4. Food + identity

A key player in distinguishing urban food space is the supermarket, whose form and public presentation is driven largely by economic efficiencies the lowest common denominator of consumer behaviour. In the past it was local markets that influenced presentation and distribution of a city’s food, today it is supermarkets, in the hands of a few corporations. The issue is not just about the limited choices available to consumers, but the lack of civic life that so many homogenous supermarkets contribute.

Supermarkets today are impersonal filling stations: pit stops designed to service the flow of life. They support individual lifestyles, not sociability (Steel, 2008, p. 114).

Nothing about their sterile environments identify their place in the city. In his analysis of modern life, supermarkets are what Augé refer to as ‘non-places’ where there is little chance of social interaction (Augé, 1995). Contemporary supermarkets and the motivations behind them have never been about human scale, their aim is simple and singular, to maximise profit. The influence of this approach extends to the rural agricultural industry that serves to supply them.
…internally the smell and look of the food is suppressed by air conditioning, lighting and packaging. The bland space extends well beyond the building to meet the requirements for bulk transport and car parking (Wigglesworth, 2002, p. 103).

The importance of the market as building type has resurfaced in conversations about urban regeneration. Preservation and renovation of market buildings to their earlier architectural glory are presented as alternatives to the supermarket in Esperdy’s article Edible Urbanism. By 1800, covered markets were recognized as a building type that “symbolized urban modernity and enlightened civicism” (Esperdy, 2002, p. 45). Whether covered or not, markets are inherently chaotic and unlike highly ordered supermarkets, but in a manner that is anticipated as part of the experience. As a re-emerging part of the food system, they are seen as part of the consumer culture as well as helping to provide insight to the value of food in the way the raw produce is displayed and sold by growers.

However, differences between markets and farmers’ markets can be profoundly misleading. One thing to note about normal produce markets is the little known journey of food from growers to consumers. It can often take up to a week, handled and resold numerous times as highlighted by the investigation of the Harbourside Market in Wellington, New Zealand (Rashbrooke, 2012). Nevertheless, the weekend market in Wellington draws huge crowds no doubt thanks to its lower prices and adds to the dynamic civic life of the city harbour. Reality can often conflict with what consumers know or care to know. With urban farms, not only are food miles reduced, but the produce can be harvested on the same day as it is consumed, giving access to the freshest possible food.

Covered markets in Britain and Europe have highlighted food as an urban revitalization tool. Examples include London’s Borough Market and Barcelona’s La Boqueria (Figure 5), where fresh produce is bountiful. These markets have been particularly successful with tourists but more importantly restauranteurs would prefer to buy their produce there as well. What if a trip to the market for weekly or even daily produce could be a part of normal civic life for the urban resident? And why would this routine be desirable when the supermarket offers other conveniences? A solution could be to incorporate an urban farm. The additional program of production into a market’s current consumption imperatives could have rippling effects in the urban food system, not only through educating residents but also by increasing chances of social interactions, creating jobs and closing the perceptual divide around where food production should take place. The consumption stage would, in this scenario, be icing on the cake.

Figure 5: Borough Market and La Boqueria (sources: Greig and Stephenson, 2014; Holbrook, 2014)

Consequently, the equation could be: urban farm + market + building. Along with aims of providing shelter, the architectural building element can contribute to a spatial and visual identity, strengthening a
vibrant program. Where market-farms can be established, the area’s physical character could be enhanced over time as a reflection of the activities, not unlike Seattle’s Pike Place Market, but with the added appreciation of production occurring at the same venue.

Over and over again, spaces of food contribute to the specificity and recognisability of a place when they attend to what is local (Franck, 2002, p. 12).

This wouldn’t just be felt in the immediate proximity of such a place but also the entire city. The food consumed today is highly driven by economies of scale, rather than by local cultures. Through design, the potential for uniting the ambience of markets with sustainable farming initiatives could see cities once again take control of their own food systems.

5. Conclusion

Food is emerging as a catalyst for urban design and architectural discourse around issues of infrastructure, security, resilience and sustainability and identity. However, further encouragement of the discussion requires that it move beyond discipline specific contexts to the mainstream media. The food supply chain had been a key force shaping cities since their origins, and should again be a topic of conversation among urban residents and authorities.

Conceptual thinking about production as rural and consumption as urban can only be redefined through a fresh and holistic view of a city’s multiple functions. This can in turn only be achieved by diminishing the physical divide, a matter to be addressed by planning authorities and other public decision makers in allowing for experimentation. At the moment it would appear that the architectural contributions to the discourse can only be speculative. Sustainable design does not equate with how green an image is but rather the opportunities it presents for the activities and functions it encourages.

Opportunities for experimentation exist in a city’s fabric, the many unused rooftops could be a logical starting point. City residents need to experience the transparent processes of market-farm food spaces in urban centres themselves to truly understand their significance. Architecture can be a protagonist and, although places will naturally take on site-specific design approaches, their resultant effect could be felt across the city through an invaluable identity of a local food culture.

References


Fifty Shades of Green: Tree coverage and neighbourhood attachment in relation to social interaction in Australian suburbs

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Abstract: Social interaction is seen as a key dimension of social sustainability and an essential feature of the social capital of cities. Yet social interaction in suburban neighbourhoods has been largely overlooked by researchers and designers; a neglect that has had negative impacts on social sustainability in the suburbs. In this paper the impact is explored of tree coverage on neighbourhood attachment in residential, low-density suburban streets in Victoria, Australia. The research is part of a wider study considering the complex relationship between four contributors to social interaction – Neighbourhood Attachment, Neighbourhood Satisfaction, Neighbouring and Walkability, and Safety – and two categories of factors that influence social interaction: the psycho-social and physical characteristics of neighbourhoods. The residents of three suburbs in Geelong, Australia, were questioned via a survey that aimed to measure how physical design factors impact the residents’ interactions. To isolate as much as possible design factors from social factors, the three suburbs chosen had equivalent socio-economic profiles. Two survey methods were used. First, questionnaires were delivered to six streets in each of the three suburbs. Each street had a different type of planning layout. Second, on-street face-to-face survey was carried out in the public spaces adjacent to neighbourhood libraries. The survey used multi-choice 5-point Likert scale questions to determine values for four scales that measure four contributors to social interaction. The wider research hypotheses that characteristics of neighbourhood form, such as tree coverage, can facilitate social interaction by increasing perceptions of neighbourhood attachment. The findings of the research reported on this paper indicated that Neighbourhood Attachment scores significantly increase as tree coverage increases in the suburbs. It is concluded that an understanding of how neighbourhood form determines social interaction in the suburbs can inform strategies for architects, urban planners and other built environment professionals to design sustainable suburban neighbourhoods; particularly through designing streets that provide sense of place and community.

Keywords: Social interaction; Neighbourhood form; Neighbourhood Attachment; Tree Coverage.

1. Introduction

Research of social sustainability has increasingly emphasised that good urban design can facilitate social interaction. It is also strongly argued that sustainable communities are a product of the integration of
social sustainability with the environmental and economic dimensions of sustainable development. Yet social interaction, as a fundamental dimension of community sustainability, has been neglected in design theory and practice; particularly in suburban housing (Dempsey et al., 2011; Burton et al., 2013).

According to Burton et al. (2013), three qualities are believed to create good neighbourhoods in the city: (1) atmosphere, which relates to that created through land use and the appearance of the physical environment; (2) engagement, which refers to residents’ social interactions via their experience with facilities, including the relationship between private housing and neighbourhood public spaces; and (3) physical diversity provided by different places and lifestyles. These qualities are seen to be enabled by neighbourhoods comprised of a mix of residential units and non-residential facilities (Dempsey et al., 2011). While social interactions can take place in residential dwellings, lively streets, active transport and public spaces, neighbourhood design can negatively affect social life when it creates a poor pedestrian environment. Research argues that suburban neighbourhoods can be associated with sociability as well as city centres (Galster, 2001; Colantonio, 2010; Dempsey et al., 2011). It is believed that neighbourhood design contributes to sustainability and provides an opportunity for social interaction (Dempsey, 2009).

This paper aims to investigate the relationship between neighbourhood form and social interaction by determining the impact that tree coverage has on neighbourhood attachment as a contributor to social interaction. The analysis shows that neighbourhood attachment is significantly increased with increased tree coverage in three Australian suburban neighbourhoods, suggesting that neighbourhood form can contribute to social interaction.

2. Background

The rapid growth of Australian suburbs is seen to have contributed to unplanned development leading to insufficient services, unhealthy environments, low aesthetic appeal, lack of greenery, identity and mundane housing (Richards, 1994). These aspects have been described as essential factors contributing to lack of liveability and civility in suburban housing (Johnson, 2007). Boyd’s The Australian Ugliness (1960) identified the negative effects of urban sprawl on social life as early as the 1960s, identifying a lack of neighbourhood character and poor social sustainability in the suburbs (Chan and Lee, 2008; Dempsey, 2009). Urban sprawl has since been seen to play a critical role in negatively impacting housing affordability, pedestrian orientation and the quality of suburban community life (Davison, 1993). While a new focus on cultural sustainability has aimed to advance the function of suburbs not just as places for living but also for positive emotional and social experiences, new suburbs still generally neglect the social need of residents. This is often due to single-use neighbourhoods failing to provide public spaces for social interactions; particularly playgrounds and shops (Jacobs, 1961) and lack of pedestrian access and soft edges (Mehta, 2013). Such suburbs are less transit-friendly and more car dependent (Leyden, 2003).

Research has shown that, despite increased withdrawal from neighbourhood life due to increased use of technology and to social differences, neighbourhood design still critically impacts social interaction (Lupton, 2003). However, while it is clear that good neighbourhood design can facilitate social interaction and sense of community, poor design can also have negative impacts (Boyd, 1960; Dempsey et al., 2012; Wilkerson et al., 2012). While these negative impacts have been well documented in high-density city contexts, lack of understanding of and attention to the impacts of design in low-density suburbs has also created problems by creating lifeless places with little sense of community. Thus, different policies have been adopted to enhance social life in cities. Studies indicate a range of strategies associated with increasing density, variety of dwellings, and the supply of mixed-use developments (Abu-Ghazzeh, 1999; Brown and Cropper, 2001; Burton et al., 2005). Giving strategic importance to good urban design is
Fifty Shades of Green: Tree coverage and neighbourhood attachment in relation to social interaction in Australian suburbs

recognised as important for providing social experiences that encourage residential interaction and increase quality of life at all age-stages (Williams, 2005). Acknowledging such criticisms, the literature supporting a relationship between neighbourhood design and social interaction indicates that research can inform solutions towards the wider objective of social sustainability. Moreover, recent research, which has included the psychological, social and health disciplines as well as studies directly focusing on architecture and other aspects of the built environment, suggests that neighbourhood design has effects beyond the opportunities it creates for social interaction. For design is also seen to promote social capital, especially in neighbourhoods with mixed uses and pedestrian-friendly planning, due to increased social ties, walkability and declining car dependency (Leyden, 2003). While neighbourhood design can have both positive or negative impacts on communities, studies have confirmed that the physical design, for instance, street layout, provision of sidewalks, greenery, streets connectivity, walkability, proximity, and the provision of public spaces are seen to impact social interaction and sense of community (Jacobs, 1961; Gehl, 1986; Gehl, 1987; Kim and Kaplan, 2004). A strong correlation has also been reported between social interaction and neighbourhood satisfaction and attachment and: safety, accessibility and the quality of public greens areas (Bonaiuto et al., 1999; Kim and Kaplan, 2004; Comstock et al., 2010).

Yet despite the acknowledged and well researched relationships between social sustainability, sense of community and social interaction, few studies have focused on the impact of neighbourhood design on social interaction in the suburbs. This is a clear research gap, but one which the research presented in this paper has addressed through the proposition (submitted for publication elsewhere) ¹ of a framework identifying which variables might be related and how when considering the relationship between neighbourhood design and social interaction. In addition, the framework elucidates the relationships between these variables, sense of community and the broader objective of social sustainability. These variables are seen to create successful neighbourhoods through better place making or improved ‘sense of place’ – a notion that includes characteristics not just of physical space but also the experiences, local knowledge and folklore of place, which play an essential role in promoting sense of community (Gehl, 1987; Kim and Kaplan, 2004; Dempsey, 2009).

In Table 1, such a framework is offered. Here, neighbourhood design factors are comprised of two primary dimensions: psychosocial and urban design attributes. There are three orders of urban design attributes that shape urban form characteristics, moving from the macro to the micro scale - urban form, neighbourhood form and dwelling form. As a pilot investigation of a wider study that will consider many of the variables in Table 1, this paper only considers the impact of one aspect of greenery – tree coverage – on perceptions of neighbourhood attachment, which it is hypothesised can contribute to social interaction. Similarly, a study of perceived residential environment qualities has shown that the provision of greenery is associated with the use of public spaces and with the extent that social activities in these spaces encourage social relations between residents (Bonaiuto et al., 1999; Comstock et al., 2010). Greenery is considered an important element of neighbourhood character, whether in open space or housing units, because it can provide shade and create space enclosure (Dempsey, 2009), and contribute to more pedestrian-friendly streets (Mehta, 2007). Hence, provision of green elements should be considered in sustainable housing development for aesthetic and functional meaning as well environmental benefit (Cook et al., 2012). However modern suburbs have been criticized for their

¹ In a yet unpublished paper - Abass, Z. & Tucker, R. (under review) “Good design makes good neighbours: understanding the impact of the built environment on social interaction in the suburbs”, submitted to Journal of Housing and the Built Environment
insufficient greenery and consequent lack of sense of place. Thus, it is argued that it is important to examine how shade from trees impacts perception of neighbourhood attachment, and how might the resulting impacts on social interaction be measured? Such knowledge might contribute to the sustainability of suburbs through place making in residential streets.

3. Methodology

Six design variables from the framework summarised in Table 1 were identified that could be readily measured through observation via walking and the use of Photomaps by NearMap – which are high resolution satellite images. These six physical characteristics were: street layout, physical infrastructure, neighbourhood connectivity, greenery (including tree coverage), interstitial spaces and physical arrangement/proximity of houses. In this paper, we consider the quantitative data used to investigate the impact of tree coverage on neighbourhood attachment. Neighbourhood attachment is seen to be considerably linked to social interaction and has been characterized as a psychosocial attribute of social experience. Neighbourhood attachment has been measured using an established scale – the Neighbourhood Attachment Scale (NAS) (Bonaiuto et al., 1999; Comstock et al., 2010).

Table 1: Neighbourhood design and social interaction (Source: Authors)

<table>
<thead>
<tr>
<th>Factor &amp; Characteristics</th>
<th>Design Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Psycho-social</strong></td>
<td></td>
</tr>
<tr>
<td>Neighbourhood attachment</td>
<td>Community involvement in public decision making, Sense of belongings on community</td>
</tr>
<tr>
<td>Neighbourhood satisfaction</td>
<td>Ease of access, Attractiveness, Maintenance buildings, Privacy within the neighbourhood</td>
</tr>
<tr>
<td>Neighbouring</td>
<td>Friendships and social contacts between neighbours, Participation in social activities, Asking help and amount of social ties</td>
</tr>
<tr>
<td>Safety feeling</td>
<td>Safe walking, level of Surveillance, Street lighting, Traffic amount</td>
</tr>
<tr>
<td><strong>Urban Form</strong></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>Perception of spaces between buildings</td>
</tr>
<tr>
<td>Dwelling type</td>
<td>Detached/ Semi-detached/ Terraced/ Apartments</td>
</tr>
<tr>
<td>Neighbourhood Layout</td>
<td>Spatial configuration of buildings, Housing, streets and open spaces</td>
</tr>
<tr>
<td>land use</td>
<td>Mixed use, Single use</td>
</tr>
<tr>
<td>Transport Infrastructure</td>
<td>Proximity, parking availability, availability of amenities, safety &amp; security at stops, access to service</td>
</tr>
<tr>
<td><strong>Neighbourhood Form</strong></td>
<td></td>
</tr>
<tr>
<td>Street design and Physical infrastructure</td>
<td>Street width, provision of sidewalks, streets connectivity furniture of street, quality of pavements, Greenery</td>
</tr>
<tr>
<td>Walkability</td>
<td>Pedestrian-oriented streetscape, Convenience moving within neighbourhood without preventions</td>
</tr>
<tr>
<td>Accessibility</td>
<td>5-minute walking distance, Access to services &amp; facilities, location, proximity</td>
</tr>
<tr>
<td>Qualities of Public and open spaces</td>
<td>Provision of Parks and playground, Availability of seats, Aesthetic appearance,</td>
</tr>
<tr>
<td><strong>Dwelling Form</strong></td>
<td></td>
</tr>
<tr>
<td>Interstitial spaces and threshold spaces</td>
<td>Front windows, balcony, low and high fences, the entrances, staircase, shared outdoor space, semi-private space, front garden and planting strip</td>
</tr>
<tr>
<td>Physical arrangement</td>
<td>Clustered groupings, Terraces, Crescents, Cul-de-sacs</td>
</tr>
</tbody>
</table>
In the study reported in this paper, the scale was administered via a survey that collected data from three suburbs in the south-west of Geelong, Australia. Geelong is the second largest city in Victoria, and expanded considerably after development to the southwest of the city after the war period. The suburbs were selected for their equivalent socio-economic profiles. Three suburbs were selected: Belmont, Grovedale and Waurn Ponds. In addition to their shared socio-economic profiles, their selection was based on three criteria: they represented different eras of residential growth, they were new housing developments, and they have different urban design layouts. Thus three different types of suburb could be compared. Six residential streets in each of the three suburbs were selected for diversity of layout, so that the impact of different street layouts on social interaction might also be eventually determined.

3.1. Participants

Residents were selected randomly and anonymously. Two primary methods were used to collect data: (1) questionnaires delivered to residents’ mailboxes in each street of the three suburbs; (2) on-street face-to-face survey was carried out by the researcher in the public spaces adjacent to the neighbourhood libraries of each suburb. Participants were informed that the collected data is anonymous and that their contribution is voluntary. From December 2015 to February in 2016, a plain language statement, consent form and questionnaire were delivered to residents on different days in the selected suburbs. 300 residents were selected randomly, so that 100 residents in each suburb received the questionnaire. The residents were asked to return their responses by the identified date using the supplied stamped-addressed envelopes. Twenty-seven questionnaires were received from Belmont, 31 from Grovedale and 20 from Waurn Ponds. For the on-street face-to-face survey, participants were asked for their address so that their questionnaire could be matched with their residential streets. They were provided with a plain language statement and consent form, and the researcher briefly described the project. The researcher recorded 10 respondents from Belmont and 12 respondents from both Grovedale and Waurn Ponds. The total numbers of completed questionnaires from both forms of data collection was 101.

3.2. Survey instrument

The survey questions investigated the experience and perception of residents on how the design of their neighbourhoods’ impact the factors identified in the literature as influencing social interaction. Thus, as well as the NAS the survey included 3 other scales: satisfaction and accessibility (Bonaiuto et al., 2003), neighbouring (Buckner, 1988; Nasar and Julian, 1995), walkability and safety (Lund, 2002; Leyden, 2003; Can, 2012). Additionally, socio-demographic and residential variables data was collected, including: length of tenure, age, gender, income, length of residency, number of house members and children, and level of education. These variables will be used to confirm the socio-economic profiles of residents. The NAS reflects social experience in the physical environment of neighbourhoods, and consists five items ranked on a 5-point Likert scale (from strongly disagree to strongly agree). The scale indicates residents’ emotional bonds to their neighbourhood and their willingness to stay in that place in relation to their symbolic and self-identity connection to their physical environment.

3.3. Measurement of tree coverage

The amount of trees and shrubs that provide shade varies greatly between the three selected suburbs. While Belmont’s streets have many mature trees and Grovedale is characterized by diverse established large shrubs and some mature trees, a lack of greenery dominates Waurn Ponds, which predominantly has gravel and stone landscapes with a scattering of immature trees. The percentage of tree coverage in each street was measured from recently taken high-resolution satellite photographs. Here, the street area
was measured as that bounded by the front-wall line of houses, and thus included front gardens, as these are perceived as part of the street-scape. The plan area of trees and large shrubs was compared to the overall street area to give a percentage (10 to 50%) tree coverage.

It should be documented that the three suburbs are of different development ages: Belmont is the most established suburb, having the most significant growth during the 1950s and 1960s; Grovedale had most development in the 1970s and 80s, whereas Waurn Ponds is the most contemporary suburb with most rapid growth in the 1990s. As might be expected, the ages of the suburbs correlate with tree maturity and hence levels of tree coverage.

Table 2. Neighbourhood attachment scale items

<table>
<thead>
<tr>
<th>Scale items</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. This is an ideal neighbourhood to live in</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>2. Now, this neighbourhood is a part of me</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>3. There are places in the neighbourhood to which I am very emotionally attached</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>4. It would be hard for me to leave this neighbourhood.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>5. I would willingly leave this neighbourhood</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

4. Results

A one-way between-groups analysis of variance was conducted to explore the impact of Tree Coverage on levels of Neighbourhood Attachment, as measured by the neighbourhood attachment scale (NAS). Tree Coverage was divided into four groups (Group 1: 10 to 20% coverage; Group 2: 20 to 30%; Group 3: 30 to 40%; Group 4: 40 to 50%). There was a statistically significant difference at the p < .001 level in Neighbourhood Attachment scores for the four groups: F (3, 97) = 7.3, p = .000. While the actual difference in mean scores between the groups was moderate, the effect size, calculated using eta squared, was large; at 0.18. Post-hoc comparisons using the Tukey HSD test indicated that: the mean score for Group 1 (M = 3.22, SD = 0.46) was significantly different from Group 4 (M = 3.77, SD = 0.5); the mean score for Group 2 (M = 3.23, SD = 0.48) was significantly different from Group 3 (M = 3.61, SD = 0.42); the mean score for Group 2 was significantly different from Group 4. Significantly higher levels of Neighbourhood Attachment occur in streets with higher coverage of trees.

5. Discussion

The results indicate that extent of greenery in the form of tree coverage significantly impacts neighbourhood attachment, such that increased tree coverage is associated with increased levels of neighbourhood attachment. Thus, in Belmont and Grovedale, where the sampled streets had higher levels of tree coverage, residents had higher levels of neighbourhood attachment compared to residents in Waurn Ponds – where there is a lack of greenery (Figure 1). It is recognised that provision of greenery in streets can create vital public spaces that are appealing to residents, add to neighbourhood character, and can facilitate social interaction and connection in suburban contexts. This outcome begs the questions: how do these results compare to previous research, and how might planning and urban design address lack of tree coverage in suburban Victoria?
The findings of this paper are very much in line with those of Bonaiuto et al. (1999), Bonaiuto et al. (2003), Kim and Kaplan (2004) who found that greenery was significantly associated with levels of neighbourhood attachment. Trees, for example, are seen to play a key role in the shaping and maintenance of shade, which creates space for community interaction and social activities, and improves the emotional bond between residents and their neighborhood. Comstock and colleagues has also found that neighbourhood form, including shade-providing greenery, can increase neighbourhood attachment by facilitating the engagement of residents in social interactions (2010). While our study suggests that tree coverage might indirectly improve social interaction via improved neighbourhood attachment, some studies have found that trees directly improve social interaction by encouraging residents to spend more time outdoors in shared spaces where face-to-face connections take place (Sullivan et al., 2004). Similarly, Al-Homoud and Tassinari (2004) indicated that pre-existing trees, as one component of space enclosure, have an important role in establishing social interaction in residential outdoor spaces. This consistent also with Uslu (2010), who claims that greenery in semi-open and natural spaces encourages residents to be outside and participate in social life. Moreover, she suggests that greenery in residential streets contributes to individuals socialising and can play a major role in strengthening a sense of place. Thus tree coverages is seen to improve aesthetics, sense of enclosure, permeability and legibility – all elements of
place-making (Ewing and Clemente, 2013). Moreover, trees help to create well-defined streets edges and open space and thus reinforce pedestrian safety (Gehl, 2010), promote walkability and develop place-making for more encounters and gathering between community members (Whyte, 1980). Thus, trees have been directly related to improved social interaction (Cook et al., 2012), and have been found to have indirect impact on social interaction by increasing neighbourhood attachment (Comstock et al., 2010).

However, lack of greenery and planting, and in particular insufficient trees, has long been recognised as a problem in Australian suburbs. This is due to lack of planting regulations and protections for existing plants in suburban developments, where it is argued that developers are less well-informed about space greening than in large cities (Cook et al., 2015). There is a clear need for greenery and landscape elements to be considered by developers prior to subdivision for planning to more canopy trees along streets in the medium term, and thus improve place character as well as health outcomes. It is also suggested that local government, councils and residents should be more involved in increasing and sustaining tree coverage (Cook et al., 2015).

It is worth underlining here that this paper reports on the early findings of a broader study that will eventually consider not just the role of greenery in social interaction and socio-cultural sustainability in Australian suburbs, but indeed will measure the impact of other neighbourhood form variables that might have impact on neighbourhood attachment and also the interaction between the variables. For it is suggested that future study needs to consider the potential effect of other variables related to place-making and the perception of spaces as green and “natural,” such as street planning layout and streetscape elements such as sidewalks and nature strips.

6. Study limitations

As the analysis presented in this paper only considers the relationship between two amongst many variables that might impact social interaction in the suburbs, it has clear limitations that need acknowledging. The first limitation concerns method. The analysis presented is part of a much wider study that considers many urban form attributes in relation to four psycho-social indicators of social interaction: (1) neighbourhood attachment, (2) neighbourhood satisfaction, (3) neighbouring and (4) walkability and safety. These urban form attributes at the street scale include the provision and qualities of nature strips, footpaths, street furniture and boundary fence sizes, as well as dwelling form characteristics that define how houses relate to the streets. To consider the interrelationship between all these variables, the wider study has selected streets and suburbs that differ beyond tree coverage, and hence it has not been possible to isolate the impact of trees on neighbourhood attachment. It should also be acknowledged that there is a clear relationship between tree coverage and the age of the suburbs, because older suburbs means more mature trees, and it may also be that other factors might also be at play, such as families with longer-term associations with place having greater attachment to those places. Beyond these methodological limitations, due to trees not being the focus of the wider study many other questions remain unanswered in relation to how people relate to/feel about/ trees, such as cultural or personal attachment to species, sound, fragrance, attachment to fauna and other characteristics of trees. Lastly, a study focused on greenery might also differentiate tree shade from other forms of vegetation cover and perceived biomass.

7. Conclusion

The relationship between neighbourhood attachment and shade-providing tree coverage was investigated to provide understanding of how green elements of neighbourhood form might contribute
towards social interaction and thus socio-cultural sustainability in suburban Australian streets. Survey responses showed that neighbourhood attachment significantly increases with tree coverage in three suburbs in Geelong, Victoria. The paper investigated the provision of greenery as only one of a number of physical characteristics in suburban streets that might impact neighbourhood attachment. The results provide empirical evidence that the physical characteristics of suburban streets impacts neighbourhood attachment, which in turn is cohesively associated with social interaction and thus is likely to contribute residents’ perceptions of community and positive social experiences. It can be concluded that, although Australian suburbs are characterised by lack of liveability and sense of place, good neighbourhood design - including planting of trees and shrubs when subdivisions are created (which is common in Europe) - that integrates the psychosocial and physical factors impacting social interaction can contribute to more vital neighborhoods better able to meet residents’ social needs.

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Developing the greenery: Results from a co-design project with landscape architects and schoolchildren in Auckland, New Zealand

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Abstract: This paper presents the preliminary results of a landscape co-design project between the researcher (studying for a Masters in Landscape Architecture), her supervisor and a class of 9-11 year old students at a New Zealand primary school. The aim of the project was to develop a method that could be used by landscape architects in contributing to school ground greening projects that promote environmental and design learning. While the project is still on-going, several key findings have emerged. These include the importance of planning and project management within the co-design process, the enthusiasm and potential of children as designers and decision-makers, and the relative ease with which such processes can be carried out, giving reciprocal benefits for all participants. The paper concludes that the method developed could be easily used or adapted as required by landscape architects and the process is a valid way of involving schoolchildren in the design of their environments. The ongoing intention is to complete the project and disseminate these findings within the industry to encourage landscape architects, and the profession in general, to become more involved in providing specialist help to schools doing school ground greening projects.

Keywords: School ground greening; landscape architecture; children; co-design

1. Introduction

School ground greening (SGG) is the general term used for the transformation of school grounds from asphalt, concrete and grass to more naturally diverse spaces that invite children to explore, experiment and learn (Dyment, 2005). A significant rationale for its current popularity is the potential for developing positive environmental values and attitudes as a result of these increased nature encounters (Williams and Brown, 2012). Expanding the learning potential further, a growing number of researchers (eg Wake and Eames, 2013; Green, 2014) propose that if children participate in the design of these environments it can foster creativity and imagination, develop communication and thinking skills, engender ownership of the space, promote sharing and increase community belonging.

The research outlined in this paper is part of a Masters in Landscape Architecture study focusing on the role landscape architects (LAs) in New Zealand could play in assisting schools with greening projects,
in a way that benefits both. Greening schools advocate Sharon Danks (2014) has outlined the increasing interest and opportunity for involvement of American LAs in SGG in a recent article written for the American Association of Landscape Architects. Set against this is the fact that LAs in NZ are typically not involved in SGG projects. This is usually for reasons of economy since school ground retrofit projects (usually connected with environmental or health learning) requires private fundraising as it is not funded through the Ministry of Education. As a result teachers or parent groups often assume the role of design/construction/maintenance although they may not fully understand the knowledge and commitment required. The result can be over-burdening, disillusionment, over-reliance on one person for continuation, or simply not taking full advantage of what SGG could offer as a learning tool and a valuable ecological and social resource for schools and communities (Passy, 2014).

In New Zealand a strong connection exists between school ground greening projects and the environmental education programme Enviroschools, managed by Toimata Foundation, a registered charity (Toimata Foundation, n.d.). Their learning process is empathetic to participatory design projects as indicated by their adoption of David Driskell’s “shared decision-making” (2002, p. 6) between all participants (eg adults and children) and their action learning cycle that is iterative and encourages reflection (Toimata Foundation, n.d.). One third of all NZ schools are Enviroschools (Toimata Foundation, 2015). However, while the programme is environmental learning-focused it is not design-specific, in a similar way that while LAs in NZ have a clear role in creating outdoor learning environments and in advocating both for human and environmental values through their work (www.nzila.org), they are not trained educators. They also have to balance acts of social and community service with economic imperatives. This predicates a need for a method that is reciprocally beneficial and efficiently devised, while still focusing on the process, which is an importance identified by others (eg Wake and Eames, 2013; Somerville and Green, 2015).

The aim of this research project is therefore to develop a suitable method template for LAs to use with schools. This will be achieved by critiquing participatory design processes both within the literature and in practice to develop a hybrid method to be tested through a real design project with school children. This paper will outline the method used and early results, while focusing on the process and benefits of co-design. Parnell (2014) defines architectural co-design with children as children working directly and collaboratively with designers to contribute and make decisions within the design process, rather than a purely consultancy role. This kind of spatial advocacy is known to be empowering.

2. Background

The identification of reciprocal beneficial outcomes from a co-design process is a strong rationale for its importance both pedagogically for teachers and students, and professionally for designers. Improved design ideas, learning better how to design with/for children and generating a positive profile to potential clients have been cited as possible outcomes for designers (eg Parnell et al., 2008; Wake and Eames, 2013; Patsarika, 2014). On the other side, unleashing children’s creativity (ie children as natural designers with knowledge of their environments), developing valuable skills, increasing ownership of the space and empowerment due to feeling control over learning are potential positive outcomes for students (eg Sorrell and Sorrell, 2005; Wake, 2010; Green, 2014).

The theory of participation has now been well described, following the drafting of the United Nations Convention on the Rights of the Child (UNCROC) in 1989. Article 12 states children have a right to have their say in decisions that affect them and to have their opinions taken into account (UNHCHR, 1989). Hart’s (1997) ladder of participation and Driskell’s (2006) modification of this into a graph have been
widely used and cited, although criticism has been leveled at the hierarchical allusion created by the ladder metaphor in Hart’s model. This is despite Hart (1997) stating that it was not intended that the top rung of the ladder—‘child initiated and shared decision-making with adults’ should be aspirational or even appropriate in every situation.

Malone and Hartung (2010) maintain that children’s participation is frequently recognized only in an adult-centric structure and therefore does not challenge dominant hegemonies. For example, many adults believing children are not capable or should not be asked to assume adult decision-making responsibilities. Such attitudes could contribute to situations defined by Hart (1997) as manipulation (eg children being directed on what to say), decoration (eg children being dressed in the teeshirts without actually being part of the project) and tokenism (eg ‘box ticking’ children’s participation without sincerity). According to Reid and Nikel (2008), perhaps the most useful role of the ladder has been the identification of these three levels of ‘non-participation.’ This aside, Malone and Hartung (2010) believe that the frequent reliance on models such as Hart’s and Driskell’s as practical tools rather than theoretical frameworks is a limiting factor to many participatory projects being truly transformative for children’s learning.

In developing a model or method it is important to distinguish between consultation and co-design with children. Parnell (2014) defines consultation as a “...structured process enabling different parties to express their views on a proposal ... denotes commitment to take on board participants’ views ... and provide feedback” (para. 18), while “ in co-design processes, users take an active, hands-on role in the design of the major spaces, working directly and collaboratively with the design team to develop designs” (para. 15). Although both Somerville and Green (2015) and Wake (2010) describe exemplary co-design projects that were long term and on-going this is not practical in many situations. Given the expertise required and probable time frame constraints in real landscape design projects, it is likely that decision-making by children will be limited. However, this does not diminish the value of carrying out the process, although it is important to be clear with children about the limits of their participation (Hill, 2006) and to focus on the participatory learning process rather than on the project outcome (Wake and Eames, 2013; Somerville and Green, 2015). As indicated in the following paragraph a method can lean more towards consultation or co-design depending on how it is set up.

The Auckland Plan of 2012 identified ‘putting children and youth first’ as a priority and led to the drafting of the Children and Young People Strategic Action Plan: I am Auckland in 2014 (Auckland Council, 2014). Coupled with The Waitematā Local Board’s (Auckland area) intention of becoming a UNICEF accredited Child-friendly City (www.unicef.org.nz), there is a commitment to involve children and youth in decision-making within their city. A recent example was a ‘Child Friendly Audit’ of Freyburg Square in Auckland CBD conducted by researchers from Massey University’s Whariki Research Centre (Auckland Design Office, 2015). They used a version of ‘Gulliver’s Mapping’ as described by Driskell (2002, p. 158) to run two charrette-style co-design workshops with a group of children to explore and photograph the square, develop design ideas, provide feedback on a draft design by Council design staff and then see the finished design and evaluate the process. Similarly, Fiona Robbé, a Sydney landscape architect specialising in children’s environments uses her interpretation of Guilliver’s Mapping to guide playground design through consulting with children, as explained in a report to City of Sydney (Robbé, 2012).

In a further co-design example (albeit more academic) Rottle and Johnson (2007) describe in detail a three-stage design charrette process used with 9-11 year old students designing a public park to be an outdoor learning laboratory. The process, which focused on ecological learning as well as design, comprised: a one hour ideas session (creating posters of ideas for park elements in facilitated groups),
followed by a one hour model-making session (same facilitated groups) showing spatial arrangement of
park elements and habitats, and finally a brief reflection session where students gave feedback on the
learning they gained from the project, using postcards. Incorporated within their method (the poster
session) was use of a conceptual content cognitive map (3CM) developed by Kearney and Kaplan (1997)
as a simple way of assessing cognitive processes required in organising information.

3. Developing a method

The school selected for this research is a mixed primary and intermediate (years 1-8) school of 300
students located in West Auckland. The school is graded as decile 2 out of 10 (socio-economic rating
based on the school’s geographical zoning) and has a diverse student composition of 31% Māori, 10% NZ
European, 40% Pacific, 19% other ethnicities. The school is an Enviroschool that has carried out some
innovative projects in their grounds already (eg cycle track, windmill powering a pump for a native plant
revegetation nursery), encouraged by their principal. Ethics approval was granted in May 2016 to work
with a mixed year 5/6 class of 28 students. The site chosen was two adjacent areas of the school grounds
including a sloped grass area with trees extending behind a classroom block plus a small flat concrete area
near the sandpit (area 1) and a small bush area (area 2). See Figure 1 for a site plan. The brief was to
work with students on a design to 1) Increase environmental learning and promote biodiversity, 2)
Encourage activity and exploration, 3) Provide for cooking, eating and socialising, 4) Provide a place for
watching sports on the field.

Due to the identified focus on developing a process that was simple, didn’t require too much time
commitment for landscape architects and allowed maximum input by students and other stakeholders
into design decision-making, a combination of the methods previously described were chosen. Rottle and
Johnson’s charrettes (2007) were used as the underpinning method due to the clear description, simplicity
of resources and close matching to the school and project in this research. Student age was similar and
the project had an environmental focus. However, two significant differences turned out to be that their
project had greater people resources available to assist with the charrettes and the students did the
design project at the end of a much larger study of the site meaning those these students were much

![Figure 1: The area of the design brief](source: Google Maps)

![Figure 2: Students measuring the site.](Authors’ photo)
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more aware and knowledgeable about the background to the design brief. In the research described here the two charrettes were carried out without prior introduction of the students to the site or brief.

Other layers were also added to the method to create a more iterative and inclusive approach. For example, students, school staff and parents/caregivers will be invited to give feedback on the first draft of the design, which will be created using student ideas from the two charrettes. This is an extension of the method used at Freyburg Sq (Auckland Design Office, 2015) since school grounds are used and maintained as a community asset/liability. The feedback received will be folded into the design and students will then be asked to complete postcard evaluations at the final design presentation to express what they thought of the process and say what they learnt. This is a combination of both Rottle and Johnson’s method and Freyburg Sq.

3.1. Method Summary and timeline

- **Workshop 1** – 3hrs (Poster session). Following introductions, a powerpoint was used to introduce the design brief and the process, plus design terms (eg site, brief, site analysis) and landscape concepts (eg sun and wind direction, shading, slope, active and passive spaces, measuring). Students then went outside to the site and put these concepts into practice, eg measuring with tapes (see Figure 2). Back in the classroom they were shown some examples of SGG projects and then put in groups to create sticky notes of ideas. These were organised into themes (3CM process), put onto large sheets and the top three favourite ideas voted on. All groups then gave a short presentation to the class on their ideas.

- **Workshop 2** – 3hrs (Model session). Held a week later, the same groups went on to develop ideas from the previous week into 3D models using simple materials such as card, modelling clay, polystyrene, mounted onto a large scale plan of the site. A clear instruction sheet was provided that organised the students’ ideas into themes according to the brief and asked them to choose at least one idea from each of three broad themes, taken from the original brief (increasing native biodiversity, encouraging student activity and exploration, creating a place for cooking and eating /passive spaces to sit, be social or watch sport).

- **Workshop 3** – 1 hr (Presentation followed by feedback on draft design). This occurred 14 weeks later (not ideal) due to other commitments. The concept plan and perspectives were presented on-screen and hard copy with students then asked to complete a simple evaluation sheet (what did they like, not like and why, suggestions for change). School staff and parents/caregivers were also invited to complete evaluation sheets. The process of collecting and analysing the feedback and making resulting changes to the design is still occurring as this paper goes to print.

- **Workshop 4** – 1 hr (Presentation of final design and evaluation of the process and learning). This will be completed in the next month using a simple postcard format.

3.2. Reflections on the method to date

The first workshop went well and the students were attentive and keen. However, as researchers we found some flaws in the method. For example the wear and tear on measuring equipment while outside was unexpected and inside during the poster session some groups fragmented due to poor dynamics, which also hampered some groups coming up with many, or appropriate ideas. The organization of their ideas into themes was only successfully achieved by one group (girls) so the 3CM value was discounted.
This was not felt to be a problem but for future reference, use of clearer written instructions may overcome this. Finally, voting on the most popular ideas to narrow ideas to three per group was thwarted by everyone voting for their own so there were many ideas with only one vote. This could be easily remedied by requiring students to vote for ideas that weren’t their own, but on reflection, lots of ideas to take to workshop 2 was good, especially coupled with us organising these under headings from the brief.

The second workshop was even more successful with students fully engaged. A ‘recap’ was carried out first and we were impressed with their recall of landscape design terms and principles. Organising students into groups (five per group) was more tightly managed and good preparation of model materials meant that the groups were able to get underway quickly. They worked very collaboratively, often in smaller groups on different sections of the plan (we used two boards per group to cover area 1 and 2 of the site). The clear presentations at the end were evidence of their excitement and interest.

In summary we recommend enlisting the teacher in some preliminary work by creating some simple resources and exercises ahead of time that students could work on. This would get them fully engaged ahead of the workshops starting. In addition, making a worksheet with clear instructions for all students is important at each stage. It is felt these two simple adjustments could have overcome nearly all of the challenges in workshop 1. If possible, more facilitators (than 2) who really know the process would also help to keep things flowing well, although overall we managed fine and involving more staff makes it costlier for LA companies. Students should be encouraged to accompany or substitute their text for drawings on the sticky notes and facilitators must ensure everything is annotated before the end of the workshop so meaning is not lost. This is emphasized by other researchers (eg Iltus and Hart, 1995).

4. Results and discussion

4.1. Workshop 1

Although the first two workshops were designed to develop design ideas sequentially, we decided afterwards to look at both separately for providing student ideas that could drive the new design, since they yielded different information (Figures 3 and 4). Using methodology developed by Robbé (2012) the ideas from the students were coded into themes and presented graphically (see Figure 5).
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From Figure 5 it can be seen that of the 85 design ideas generated by 28 students, the largest number were to do with nature, followed by built structures. The focus on nature is logical given the brief and the outdoor location, although it can be seen that some students did come up with ideas that were only suitable indoors. However, within the nature ideas, more ideas were to do with edible plants and domestic animals than about natives and natural systems.

Figure 5: Spread of ideas from the Poster Session. (Authors’ work)

This may therefore be an opportunity to encourage knowledge of native habitats, especially plants with ethno-botanical or edible value and food for birds and other fauna. This concurs with one student idea to, “Get more trees and then the tui [native bird] can come”.

Of all the ideas for structures, more than half were for treehouses or huts, which connects strongly to nature, especially since some included slides, ropes and tunnels. Sometimes education was included eg, “A small hut for juniors and seniors. Facts about animals, trees, plants”. The category called outdoor games/sports included lots of ideas for journey, active movement, imaginative play and challenge (eg flying fox and climbing wall, maze, tyre swing), as well as structured games. Art and sculpture ideas were mostly nature-focused with plants, birds, fungi and animals suggested as well as performance spaces.

Under the theme ‘sitting/eating place’ there was not a lot of focus on eating, which was surprising since the school wanted the project to include a pizza oven and the students had seemed excited about this. However, spaces to watch sport (the site is next to the rugby field) and to relax in were the dominant suggestions, for example “Around the field there should be an area where you can rest & watch rugby game” and “We could make like a little chilling place just in the center of the small forest”.

Perhaps the strangest theme was Fundraising – included because 4 comments were made about charity or making and selling things to get money. It does indicate students are aware that to get things they need to raise money, although the reality of schools in lower socio-economic neighbourhoods being disadvantaged due to lack of parents with the time and connections for the school to be ultimately successful at fundraising has been raised by researchers such as Dyment (2005).

4.2. Workshop 2

Three groups of boys and two of girls were immersed in creating models for at least 2 hours (see Figures 3 and 4). The models were photographed and analysed alongside listening to video footage of students describing their models. All groups put a pizza oven into their model, as instructed, although only two groups expanded on this by creating a place for sitting and eating in their design models. The pizza oven
was located on the only flat and open area of the site in 4 of the 5 models. Interestingly, 3 out of 5 groups included a treehouse in their model, a decrease in popularity from the poster session, but these included slides, ramps/ladders and a rope swing to represent a flying fox. Due to us cueing it, 4 out of 5 groups included a water feature, usually centred on the back of the two classrooms where a downpipe takes rainwater from the roof. Four of the 5 groups created adventure areas (eg maze, campfire, use of punga logs which are the trunks of native tree ferns) within the small planted native bush area on the site and three of these created entrance gateways to mark these.

4.3. Design response

The challenge for the researchers/designers is taking such an array of ideas and fitting it to a coherent design that attempts to meet multiple needs (eg children, caretaker, safety, budget). While there was no set budget, since this design may not be realised, it is important to create a design that may be achievable for the school, eg through staging, fundraising or grant application. The current design is shown in Figure 6. This may change in minor ways once collection and analysis of all the feedback has been completed. From Figure 6 it can be seen that the ten most popular ideas from both workshops have been included in a central box. The text and graphics surrounding the plan explain the concept fully and include pictures of the students’ models as illustration of the design inspiration coming from the students. The numbers next to the text descriptions refer to the student ideas list. The concept has focused on the brief in creating areas for cooking, eating, sitting, socializing, imaginative and active play, performance, learning and quiet time. It encourages as much student autonomy as possible, in a safe environment that is flexible and multi-use while being mindful of maintenance requirements. More elements could be easily added or subtracted, eg through student construction of animal feeders and habitats within the bush area. Creating a water feature and rain garden to address a drainage problem is an excellent example of the advantage of involving a LA in the process, with an outcome that will benefit the school, create an attractive space and provide student learning about managing human systems in a natural way.

5. Conclusion

Although the research is incomplete it is already evident that this process can lead to unique ideas relatively quickly and simply through a collaboration between LAs and students. It is, however, important that planning and preparation is rigorous. Analysis of the resulting data is easily achieved and invaluable in foregrounding the richness of children’s ideas, provided the brief and instructions are clearly communicated. Having some introductory work undertaken by the teacher ahead of the design charrettes would be beneficial. Early interpretation of the feedback data from workshop 3 indicates students are enjoying the process and are excited and complementary about the concept, although quick to point out perceived health and safety issues. In conclusion, the process is rewarding and fun for all participants. The workshops were exhausting yet exhilarating as children view things refreshingly different. Therefore, it is important not to pre-determine with adults’ ideas and to encourage students’ own ideas within a structure informed by adults’ specialist understanding of issues and regulations. We believe co-design with children will become an increasing future requirement in school-based architecture and landscape architecture and we hope this method (or a variant) may be helpful in many situations.
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Figure 6: First draft of concept plan following workshops 1 and 2 (Authors’ work)

References


Re-Thinking the role of Urban In-Between Spaces

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Abstract: As urban areas continue to grow in population and size some experts have called for already settled areas to be used more efficiently. One popular approach is to redevelop individual sites in order to intensify their use, which in turn leads to a more compact arrangement of form. Another approach, which has to date been largely unexplored, is to make better use of existing spaces between buildings and other land uses; effectively these are the spaces that are left over through earlier uncoordinated development. It would appear there is potential for these in-between spaces to become locations for strategic intervention. The paper develops a conceptual framework focussed on ecological sustainability, and speculates over the extent to which private leftover urban spaces can be utilized in different ways within cities. This knowledge is distilled into a strategy for sufficiency. The research explores how small changes in an urban system can become a catalyst for an overall transformation of a city and its ecology. It is driven by the hypothesis that leftover urban spaces can be utilized in ways that can help regulate micro-climate, produce energy and absorb carbon emissions.

Keywords: In-between spaces, spatial classification, urban sufficiency

1. Introduction

Urbanized areas cover only around 6% of Earth’s surface (Meyer and Turner, 1992) and yet they have extraordinarily large ecological footprints, and collectively they create significant environmental impact. The ecological footprint of a city extends over an area many times larger than its physical size. An unprecedented 54% of the population currently lives in cities and by 2050 that proportion will rise to more than 70% (United Nations, 2014). The majority of world population growth, anticipated to be in the order of 2.5 billion people over the next 30 years, will settle in cities. Cities appropriate a large share of earth’s carrying capacity in terms of resource input and waste sinks (Rees & Wackernagel, 1994). The consequences of urban development are that it fragments, isolates, degrades natural habitats and that it modifies hydrological systems (Arnold and Gibbons, 1996) while disrupting energy flows and nutrient cycles (McDonnell and Pickett, 1990).

Ecosystem services are the benefits (such as food) and services (such as waste assimilation) that humans derive directly or indirectly from ecosystem functions (MEA, 2003; Costanza & Folke, 1997). Many of these services are essential to human well-being and thus important aspects of liveable cities (Chiesura 2004). Urban ecosystems also hold the keys to potential solutions for environmental issues. In particular,
as agricultural and natural landscapes are lost to development around the edges of cities, there are opportunities for urban green spaces to provide and maintain ecological habitats. The environmental impacts of urbanization are intense and also lead directly to climate change (Satterthwaite, 2008). With each passing year, it becomes clearer that cities should be able to grow sustainably from within in order to diminish impacts on natural ecosystems and to avoid unnecessary appropriation of precious agricultural land.

This paper summarizes a development strategy for supplying ecosystem services in urban areas through a planning process that targets neglected in-between left over spaces within the fabric of a city. The authors propose opportunities to develop these often neglected spaces in ways that can contribute to the social and ecological health of the city. Different forms of leftover spaces can be found in cities and each has the potential to become a stepping stone for nature to flourish.

The paper is divided into three parts. Firstly, it discusses the concept of sufficiency in terms of environmental and social sustainability. This sets the context within which urban left over spaces can be examined. Secondly, the paper offers a spatial classification for in-between spaces and discusses temporary urbanism for semi-private spaces, a concept that can create support systems within urban areas. Finally, different potential uses to which in-between spaces could be put, driven primarily by the sufficiency agenda are discussed. In this discussion, a landscape ecology approach that integrates various sustainability foci is suggested as the most comprehensive and cost-effective means of achieving sufficiency.

2. Sustainability and sufficiency

Cities have historically been dependent on surrounding hinterlands for their food supplies and other goods and services (Folke et al. 1997). However, over the past century, this service area has extended to become global. Through specialization of markets and transport technologies, cities are becoming less able to provide for the wants and desires of their residents. An issue that can challenge sustainability outcomes is the strong focus placed on economic growth and development. Social imperatives for economic growth are virtually unchallenged and initiatives for growth naturally lead to transformation and change. The resulting churn affects the built environment as well as the commodities people surround themselves with and as a consequence, their service lives become shorter and shorter (Schmidt & Science, 2012). Balancing the need for economic development with approaches that privilege ecological systems is understood to be key to developing sustainable, resource efficient cities.

The term urban sufficiency describes an approach that could help achieve better levels of environmental sustainability within the cities. Sufficiency represents a closure of the gap between demand and sustainable production and is closely related to the notion of efficiency (Linz 2006). Thematically, one can conceive of sufficiency, along with consistency and efficiency, as one of the main pillars of sustainability (Linz 2004). In the ecological debate, sufficiency describes a behavioural attitude that, either collectively or on an individual basis, calls for less consumption of resources (Linz 2006).

Until now, there has been little consideration of sufficiency in the fields of architecture and urban planning. A sufficient system keeps its consumption within certain limits and these are only increased when the environmental inputs allow for it. Manfred Linz calls sufficiency the search for the right balance: one where there is neither scarcity nor abundance/excess (Linz 2004). A sufficient system can approach such a balanced state by improving the efficiency of its internal procedures. This approach is mainly a collective one in which people need to identify themselves the options of small steps or initiatives rather than bringing in the fundamentally new form of transformations on a larger scale. Lynch (1981) claimed
that the good city is one in which the continuity of complex environment is maintained while dynamic change is allowed. The environmental sustainability in cities can be based on by increasing the carrying capacity of sinks, biodiversity and its integration in eco-system whereas, social sustainability is about life-enhancing condition within communities, and a process within communities that can achieve that condition is seen (McKenzie, 2004). Cities that enhance the quality of life for their citizen’s with higher levels of prosperity; they are likewise liable to get themselves more progressed in terms of sustainability. Florin (1989) suggested that the citizen participation in community organizations has been a major method for improving the quality of the physical environment, enhancing services, preventing crime, and improving social conditions.

2.1. Challenges in cities

Contemporary cities are facing environmental challenges related to global warming and climate change as well as shortages of energy and water. Urban areas are sustained by socioeconomic infrastructures that operate on global scales; the ecologically productive area needed to support a city can be 100 to 300 times larger than its physical footprint (Rees & Wackernagel 1994). As the density of buildings within cities increases, ecosystems supported by open spaces become further threatened. Urban ecosystems are also often of poorer quality, where levels of biodiversity are lower than in natural settings. In addition, urbanized areas modify microclimates and air quality by altering the nature of the land surface and by generating and storing heat (Oke, 1987). This is seen most clearly in the urban heat island (UHI) effect, where air and surface temperatures in urban areas tend to be higher than in the surrounding rural areas. Combined with other sources of heating, such as isolation and the effects of people and equipment, it leads to a need for additional energy to condition the places we occupy. Finally, urban areas free a vast quantity of naturally occurring trace materials (e.g., cadmium, zinc, mercury, nickel, arsenic) and exotic new anthropogenic substances (e.g., polychlorinated biphenyls) (Pacyna and Pacyna 2001).

Self-sufficiency is a concept that can help achieve a more sustainable society by reducing the amount of resources that we consume or by producing enough to fulfill one’s need. Ecologically convincing as it is, it is also a normative approach at the individual or collective level, asking for nothing less than a revolution of our contemporary consumption-oriented society.

Urban areas can be seen as both the causes of and the solutions to the current environmental crisis. As populations of large cities grow, this, in turn, creates demand for further development. Future cities will also have to deal with limited urban spaces and resources, undertake the preservation or conservation of sense of place, and consistently enhance the current urban environment. To curb the need for further expansion, urban planners have been exploring ways of making better use of existing areas. One response to this challenge is intensification, which is implemented through the redevelopment of existing sites in more intensive ways. However, there are other opportunities to make use of areas that are currently not being used effectively and one of these can be seen in the spaces left over by patterns of uncoordinated development of individual sites. It is often overlooked that urban green spaces can help store carbon emissions at the same time they provide opportunities for nature to inhabit cities. On a map of a city, there appears to be no place for spaces or voids without any function (Landgraf, 2015). The most regrettable loss for growing cities is the loss of voids (Armstrong 2006).

The concept of sufficiency can be utilized in cities to direct more efficient use of in-between spaces to mitigate the negative climate effect. To supplement other efforts aimed at combating the current ecological crisis, the transformation of underused, abused or deserted spaces within the city could coordinate green infrastructure. These spaces could be used to help reduce carbon waste and produce
energy through renewable resources as well as to feed people through small-scale urban farming. Although such production would never replace the supply side of rural land in terms of its volume, it presents opportunities to supplement remote production of energy and food. Sufficiency first and foremost a social or normative parameter (Linz, 2006) and thus invites exploration in the urban context.

3. In-between spaces

Urban in-between spaces can be seen as an ephemeral object, a site - yet not only space - but also a possible future (Rahmann & Jonas, n.d.). Hajer and Reijndorp first used the term in-between spaces in 2001 and claimed that these urban spaces could be used to bring together “disparate activities and character in a manner that creates valuable exchanges and connections” (Carmona, 2010). The term can refer to spaces of absence, voids, and the gaps between the forms of objects (Piccinno and Lega n.d.). They are the edges and leftover spaces, which are ever-present in urban and architectural design and which tend to unintentionally collide or create unfortunate divisions. These spaces intervene between adjacent objects that are ultimately problematic for the physical and social fabric. Instead of looking only at the built elements of the urban environment more weight should be given to the space in-between on the micro level. The use of in-between spaces is often seen as an architectural solution that deals with prevailing conditions in extreme climates. (Osorio, 2012).

The term in-between has been largely depicted in cultural and social studies as a state of liminality, often being often associated with contemporary geographical, economic and political questions. The concept of in-between also implicates the ‘inter’ prefix, one that suggests juxtaposition, overlapping, and concurrence, particularly between things (Luz 2001). Spatially, the in-between implies a middle location between two events or distinct spaces, for instance: between inside and outside, between here and there, between this and that (sides). While in-between spaces are often conceived of simply as a connection between two extreme ends, the logic of duality or binary system can also be blurred to recognize the physical presence of this connector.

Hudson & Shaw note that a planning guidance and policy for appropriate implementation is critical for urban voids, which are overlooked and yet depicted as negative from the realms of planning, architecture, design and urban theory” (Hudson & Shaw, 2011). Because of this, they often fade away with time or slip out of the main urban actors’ notice, left with no significant purpose. They consist of large or small scale places, public or private and built or unbuilt, which are in some kind of in-between phase - a pause - in functionality (Smet 2008). This paper investigates the potential of semi-privately owned left over spaces dispersed around urban areas. Previous studies have focused on public spaces and neglected the potential of semi-private and private spaces to be used constructively. The spatial conditions are those at the edges and corners of roadways, around and between buildings and those where the original purpose for space has or will soon become obsolete. The different scales of an urban left over space range between the building, plot, and block, even to the neighbourhood scale. In order to understand and evaluate these in-between spaces, they invite classification. The spaces are mostly found in between two buildings, in front, at the sides or at the rear of buildings but rooftops can also be seen as leftover spaces. Figure 1 suggests a few of the underutilized spaces that exist in an urban fabric and can be seen as neglected ones. These spaces are more tolerant spaces which represent sites for spontaneous activities to unfold, activities and experiments evocative of a future beyond restrictive capitalist (Hudson and Shaw, 2011).
Re-thinking the role of Urban In-Between Spaces

3.1. Spatial Classification

Roger Trancik was one of the first to write about lost or under-managed spaces when he suggested that these are anti-spaces within cities, making no positive contribution to the surrounding spaces and which are consequently in need of a redesign (Trancik, 1986; G Doron 2006). Following this, other researchers began to explore the topic using interpretations and terms such as loose, liminal, vacant, transitional, indeterminate, neglected and derelict. In most cases, while adding some slight semantic differences, these definitions have only contributed to increase confusion about the subject and have only focused on one type of space rather than their broader connections (De Girolamo 2013). They are largely defined according to their aesthetic merits and other qualitative aspects. Researchers also base their evaluations on cause and effect criteria, overlooking the potential and opportunities for regeneration they offer. Such spaces are unique, an anomaly which is located in a certain place and time which should be properly managed if not colonized (G Doron 2006). In urban planning and design, there has been little analysis of this aspect; temporariness and impermanence are rarely viewed as attributes of growth and regeneration (De Girolamo 2013).

As this paper is focused on the city only those left over spaces in urban settings are discussed. By way of field observations, these spaces have been identified as being in-between buildings or structures, at their edges and within. They extend across the boundaries of open/close, interior/exterior, private/public and have no official program or usage or they take the form of underutilized and informal parking areas (G Doron 2006). In-between becomes a spatial category by highlighting the value and variety of ‘between-ness’ from a spatial and transient perspective.

The in-between spaces within urban areas can then be divided into two qualitative categories; continuous spaces are those in transition where dimensions of time, space, and other circumstances are
relevant. Discontinuous space is temporal, having diverse physical circumstances and which do not relate well to the setting. These spatial types are seen as cracks, openings or gaps. In the existing fabric of our cities, there are many unplanned left-over spaces that are not considered purposeful and which arise during development (Spaces left Over After Planning or SLOAP). The classification system used in this research for in-between spaces is represented in figure 3.

Figure 3: classification for in-between spaces (Source: author)

There are distinctive terminologies that are associated with in-between spaces differentiated through their use, scale and size. According to Sola-Morales (1996), urban in-between spaces are qualified through their own senses of absence and emptiness and, therefore, they can remain as formal elements that symbolize the urban. In addition, they do not depend on a larger integration with the efficient and productive grid of the city. Through the use of advancing technologies, these sites can be developed as an active part of cities where the citizens can have a sense of identity, maintain social interaction and enhance the nature. Lefebvre encourages the inhabitants of urban society to fight for the restoration of the places of their cities to spaces for multiplicity, meetings, games and festivity. His work of “The Production of Space” celebrates the urban grid: the streets, the squares and the parks of the traditional city (Shukla, 2013). Overmeyer (2002) discusses some creative transformations and re-appropriation tactics as a generator for future development.

4. Potential

Although many in-between spaces represent a threat to safety and security if they are not being used purposefully, they also represent a positive potential if they can be appropriately activated. The semi-private spaces within cities become important where the space is accessible and controlled by residents and associate people. The ownership and stewardship become relevant consideration and design solutions could, therefore, be diverse in range as they reference the size, shape, light, air, accessibility or vegetation of the site. While the general public generally has the very little functional purpose for these spaces, one role they can play is a mediator between new and old elements in the urban fabric. It is
understood that in order to generate appropriate design proposals it is important to reference the context of in-between spaces. It is imperative to analyse and capture the complex spatial condition of places and uncovering the spatial relationship set up between these places and their environment.

The layer of urban in-between spaces can form a flexible approach in areas of development where the spaces can act as a connecting element, retaining and building local patterns of open in-between space. However, private ownership and authorship rights for utilizing these spaces arise and lead to conflict. Addressing this, the concept of eco-easements can be applied where the owner of the private land agrees with another party to allow the land to be used in a particular manner. Eco-easements can be struck to allow the full potential of land or roof to be realized by an interested party parties while ownership is not affected.

Through urban regeneration, municipalities can make effective use of in-between spaces by enabling ‘grow-in’ strategies. Carbon mitigation – helping to reduce a known cause of climate change – involves reducing the flow of heat-trapping greenhouse gasses into the atmosphere, either by reducing sources of these gasses or by enhancing the sinks that accumulate and store these gasses (Holly Shaftel, 2016). The use of these leftover spaces can be used to enhance the carbon sinks within the cities. The process of absorbing carbon through plants/trees as a photosynthesis process or by soil can be much slower than the rural region but the initiatives of urban farming can be taken. As this is an opportunity to achieve a climate-friendly agriculture by both sequestering carbon and reducing emissions. The main strategies are to enrich soil through biochar, to promote climate-friendly livestock production systems, to minimize the use of inorganic fertilizers and to restore land degraded through deforestation for agricultural purposes (Schaffnit-Chatterjee & Kahn, 2011). Urban agriculture represents a potential of increasing food production as well as to mitigate the negative carbon emission produced by the building construction and use or by use of motorcars. It also provides benefits to the community with an access to fresh and affordable food is an important component in helping to address low rates of fruit and vegetable consumption. Supermarkets and other fresh food stores in a neighbourhood can influence access, together with locality convenience, variety and the cost of fresh produce (Kent and Thompson, 2014). Energy Gardens can be seen as a potential since they concentrate on generating new biomass through plantations.

Renewable energy sources (with the exception of large hydro) are widely dispersed compared with fossil fuels, which are concentrated at individual locations and require distribution. Hence, renewable energy must be used either in a distributed manner or concentrated to meet the higher energy demands of cities and industries (IPCC 2007). The building sector is typically the largest consumer of electricity and often accounts for a significant portion of national greenhouse gas emissions. An intelligent micro-grid can incorporate buildings into the system as both electricity suppliers and energy consumers. This would enable a smooth interconnection of supply with demand and the integration of the diverse range of energy services (heating, cooling, lighting, electronics, motor drives etc.) that have traditionally been operated separately (IEA 2009).

Local scale energy production is more cost effective than large scale projects. Integrating solar photovoltaic (PV) panels onto roofs, specific open areas with the high potential to sun gain and facades of the buildings at the design-and-build stage is a growing development in many cities. PV systems can be used virtually anywhere and buildings offer large areas with which to capture solar radiation to produce electricity that can be either used in the building or fed into the electricity grid. Significant shares of around 10-30% of the total electricity demand of a city could be met by PV systems on buildings providing electricity at the point of use (IEA 2009). Solar PV cells vary in efficiency, performance, price and their
annual output depend on the local mean annual solar radiation levels. Wind energy has also the potential in cities and horizontal wind turbines can be used on the roof tops. Small wind energy systems (<100 kW) are usually designed to provide power to remote locations and micro-turbines (<2 kW), but they are also increasingly being used as independent and low-carbon alternatives to utility-generated electricity. Micro-wind turbines can power a single dwelling, whereas small systems are more suited for an apartment block, a business or a whole community (IEA 2009).

In-between spaces can also be used to collect and store rainwater, which can be further used to cool down buildings in hot areas, where water is generally scarce, or for urban vegetation purposes. Urban areas tend to exhibit higher temperatures than their rural surroundings, which can in certain conditions lead to thermal discomfort and impacts on human cardiovascular and respiratory systems. During the day, as air temperatures increase in poorly ventilated buildings more energy is consumed to cool these spaces. In cities, the micro-urban hot spots are formed at parking lots, non-reflective roofs, and asphalt roads. Hence, assessment of UHI effect and development of strategies by which in-between spaces can be used to mitigate local temperatures can be helpful. Urban heat sinks, known as negative heat islands, have been developed in the cities that are colder than the surrounding countryside. These heat sinks can be utilized mainly during the morning and in temperate, tropical, semi-arid and arid climates (Pena 2009).

There are two main UHI reduction strategies that can be applied to in-between spaces. First is to increase surface reflectivity to reduce radiation absorptions. This can be done by simply placing the light colored panels or paint on existing material surfaces. This technique can be applied roofs to reduce energy demand for cooling as well on the pavements which are based on the whitened asphalt roads. The second is to increase vegetation cover to control temperature rise. Trees form a nice canopy, shading the area and have a cooling effect on views. Trees are also a mediator between nature and humans while increasing the biodiversity within the cities. By installing more trees into in-between spaces the environment can be cooled down while allowing biodiversity to flourish.

Another potential for in-between spaces is for them to be used tactically. Tactical urbanism is a recently developed concept, often used to refer to low-cost, minimum effort, temporary interventions that improve the liveability and aesthetics of local neighbourhoods. Small scale and short-term interventions can inspire long-term change as this approach is “deliberate, phased approach to instigating change; the offering of local ideas for local planning challenges; short-term commitment and realistic expectations; low-risks, with possibly a high reward” (Pfeifer, 2013). The tactical approach offers low cost, adaptable processes whereby the urban landscape becomes an urban lab for people to test out their diverse ideas. This approach can be fused together with landscape ecology initiatives which can work on different scales and focus on the relationship between urban landscape patterns and socioeconomic procedures. Benedict and McMahon (2003) point out that two principles are essential to conceptualizing the notion of green infrastructure as fundamental to moving towards more sustainable cities; namely connectivity (physical and visual) and context. Those cities committing to such an approach by supporting sustainable projects are likely to benefit in the long run through the value of ecosystem services for urban residents and the broader public. The urban landscape cannot be viewed as something static, but it is vital to achieving a coherent design solution. Thinking in terms of eco-framework different strategies may concentrate on the potential of landscape infrastructure to consider modifications and transformations, for example, climate change, food insecurity, and limited resources.
5. Conclusion

This paper has discussed the potential for urban in-between spaces to be used positively and in ways that can help meet our future needs. The ability to recognize in-between spaces in the urban context is an integral part of an urban redevelopment process, where structured and layered approaches become useful to understanding what these places will be and these spaces have to offer. Under the pressure of urban growth and densification, urban voids can function as mediators between existing and new. Voids can provide the tissue of the familiar and unfinished under conditions of renewal and replacement. These spaces can function as generators and canvases for creative expression that enables recognition of a human scale. In order to take benefit from these in-between spaces both short and long-term strategies should be well planned and documented.

The role of sufficiency in designing these spaces can help the city to mitigate negative climate effects but will also provide some revenue to the locals or artists for displaying their work or make graffiti on walls. There are a lot of other possibilities but we need to know about the life cycle of this temporary intervention to become a permanent one in the end and become more significant for city planning. As noted by Linz (2004), to foster and alleviate the change for sufficiency we need to promote three steps; big public-administrative measures, economic measures to ensure or improve ecological compatibility, and small-scale steps by the individual. The authors propose that in-between spaces provide an opportunity to rethink existing notions of open space distribution and characterization. In recognizing their full potential, the small and divided character of these spaces within the urban fabric can be preferably viewed as an opportunity than a constraint. Professionals can also consider temporary use projects as a part of the spatial planning and design process. Self-sufficient solutions can provide a lot of opportunities for the population in terms of growing their own food, making an environment more sustainable and generating some capital. There is considerable potential for their effective use, as they can be seen throughout the city as open ground surfaces, rooftops, beneath buildings, adjacent to streets and within underutilized car parking areas.

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An investigation into the way landscape aesthetic affects healthy behaviour

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Abstract: Modern society is increasingly aware that public health is inextricably linked with the condition of our immediate landscape. Landscape here refers to a combined quality between nature and culture that people see and experience. Exposure to landscapes (natural or built) are considered as one of the key elements of human health, and is closely related to the concept of people’s perception. There is a growing belief that people can achieve a healthier lifestyle by residing and working in regional areas. Unfortunately, little information is available to analyse the relationship between preferences of two landscape settings (i.e., man-made and natural) with healthy behaviours in regional areas. In this paper, people’s preference to four types of landscapes (i.e. natural, community facilities, business and commercial, reserve) are examined, coupled with the way it affects healthy behaviours (i.e. being outdoor, social connectedness and physical activity). It was found that a significant relationship does exist between preference of landscape aesthetic and healthy behaviour choice. Participants held strong preferences towards two types of landscapes namely, community facilities and natural landscape. It was also found that business and commercial landscape was the most preferred landscape for supporting healthy behaviours.

Keywords: Landscape; perception; healthy behaviour.

1. Introduction

The predominant health problem of the 21st century is chronic diseases associated with sedentary lifestyles (Freeman, 2001; Giles-Corti, 2006). It is believed that inactive lifestyle is partly due to the current shape of our surroundings with increasing reliance on the automobile and a decreased ability to engage in health-related activities (Freeman, 2001; Lopez and Hynes, 2006; Berke et al., 2007). Some studies (Frank and Engelke, 2001; Perdue et al., 2003) have proven that the deteriorating physical features of built environment can negatively influence public health. In Australia, the Government has recognised that multi-level interventions (i.e. individuals, social environment and built environment) are more likely to be effective in improving healthy lifestyle (SA Active Living Coalition, 2012).
The European Landscape Convention (Council of Europe, 2000), considers landscape as one of the key elements of people’s health. Landscape is believed to play an important role in encouraging, or discouraging, vigorous healthy activity (Gesler, 1992; Velarde et al., 2007). Landscape can also be defined as a zone that is perceived by people, whose visual features and character are the result of the action of natural and/or cultural factors (Council of Europe, 2000). Landscape is something to be seen, remembered and to delight in (Lynch, 1960). Landscape in this perspective refers to a combined quality between nature and culture that people see and experience. Thus, the landscape becomes an aesthetic object, a quality which one visits to enjoy. The term landscape in this article is referred to its visual properties, including human-made landscape, physical and biological resources (Daniel and Vining, 1983; Amir and Gidalizon, 1990). Beauty in landscape comes from the object and the observer (Muir, 1999; Daniel, 2001). Hence, this study discusses the aesthetic landscape as a subjective impression of its viewer. Hull and Revell (1989) expressed this broad approach to landscape as the outdoor environment, natural or built, which can be directly perceived by a person visiting and using that environment. Some studies (Frank and Engelke, 2001; Lopez and Hynes, 2006; Ewing et al., 2008) have considered the link between urban landscape and physical activity. Other studies focused on the link between human perception and the way people engage with their surrounding landscape (Zube, 1991; Porteous, 1996). Unfortunately, little attention has been undertaken to provide an understanding of the way human perception of landscape affects the vigorous choice of healthy behaviours. Therefore, this paper attempts to provide an understanding on the way aesthetic perception of landscape influences people’s healthy related behaviours within different types of landscapes. Such an understanding may be able to provide alternative design solutions beneficial to the overall public health.

Considerable number of people are moving to outer urban areas due to the perceived attractiveness of landscape and lifestyle (Luck et al., 2010). People are seeking a better and healthier lifestyle, which they believe can be achieved by living and working in particular regional areas (Luck et al., 2010). Few studies (Murphy, 2002; Burnley, 2003; Antrop, 2004; Ragusa, 2010) have briefly touched on the way regional landscapes affect health in general. Although a relatively large body of evidence exists about landscape as a contributing factor to health in the outer urban areas. There is still a gap on the lack of information that map-out criteria for landscape in regional area as a determinant for healthier lifestyles. Furthermore, little information is available on the relationships between people’s landscape preference and healthy related behaviours in regional area. It is believed that no such focused study is available today. Therefore, this study aims to address the gap in knowledge by investigating the role of landscape aesthetic preference plays in affecting healthy related behaviours in a regional context.

2. Landscape aesthetic preference and healthy behaviour

Some studies have revealed landscape preference similarities among alike cultures. North American, European and possibly some other cultures as well, generally prefer natural landscape over man-made landscape yet their preference for natural landscape tends to be more subtle than urban landscape (Ulrich, 1984; Parsons, 1991; Zube, 1991). However, there is no means of sufficient evidence on the degree of consistency among landscape types. Some studies found that the presence of natural elements tends to lead to increased liking for urban environments (Parsons, 1991; Antrop, 2004; Naderi and Raman, 2005; Crow et al., 2006). Similarly, Zube (1991) revealed that man-made elements contribute to the increased likelihood for natural landscapes. Hence, it is evident that a complex relationship exists between landscape and human experience. Indeed, the link between the two is affected by the context of a particular setting and people’s experience. Moreover, in most of the above mentioned research, the focus
An investigation into the way landscape aesthetic affects healthy behaviour

is on landscape in urban or city settings and little information is available on the landscape in a regional context.

Nowadays, there is an increasing concern on the importance of engaging landscapes (Bourassa, 1988; Brandenburg and Carroll, 1995; Jorgensen, 2011). An appealing landscape contributes to human health (Abraham et al., 2010, p.59). At the European Landscape Convention in 2000, landscape protection, management and planning was promoted, and considered landscape as a key element of individual and social well-being (Velarde et al., 2007, p.199). Since that time, additional studies have stated that different landscapes have the potential to reduce modern lifestyle diseases (Frank et al., 2004; Booth et al., 2005; Berke et al., 2007; Ewing et al., 2008). Other studies highlight the importance of being outdoors (Krenichyn, 2006; Gidlöf-Gunnarsson and Öhrström, 2007; Abraham et al., 2010), the facilitation of social contacts (Commission, 1997; Green, 1999; Semenza and March, 2009) and physical activities (Bauman, 2004; Berke et al., 2007; Foster and Giles-Corti, 2008) as three significant factors contributing to health benefits. Abraham et al. (2010) and Lopez and Hynes (2006) suggested that landscape can contribute to an improvement in physical health. Furthermore, he argued that being in the landscape promotes emotional relaxation and mental health (Gidlöf-Gunnarsson and Öhrström, 2007; Velarde et al., 2007). An appealing landscape can also promote social support and emotional stability (Abraham et al., 2010; Ward Thompson, 2011).

Some studies have found the association between landscape and health (e.g. Ulrich, 1984; Burgess et al., 1988; Gesler, 1992; Velarde et al., 2007). These studies were undertaken with consideration to visitor experience within natural landscape places and elements; and confirmed that natural landscapes have a significant impact on public health and well-being. In their study (Abraham et al., 2010), landscape is described as a continuum of ‘wild’ natural and designed environments in urban and rural areas, which promote health benefits to the community. Unfortunately, little research has been undertaken on the preference of natural versus man-made landscapes, and how they affect human behaviour in rural or regional environment. This study analyses three types of healthy behaviour, which are the choice of being outdoors, social connectedness and physical activity. Thus, this study hopes to provide a contribution to the existing body of knowledge, by seeking to understand the way people’s preference on different landscapes affect healthy behaviours in a regional context to help professionals in future decision making for designing, planning and developing regional areas as healthier places for the public.

3. Methodology

This study employed a single case study as the preferred research strategy, because a case study allows for an exploration data collection of the current phenomenon. A questionnaire survey was utilised as the method to collect the required data. A concurrent mixed-method (triangulation) was employed to best understand the complex relationship of how landscape aesthetic perception affects healthy behaviour choice. This method was utilised as a means to offset the weaknesses inherent within one method with the strength of another method as researchers concur that biases inherent in any one method could neutralise or cancel the biases of other methods (Ragusa, 2010).

3.1. A case study of townships of Normanville, Yankalilla, and Carrickalinga

The District Council of Yankalilla covers some of the most scenic parts of the Mount Lofty Ranges. Extending from the Willunga escarpment to Cape Jervis, the district is characterised by productive agricultural land, water catchments, conservation parks and spectacular coastal scenery (DPTI, 2013).
Yankalilla Township is the district’s main service centre. However, most residential growth is occurring in the nearby coastal settlements of Normanville and Carrickalinga, which are both popular with holiday makers and visitors alike (DPTI, 2013). Due to this unique characteristic as holiday destinations in the regional area, these three townships were selected as the case study.

These three townships were also chosen based on their geographical location in relation to the city of Adelaide; with the majority of settlements being located approximately a one-hour drive from Adelaide. These townships were also chosen on the basis of their proximity to the sea/coastal areas, which is one of the main features for the counter-urbanisation or sea-change phenomena (DPTI, 2013). Furthermore, in the Final Strategic Direction Report (DCY, 2012), District Council of Yankalilla has outlined its focus for optimising health outcome of the public, one of them is to manage and direct the future development of the townships to facilitate active healthy lifestyles. The district community has expressed a desire to protect the existing natural and built environment to ensure that the area largely retains its current “rural” feel (DCY, 2008). This report has further strengthened the increasing awareness of the association between landscape and health within its local community. Therefore, the three townships are deemed to be a suitable case study for this research. As mentioned previously, this study aims to investigate the way preference of different landscape types (i.e. natural or man-made) influence people’s healthy behaviour.

In the Community Land Management Plans (DCY, 2013), there are three classifications of man-made landscape: reserves, community facilities, and business and commercial facilities. Meanwhile, the availability of community facilities and commercials buildings is limited in this area. Based on this, the study has chosen the following 10 major landscape features, which represent the different landscape classifications across the three townships as the focus of this study.

- **Reserve**: Bungala Park, Robert Norman and Apex Parks
- **Community facilities**: Yankalilla Golf Course, Yankalilla Memorial Square, Carrickalinga Linear Track
- **Business and commercial**: Yankalilla Town Centre, Normanville Town Centre
- **Natural**: Bungala River, Normanville Beach, Carrickalinga Beach
3.2. Survey questionnaire

A questionnaire survey is used as the primary method of data collection. The questionnaire allows respondents to spend a relatively long time on the survey, since they can be completed at the convenience of the respondent (Neuman, 2000). The questionnaire assists in establishing people’s opinion between landscape and health in a single survey (Neuman, 2000). In this study, 500 questionnaires were distributed to households within the three townships namely Yankalilla, Normanville and Carrickalinga. At 30% response rate, a total of 149 valid questionnaires were received. The questionnaire was designed to investigate people’s preference regarding natural and man-made landscape and the activities for such landscape. Respondents were asked to express their preferences of landscape type, by allocating a score from the five points on the Likert scale ranging from ‘1 = very bad’ to ‘5 = very good’. Respondents were also asked to describe the way they use these landscapes. For example, frequency of visit, the reason, and chosen healthy related activities. Survey data was coded into Statistical Package for the Social Sciences (SPSS) software. ‘Correlation’ was used to investigate people’s preference and their behaviour approach.

4. Results and discussion

The aim of this study was to identify people’s opinion of landscape and the way it’s affecting their choice of healthy behaviours. This section discusses the findings of the relationship between landscape type and healthy behaviours. It examines the descriptive aesthetic values of four types of landscapes. It also examines the descriptive values of people’s preference on three types of healthy behaviours within four different landscape types. Finally, it discusses the strength of correlation between aesthetic opinion and the choice of healthy behaviours.

4.1. People’s preferences of existing landscape

The survey investigated people’s aesthetic opinion of ten existing landscape features across the Townships of Yankalilla, Normanville and Carrickalinga. The results in Table 1 show that respondents agreed that Normanville Beach has the best quality of landscape with the highest mean score of 4.5532. This showed that people’s appreciation of natural landscape is higher when compared with man-made landscape. However, the result also revealed that Bungala River, another main feature of natural landscape in the townships has the lowest score. This is expected due to limited access and the under-developed condition of Bungala River. Yankalilla Golf Course and Yankalilla Memorial Square were found to be the second and third preferred landscape based on people’s aesthetic opinion. This showed that community also appreciated man-made landscapes.

This study then investigated the aesthetic opinion between four different landscape types, namely reserve, community facility, business and commercial, and natural. The ‘compute variables’ was used to combine results from ten landscape features into four categorical landscapes. The results in Table 2 show that among the four landscape types, community facility was the preferred landscape based on respondent’s aesthetic opinion. Community facility was considered as the most preferred landscape due to the perceived attractiveness of Yankalilla Golf Course. Despite the high preference of beach features, according to participants, natural landscape was considered as the second most preferred landscape type with a mean score of 4.3830. This is expected due to the unattractiveness of Bungala River as one of the natural landscape features. Business and commercial landscape received a mean score of 4.2553. Meanwhile, reserve scored the lowest among respondents with a mean score of 4.2447.
Table 1: Descriptive statistics of aesthetic opinion on existing landscape features

<table>
<thead>
<tr>
<th>Aesthetic Opinion</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yankalilla Golf Course</td>
<td>149</td>
<td>4.4468</td>
<td>.71653</td>
</tr>
<tr>
<td>Yankalilla Town Centre</td>
<td>149</td>
<td>4.1489</td>
<td>.75119</td>
</tr>
<tr>
<td>Yankalilla Memorial Square</td>
<td>149</td>
<td>4.4255</td>
<td>.58028</td>
</tr>
<tr>
<td>Bungala River</td>
<td>149</td>
<td>3.8680</td>
<td>.79704</td>
</tr>
<tr>
<td>Bungala Park</td>
<td>149</td>
<td>4.2553</td>
<td>.67464</td>
</tr>
<tr>
<td>Robert Norman &amp; Apex Park</td>
<td>149</td>
<td>4.2340</td>
<td>.75794</td>
</tr>
<tr>
<td>Normanville Town Centre</td>
<td>149</td>
<td>4.3617</td>
<td>.60525</td>
</tr>
<tr>
<td>Normanville Beach</td>
<td>149</td>
<td>4.5532</td>
<td>.61885</td>
</tr>
<tr>
<td>Carrickalinga Linear Track</td>
<td>149</td>
<td>4.3191</td>
<td>.86241</td>
</tr>
<tr>
<td>Carrickalinga Beach</td>
<td>149</td>
<td>4.4043</td>
<td>.77065</td>
</tr>
</tbody>
</table>

Table 2: Descriptive statistics of aesthetic opinion on four landscape types

<table>
<thead>
<tr>
<th>Aesthetic Opinion</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural landscape</td>
<td>149</td>
<td>4.3830</td>
<td>.73878</td>
</tr>
<tr>
<td>Community facility</td>
<td>149</td>
<td>4.4468</td>
<td>.61885</td>
</tr>
<tr>
<td>Business &amp; commercial</td>
<td>149</td>
<td>4.2553</td>
<td>.63308</td>
</tr>
<tr>
<td>Reserve</td>
<td>149</td>
<td>4.2447</td>
<td>.62443</td>
</tr>
</tbody>
</table>

4.2. Landscape type and healthy behaviour

The descriptive analysis above has indicated that natural landscape, community facility, business and commercial, reserve were the four types of existing landscapes within the Townships of Yankalilla, Normanville and Carrickalinga. This study then investigated the way aesthetic perceptions of four landscape types affect the choice of healthy related behaviour. This study examined three types of healthy behaviour, which are being outdoors, physical activities and being involved in social events. The ‘ANOVA’ was used to identify whether the values were similar or they had significant differences. The F statistic, or F value, is a random variable that has an F distribution and P value is the estimated probability of rejecting the null hypothesis (no differences). For example, if the confidence level is p < 0.05, the results show significant differences between the variables. The results led to the rejection of the null hypothesis that respondents had the same preferences of healthy behaviour. As shown in Table 3, the results show diverse preferences of healthy behaviour across different types of landscapes.

The result highlighted that business landscape (M=4.0957) was found to be more engaging people to be outdoors compare to natural setting or other type of man-made landscapes. In terms of its affect to encourage being outdoors activity, natural setting was associated with an intermediate mean value (M=3.9787), in contrast to community facilities and reserves, which have the smallest mean value (M=3.9574). As shown in Table 3, all four types of landscapes were found to have statistically significant relationships with being outdoors activities. It is also revealed that the aesthetic quality of natural setting has the highest significant effect on the ability to encourage people to be outdoors (F=11.261, p=.000), rather than man-made landscapes. In terms of man-made landscapes, the aesthetic quality of business landscape (F=6.335, p=.000) has an intermediate effect in encouraging people to be outdoors, in contrast to community facilities (F=8.746, p=.001), which have a high potential effect, or reserve (F=5.648, p=.001), which has the lowest significant effect.
In terms of physical activities, this study found that people were more likely to be involved in physical related activities in business and commercial landscapes (M=4.1265). The second preferred landscape type was community facilities (M=4.0851), which then followed by natural settings (M=4.0000). Meanwhile, reserve was found to be the least preferred landscape to do physical activities (M=3.9255). As shown in Table 3, all four landscape types have a significant relationship with the likeliness to do physical activities. The result also revealed that both natural settings and business landscapes have a high numerically significant effect on the ability to encourage people to do physical activities (F>12.000, p=.000). The aesthetic quality of community facilities (F=10.023, p=.000) has an intermediate effect in encouraging people to do physical activities, meanwhile, reserve (F=4.597, p=.004) has the lowest effect.

In terms of social activities, it was revealed that business landscape (M=4.3298) was again found to be the most preferable landscape type. For supporting social events, natural setting and community facilities were associated with an intermediate mean value (M=3.9787), while reserve was the least preferred landscape (M=3.9043). The result also indicated that the aesthetic opinion of three types of landscapes-natural setting, reserve and business landscapes-have statistically significant relationships with the likeliness to be involved in social events (p<0.005). In contrast, it was found that there was no significant relationship between the aesthetic opinion of community facilities and social events (p>.005). The aesthetic opinion of reserve has the highest numerically significant effect on the ability to increase social activities. Meanwhile, natural settings (F=4.488, p=.017) have an intermediate effect, and business landscape (F=4.324, p=.005) has the lowest potential effect in encouraging people to be involved in social event.

<table>
<thead>
<tr>
<th>Healthy behaviours</th>
<th>Landscape type</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Likeliness to be out and about</td>
<td>Natural setting</td>
<td>3.9787</td>
<td>.73690</td>
<td>11.261</td>
<td>.000***</td>
</tr>
<tr>
<td></td>
<td>Man-made reserve</td>
<td>3.9574</td>
<td>.62406</td>
<td>5.648</td>
<td>.001***</td>
</tr>
<tr>
<td></td>
<td>Man-made community facility</td>
<td>3.9574</td>
<td>.65798</td>
<td>8.746</td>
<td>.001***</td>
</tr>
<tr>
<td></td>
<td>Man-made business and commercial</td>
<td>4.0957</td>
<td>.73454</td>
<td>6.335</td>
<td>.000***</td>
</tr>
<tr>
<td>Likeliness to do physical activities</td>
<td>Natural setting</td>
<td>4.0000</td>
<td>.84327</td>
<td>12.503</td>
<td>.000***</td>
</tr>
<tr>
<td></td>
<td>Man-made reserve</td>
<td>3.9255</td>
<td>.74439</td>
<td>4.597</td>
<td>.004***</td>
</tr>
<tr>
<td></td>
<td>Man-made community facility</td>
<td>4.0851</td>
<td>.82961</td>
<td>10.023</td>
<td>.000***</td>
</tr>
<tr>
<td></td>
<td>Man-made business and commercial</td>
<td>4.1265</td>
<td>.67077</td>
<td>12.050</td>
<td>.000***</td>
</tr>
<tr>
<td>Likeliness to be involved in social gathering</td>
<td>Natural setting</td>
<td>3.9787</td>
<td>.79371</td>
<td>4.488</td>
<td>.017**</td>
</tr>
<tr>
<td></td>
<td>Man-made reserve</td>
<td>3.9043</td>
<td>.76356</td>
<td>5.645</td>
<td>.001***</td>
</tr>
<tr>
<td></td>
<td>Man-made community facility</td>
<td>3.9787</td>
<td>.67532</td>
<td>2.038</td>
<td>.142</td>
</tr>
<tr>
<td></td>
<td>Man-made business and commercial</td>
<td>4.3298</td>
<td>.67789</td>
<td>4.324</td>
<td>.005**</td>
</tr>
</tbody>
</table>

*p<0.05,  **p<0.01,  ***p<0.001

4.3. Correlation between landscape aesthetic opinion and healthy behaviour

The degree of correlation between people’s opinion of landscape aesthetic and preference of healthy behaviours show significant correlations between the two. A series of ‘Pearson Correlations’ was performed between all of variables. As presented in Table 4, people’s aesthetic landscape opinion has a significant association with healthy behaviours. Specifically, there were three types of landscape that were found to have a significant association with the likeliness of healthy related behaviours. The three landscapes were natural landscape, business and commercial facilities and public reserves.
As shown in Table 4, the result suggests that there was a significantly strong correlation found between the aesthetic opinion of business and commercial facilities with the likeliness to be outdoor and physical activity. There was also a strong correlation found between natural landscape and likeliness to participate in physical activities and being outdoors. In contrast, a lower correlation value was found between both business landscape and natural landscape with the likeliness to be involved in social gathering. The result also highlighted that there was a strong correlation between the aesthetic opinion of reserve and the likeliness to be involved in social gathering. Meanwhile, the result shows that there was a numerically lower association found between both community facilities and reserve landscapes with likeliness to do physical activities and being outdoors. Interestingly, there was no significant correlation found between community facilities and likeliness to be involved in social events. In general, preferences of landscape aesthetic were found to be a potent predictor of likeliness to participate in three types of healthy behaviours (i.e. being outdoors, physical activities and social gathering).

Table 4: Correlation between preferences of landscape aesthetic and healthy behaviour

<table>
<thead>
<tr>
<th>Aesthetic opinion</th>
<th>Mean score</th>
<th>Likeliness to be out and about</th>
<th>Likeliness to do physical activities</th>
<th>Likelihood to be involved in social gathering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural landscape</td>
<td>4.3830</td>
<td>.574**</td>
<td>.604**</td>
<td>.348*</td>
</tr>
<tr>
<td>Community facilities</td>
<td>4.4468</td>
<td>.528**</td>
<td>.559**</td>
<td>.283</td>
</tr>
<tr>
<td>Business &amp; commercial facilities</td>
<td>4.2553</td>
<td>.589**</td>
<td>.713**</td>
<td>.496**</td>
</tr>
<tr>
<td>Reserve</td>
<td>4.2447</td>
<td>.543**</td>
<td>.531**</td>
<td>.506**</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

4.3. Discussion

This research analysed the opinion of the people with regard to the aesthetic of landscape and healthy behaviour. In general, this study found that there was a significant relationship between preference of landscape aesthetic and the likeliness to participate in healthy related behaviours. In line with previous studies (Ulrich, 1984; Parsons, 1991; Zube, 1991), the survey found that people’s appreciation of upheld natural landscape is higher than man-made landscape. This study found that participants held strong preferences towards two types of landscapes, which are community facilities and natural landscapes. This indicated that both man-made and natural landscapes are being appreciated by people. It was also found that business and commercial landscape was the most preferred landscape for supporting healthy related activities. This confirmed the hypothesis that the presence of natural elements tends to increase liking for urban environments (Parsons, 1991; Antrop, 2004; Naderi and Raman, 2005; Crow et al., 2006). Particularly, in this study, it is believed that such results had come into view because of the perceived greenery at the Yankalilla Golf Course and Yankalilla Memorial Square, which is also supported by the visible beach view from Carrickalinga Linear Track. In contrast, public reserve was found to be the least preferred landscape, in terms of the aesthetic value and its role in supporting healthy behaviours. It showed a degree of consistency with the District Council of Yankalilla, which has identified the condition of public reserves almost undeveloped (DCY, 2013).

5. Conclusion

The aim of this study was to investigate the way landscape aesthetic opinion affects healthy behaviours in a regional context. The result of this study has demonstrated that a significant relationship was found between people’s aesthetic opinion of four different types of landscape (natural, community facility, business facility, and reserve) and three types of healthy behaviours (being outdoors, physical activity and
An investigation into the way landscape aesthetic affects healthy behaviour

social activity). Specifically, the aesthetic preference of landscapes was found to significantly affect physical activities, thus facilities that support physical activities may be an important investment. The aesthetic preference of landscapes was also found to have an intermediate affect in encouraging people to be outdoors. Meanwhile, the aesthetic preference was found to be less significant factor for improving social connectedness. However, it is still important that the landscapes and its facilities support both social activities and outdoors activities for increasing health benefits of public. Recognising the people’s preference and involving them in the planning and management of natural and man-made landscape may help in designing alternative solutions to the regional environment that will be beneficial to people’s health. This is possible because the people have a close relationship with their surrounding landscape and are aware of its role in affecting their choice of healthy behaviour.

While these results have reflected that there was a strong relationship between landscape and healthy behaviour, the result of this study cannot be generalised. This is because the sample size and the scope of this study were small and limited to a regional area in South Australia. In order to test the validity of the findings, this study might be developed for a future study with a larger sample that addresses landscape preferences as a determinant for healthy related behaviours.

References

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Mobile gaming for agonistic design

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Abstract: This paper demonstrates how mobile games can contribute to participatory design and its aim of achieving positive change through the involvement of stakeholders. This overarching goal is considered via a particular case-study that utilizes a purpose-built smartphone game. The case-study applies this game to the design challenges of urban cycling. Utilisation of the game in a stakeholder workshop suggests that mobile play can aid understanding and help to establish communication amongst diverse participants. For further information and media, see https://osf.io/vy5dq/

Keywords: mobile games; urban cycling; participatory design; infrastructuring; urban design.

1. Participatory design toolkits

“What are we looking at? Are we there? We’re in it? On that bike?” Participant A, first reaction to PocketPedal.

This paper engages with agonistic characteristics of participatory design or “constructive controversies among ‘adversaries’ who have opposing matters of concern but also accept other views as ‘legitimate’.” (Björgvinsson et al., 2010, p. 48) In the presence of such controversies, design can be understood as a negotiation of social change between individuals, social contexts and design artefacts (Latour, 2005). Consequently, an important objective of participatory design is to promote the negotiation of social change for the production of critical alternatives rather than objects or products (Gerrard and Sosa, 2014).

Construction of conditions needed for such negotiations has been described as infrastructuring, or the aligning of inscribed norms and values across contexts through socio-material negotiations. (Star and Bowker, 2006[2002]; Karasti et al., 2010) This search for alignment is motivated by the recognition that physical construction will not be supported without a cultivation of fertile social infrastructure (Clement et al., 2012; Karasti, 2014). This type of infrastructure sustains and enables dreams of the new. It consists of knowledge, know-how and institutions, existing as dynamic fabrics of relationships – a kind of ecology. Successful establishment of such infrastructure depends on the construction of a “common language” (Neumann and Star, 1996). The toolkit discussed in this paper aims to assist with this shared language.
This commonality does not necessarily resolve as a consensus, or even compromise. Instead, the non-existence of a single homogeneous public and the resulting agonism can be seen as a norm. Consequently, in conditions of agonistic democracy (Mouffe, 2005), the goal is not consensus, but the discovery and cultivation of commonalities. Such commonalities can manifest as “boundary objects” (Star and Griesemer, 1989) that can inhabit different communities of practice. These objects can be used and understood differently by different groups but retain their identity across sites. Stakeholders can “colonize” such objects for the “collective creation of values”. Work discussed below seeks to activate such boundary objects through the introduction of mobile-game worlds as shared ‘design things’ (Ehn, 2008).

Figure 1. In game images. I: an open door blocks the player’s path. II and III: difficult intersections – in order to make room for left hand vehicles, the player must move across lanes of traffic. IV: the player has successfully navigated the level.

“All people are creative and can contribute to design if provided an appropriate setting and tools” (Vaajakallio and Mattelmäki, 2014). Design games can act as such tools, and help stakeholders explore the world and its future states (Lerner, 2010; Sanders and Stappers, 2014) making solutions more probable (Brandt, 2006; Vaajakallio and Mattelmäki, 2014) in the processes identified above as infrastructuring.

Computer games can further extend the capabilities of design games (von Borries et al., 2007; Lerner, 2014), and are effective as tools for social inclusion (European Commission's Joint Research Centre et al., 2013). Yet, their detailed environments can be less open to individual interpretation than board or parlour design games (Brandt and Messeter, 2004). Furthermore, stationary videogame systems can exclude non-gamers, requiring dedicated spaces and knowledge of unfamiliar conventions and demanding controllers.

At the moment of writing, the accessibility of games is being redefined by portable devices such as smartphones. Games running on such devices can be played in diverse locations and social situations by much broader publics. Such ‘mobile’ games have been used in the context of design – for example, for exploration (Ehn et al., 2014), the education of planners (Valdez Young, 2013), or to demonstrate the interrelationship between games and cities (de Souza e Silva and Hjorth, 2009). However, a review of
current literature indicates that purposeful application of games for infrastructuring, and more specifically to the construction of common languages in the context of intractable design problems, has not been previously attempted. Development of possibilities promised by this approach is the focus of this paper.

2. Urban cycling as an agonistic test-case

“It’s kind of continual, isn’t it? It’s just continual drip drip annoyance. It’s not one particular thing, it’s all the time.” Participant B, attempting to articulate the problems of St Kilda Road.

As its case-study, this paper considers St Kilda Road, a busy commuter corridor with inadequate cycling provisions in Melbourne, Australia. The challenges of tackling urban cycling are appropriate as a case-study because of their similarity to other design problems involving multiple and diverse stakeholders. To date, conventional design approaches have been ineffective in improving the road’s cycling conditions. Research discussed in this paper seeks to consider viable extensions to the established design methods.

According to a recent report, on an average day, St Kilda Road is used by 41,000 vehicles, 200,000 tramway passengers and 3,000 cyclists (GHD, 2014). Such traffic exceeds governmental recommendations for when bicycles and cars should be physically separated (Austroads, 2011). In contradiction to these guidelines, cycling provisions along the route consist of lanes painted onto the road. These lanes are narrow, discontinuous at intersections, and, in some places, cross multiple streams of motor traffic. Such road conditions lead to physical collisions and social hostilities. This is recognised by cycling support groups (Bicycle Network Victoria, 2000) and governmental organisations (Austroads, 2011) alike, yet proposals to isolate cyclists from vehicles have not been implemented. The rest of this section describes typical design challenges of this situation and establishes directions for subsequent exploration.

2.1 Understanding complexity

The first of these directions emphasises the highly complex nature of typical design challenges that cannot be easily represented by numerical data. In the period of 2010–2015, VicRoads, the governmental road authority, recorded 122 crashes involving cyclists along St Kilda Road, one of the highest collision rates in the state (VicRoads, 2016). These included the following common events: 1) DCA 163 ‘vehicle door’ event occurring when a driver or passenger in a parked car opens a door in the path of a passing cyclist. A study commissioned by the Road Safety Action Group found that all cyclists observed along St Kilda Road ride within car door swings (CDM Research, 2015); and 2) DCA 167 ‘Left turn side swipe’, an event occurring when a vehicle veers into a cyclist when attempting to turn off/on St Kilda Road, mostly at intersections. The primary cause of such incidents are motorists unaware that a cyclist is riding between them and the kerbs (Johnson et al., 2010).

While useful, such statistics cannot portray near misses, the context of accidents or stakeholder behaviours, and can distort the character of events through rigid categorisation. For example, an incident involving a cyclist coming off a bike as the result of needing to avoid a suddenly opened car door might be classified as the generic DCA 174 Out of Control on a Carriageway, rather than as a dooring incident. In other cases, efforts to reduce kerbside side-swipe collisions by implementing left-hand turning lanes at intersections force cyclists to merge with streams of centre-lane traffic. The complex chains of events surrounding the resulting events can be lost during data collection and classification.

Moreover, it has been estimated that only 1 in 30 non-fatal cyclist crashes in Victoria are reported to the police (Harman, 2007). Crashes are usually recorded by police when assessing property damage after the event. Therefore, it can be difficult to report crashes that did not affect the vehicle, but have caused...
significant injury to a cyclist (Monash University Accident Research Centre et al., 2012; Amy Gillett Foundation et al., 2015). This paper suggests that these observations highlight the need for analysis and design tools that can better engage with urban cycling as a complex situation and a holistic experience.

2.2 Engaging with diversity

The second direction explored in this paper acknowledges that complex design challenges can be experienced differently by different stakeholders. For example, the Amy Gillett Foundation’s report (2015) demonstrates that current reporting mechanisms do not recognise the varied travel experiences of drivers and cyclists. On the road, cyclists are more vulnerable than drivers (Monash University Accident Research Centre et al., 2012), navigating through the urban environment in a different manner than motorists. This situation is not only stressful for cyclists, who expose themselves to higher chances of harm, but also for drivers, who must interact with road users with unfamiliar and potentially unpredictable behaviours. This ‘traffic stress’ differs not only between types of road users but also between genders (Garrard et al., 2008) and individuals (Mineta Transportation Institute et al., 2012).

Such differences effect on-road events (Vanlaar et al., 2008) and, consequently, cyclist safety (Aultman-Hall and Hall, 1998). Studies indicate that awareness and empathy improve road safety. For example, the likelihood of collisions between cars and motorcycles decreases not only when a car driver rides a motorcycle him/herself, but also when a driver simply knows someone who does (Crundall et al., 2008). Accordingly, design and consultation tools need the ability to present complexity from multiple points of view, providing experiences that might otherwise be inaccessible to key stakeholders.

2.3 Communicating accessibly

Examples of how the propagation of knowledge through friends or families helps to develop more nuanced understandings of complex situations affirm the need for effective communication. To reduce the frequency of crash events along St Kilda Road, campaigns have attempted to inform drivers by attaching ‘watch out for bike’ stickers to vehicle doors (Bolitho, 2013), and installing temporary warning signs (CDM Research, 2012), without success. Such studies point out that personal stories are more likely to bring change than deterrents such as general warnings or fines. At the same time, it has been shown that effective road-user education is essential for the promotion of cycling and cycling safety. This teaching needs to focus on cyclists (Australian Government’s Department of Health and Ageing et al., 2008) but also on the general public who need to “be educated about the severity of the pedestrian and bicyclist crash problem and the urgent need to deal with it. […] Instead of being viewed as punitive measures aimed against motorists, [bicycle-safety measures] should be presented as new opportunities for all segments of the population.” (Pucher and Dijkstra, 2000, p. 30). Consequently, this paper argues that there is a need is for new tools that can communicate complex situation to a variety of stakeholders in an intuitive, memorable and emotionally relevant manner.

3. A game of urban cycling

“There are a lot of dangers for cyclists out there in Melbourne today – such as cars parked on the bike lane, which stop you getting a high score!” Participant C, reflecting on his ride.

The research discussed in this paper engages with one particular type of tool, a mobile game that simulates urban cycling. Called PocketPedal, this game was developed to understand how design can benefit from the integration of interactive and situated technologies.
PocketPedal is a single-player, real-time, quick-paced 3D game that runs on smartphones. The player’s objective is to traverse a segment of St Kilda Road without crashing, cycling safely to obtain a high score. The player is present in the game as an avatar of a cyclist. The game randomly assigns a new avatar at each run, for example a middle aged man in lycra (MAMIL); a young male office worker; or a female university lecturer. The player attempts to reach the city one ride at a time, negotiating through increasingly difficult challenges. Each attempt is short, from tens of seconds to several minutes. Players aim to improve their score through multiple attempts. The game does not require introductory tutorials; on-screen messages give suggestions and provide feedback as required. An attempt is terminated if the player reaches the city or if the avatar experiences a serious collision [Figure 1.IV]. At that moment, the game presents an assessment of the completed ride or a description of the injury and restarts.

PocketPedal’s environment is made of colourful, blocky objects. Players access the game via a third-person camera view, seeing the road from an overhead perspective [Figure 1.I]. The camera shows a limited fragment of the road constraining forward planning [Figure 1.I]. A shallow depth-of-field effect blurs distant objects, further limiting perception [Figure 1.I, top left corner].

The game implements the following ‘objects’: 1) Avatar: a representation of a cyclist whose motion is informed by a physics simulation. 2) Route: a precarious on-road bicycle path that proceeds between parked vehicles and lanes of motor traffic [Figure 1.I, central area]. 3) City: a two-kilometre section of St Kilda Road with a river, a main bridge, major landmarks, surrounding buildings, landscaping and road furniture [Figure 1.I]. 4) Roads with comprehensive road markings, vehicular and cycling lanes, cyclist stopping areas before intersections, tramways, intersections and other features. 5) Vehicles are organized into automated traffic moving according to road rules. Density of the traffic represents actual on-road conditions. There are vehicles of different types – cars, trucks, buses, etc. – with different driving patterns and access permissions. Based on realistic probabilities, the vehicles are ascribed types of driving behaviours ranging from obedient to aggressive. Stationary vehicles are generated at parking spaces located between the path and the kerbs. Depending on their size and behaviour they can partially obstruct the bicycle lane. Vehicles can also double-park, blocking the bicycle path completely. Stationary vehicles can also open their doors when the avatar cycles past.

Players interface with the game through touch. Tapping the centre of the screen makes the avatar pedal forward. Tapping the edges controls turning, and a down swipe initiates breaking. The player’s performance is represented by two numbers. The first, the score [Figure 1.II, top left corner], aggregates with distance, while the second [Figure 1.II, top right corner] acts as a multiplier that accelerates or decelerates the rate with which the score changes. This multiplier represents the quality of the player’s riding and is increased when the player stays in the bicycle lane, or navigates through other cycling provisions such as stopping boxes [Figure 1.III, central area]. When the player leaves the lane – or is too close to a hazard – the quality multiplier decreases, and the rate of point aggregation is reduced. If the multiplier is at zero, the player stops gaining points and cannot increase his/her score.

3.1 Game mechanics and participatory design objectives

PocketPedal provides an immersive experience of the road. As described earlier, cycling collisions are not discrete incidents. Crashes instead occur as sequences of events in dynamic and interconnected environments. In a game like PocketPedal, these sequences can be persuasively replicated.

For example, [Figure 1.I, central area] shows the open door of a parked car blocking the path, requiring the player to leave the kerbside and merge with fast moving traffic. The proximity of car parking spaces
to unprotected bicycle lanes is problematic not only because of the ever-present danger of ‘dooring’ but also as a source of continually accumulating stress and its effects. Unlike statistical surveys, PocketPedal represents not only the unitary events of serious collisions but also the context: cognitively demanding navigational tasks; reasons for sudden direction changes; and the need for making choices between similarly unattractive options, all under pressure. Often, the apparently erratic behaviour of a cyclist (or a player) can be explained by the accumulated frustration of having to slow down or stop to comply with the rules and provisions of the road that might seem illogical, unreasonably dangerous and unfair.

The game also provides an opportunity to replay the same situation in quick succession, supporting the accumulation of knowledge, experiences and skills that are hard to achieve with other tools or on the real-world road. The virtual road can provide such experiences because of its automated traffic that is based on observed driving behaviour. ‘Aggressive’ vehicles are (Walker et al., 2014) are blind to the player and change speeds quickly, drifting in and out of their lanes and swerving suddenly. ‘Cautious’ vehicles, on the other hand, accelerate slowly, remain in their lane and are responsive to the player, slowing down several metres behind the avatar and other vehicles. Novel events reliably arise from the interaction between the spatial conditions, the player and differentiated non-player road users. For example, in PocketPedal, side-swipe collisions are produced by the ‘tunnel vision’ where automated vehicles focus on the events in front of them and are likely to miss an avatar at the side, like in real life. Real-world events of this kind were discussed in the section on urban cycling and emerge in the game not as predetermined occurrences but as an emergent effect of local interactions. Generated in response to local conditions, such events are always different. They can happen at low or high speeds, in different lanes, at straight sections or during turning. To the player, these collisions might appear as unfortunate accidents, products of irresponsible driving by the motorists, hard-to-avoid errors induced by the challenging driving conditions, or bad personal decisions.

Another example of the effects produced by game mechanics relates to the scoring system. This system encourages players to become invested in their avatar’s success, facilitating active engagement. Moments such as when a bicycle lane disappears [Figure 1.III], or when multiple parked vehicles block the path, are made frustrating because players have no choice but to accept a reduced score. In other cases, players with good scores may ride faster and more recklessly, confident that their score is already high. Finally, players, wanting to better a previous score, might employ new navigation methods. These discovered behavioural changes could be tactical – moderating the speed more carefully – or strategic, such as ignoring potentially dangerous cycling infrastructure [Figure 1.II, 1.III]. As the game is intended to support short, repeated attempts, players are encouraged to experiment with many methods and approaches that would be much harder or impossible to try on a real road.

To conclude, even when experienced by an individual player, the mechanics of PocketPedal create a magic circle (Huizinga, 1949[1944]) within which players can be safely exposed to the physical (Garrard et al., 2010) and emotional (Aldred, 2012) challenges of cycling. However, the design of PocketPedal presumes its immersion into the context of social play and the additional effects possible through such integration are discussed in the subsequent section.

3.2 Mobile gaming for infrastructuring

How can a game act as a boundary object? Can it provide enhanced capabilities to “align the participants around a shared, though problematic or even controversial, object of concern” (Ehn, 2008, p. 93)? To support such alignment, PocketPedal is intended to be experienced collectively. The observations presented here are derived from a workshop that included cyclists, drivers, workers, doctors and planners.
During the workshop, stakeholders participated in a series of curated activities. Data was collected through video recordings, interviews and questionnaires, before, during, and after the event.

This social context of group play in a shared physical location provides for a dramatically extended repertoire of play patterns, especially in the case of mobile games played on portable devices. For example, a mobile game can be controlled by a group suggesting actions, played by individuals in parallel, exchanging remarks; played in turns, with debriefings or competitively; demonstrated and commended on by experienced players; framed by other games or activities and so on. In the words of Participant D, observing the workshop group:

“The game is a great leveller, with drivers and cyclists meeting in more neutral ground.”

The rest of this section presents two beneficial effects of curated social play: 1) ‘nested play’ and 2) ‘parallel play’.

Nested play inserts PocketPedal into other activities, exposing players to multiple modes of interaction. This curated embedding encourages direct and incidental communication, extending the capabilities of the in-game mechanics. For example, in the workshop, the game was preceded by ‘warm-up’ activities including: 1) a quiz where participants had to match slides of game scenes with city locations; 2) a sorting task, where participants had to label themselves as types of road users; 3) a ‘reverse interview’ where pairs of participants had to ascribe behaviours to one another; 4) an activity where participants had to analyse a movie of the road; and 5) a card game that asked players to organise photographs into different types of cycling journeys. Such activities interfaced people that do not typically meet and encouraged them to engage with subtleties of their existing preconceptions. Beyond that, these warm-up exercises allowed exploration of alternative and possibilities. Such explorations helped participants to appreciate game environments in greater nuance than was warranted by in-game geometry or automation. The contexts of the varying out-of-game experiences discussed during these curated activities also lead to reconsiderations of in-game events in reference to other locations and situations.

Further nesting encouraged players to engage with each other and with different capabilities of the game. Collaborative play saw one player guiding their avatar at the instructions of the group, requiring participants to negotiate a shared goal, at speed, and with immediate consequences. Other activities paired a playing participant with an observer, who documented their attempts and then recounted his/her observations. Role-switching between actors and spectators challenged players to come into new social relationships and develop novel understandings.

“Oh you are a lycra person – alright, speed up!” Participant B observing another player.

‘Cool-down’ activities included: 1) a roundtable where participants discussed hopes and ideas for future change, 2) a questionnaire were participants answered questions around their game experience, and 3) follow-up interviews conducted a week after the event. Cumulatively, these activities provided an opportunity for collaborative reflection: sharing of experiences, comparisons of interpretations and the voicing of thoughts on future design possibilities. As it was mentioned by Participant D, “approaching the issue in an unorthodox way enabled the opportunity for novel ideas.”

Within this context, parallel play is a set of deliberately curated relationships made possible by the mobile nature of the game. Although experienced collectively, the phones with PocketPedal city are carried personally: a reversal of one’s normal relationship with the urban, which exists as a shared entity that is experienced by individuals. This configuration offers several benefits for infrastructuring. Firstly, portability allows for virtual experiences to be staged anywhere, at any time. In the context of the
workshop, players could interact with the game in any space, with any participant, as groups or
individuals, easily rearranging. At one time several participants could play as individuals; others in a small
group, standing near the window, while the rest preferred the sunny outside. The familiarity of the phones
helped non-gamers – most of the workshop group – feel at ease as players. Instead of being intimidated
by unfamiliar activities, parallel smartphone play facilitated rapport and creativity – triggering laughter,
excitement and the formation of friendly rivalries.

Participant A, not so familiar with games, isn’t going so well: ending her ride in a high-speed
crash. The music slows down and becomes sombre. ‘You crashed!’ the game flashes. ‘You’ve
ended up with a sad family!’ Participant B, in another group, turns around to offer
condolences. ‘I hit a truck’, she sympathises, ‘I was going too fast’.

Such interactions are an example of parallel action. When playing PocketPedal, some players moved
together, comparing riding conditions in tight groups. Others, hearing laughter and commotion, would
become curious and roam. To see the small screens, players needed to move closer, provoking
spontaneous interactions. These could be as simple as pointing out an unseen hazard on another’s screen,
leaning over to commiserate over a crash, or expressing mock dismay at the low amount of traffic another
is facing in comparison with that in their journey. On the other hand, the interactions could be more
sophisticated when sharing a personal memory or discussing the political context.

It is impossible to completely know, or ‘fix’, complex systems because they can result in pragmatically
useful but incompatible knowledges. (Bucciarelli, 2009). Yet, in the words of Participant D,

“[Playing the game in the workshop] made the issues seem more tangible, approachable
and open to change, [going beyond] the general opinion that cycling infrastructure is bad as
a whole and therefore too large a problem to fix.”

Collaborative mobile games allow stakeholders to co-play through issues via immersive simulations that
support spontaneity and improvisation in combination with curation. To conclude, curated and
embedded, the game emerges as a provocative boundary object that can highlight issues of concern and
establish common languages without dismissing actual disagreements.

4. Steps towards a common language

“That’s obviously the ex-husband”, Participant A, noting an aggressive vehicle manoeuvre.

The magic circle of play is attractive and powerful because it gives access to the unlikely and the
impossible. However, this magic can also isolate players from the everyday world, transposing them into
a distinctly otherworldly state. By contrast, strategies discussed in this paper seek to capitalise on the
characteristics of curated play to establish common languages that link stakeholders to real-world issues
while maintaining the ‘magic’ of playing. Such languages are necessary for social infrastructuring and,
consequently, for the emergence and adoption of viable design decisions. The discussion of mobile
gaming in application to the design challenge of urban cycling demonstrates that these games hold
exciting promise as tools for participatory design. They are able to facilitate better communication by
acting as immersive and engaging boundary objects. The shared engagement with these boundary objects
leads to greater inclusion of diverse stakeholders and the development of rapport that is necessary for a
deeper understanding of the experiences and needs of others. With this, games can contribute to more
nuanced appreciations of complex design situations and the subsequent construction of platforms for
change.
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Challenges for design control:
Understanding what people want and how to get it

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Abstract: The appearance of the built environment plays an important role in people’s physical, financial and psychological wellbeing. In light of this, it is important to ensure that transformation of urban streets and public spaces through individual projects can satisfy the aesthetic expectations of the public as well as of those who are directly involved in their production. Within projects, outcomes are regularly controlled by the steering group on behalf of internal stakeholders. To ensure that the needs of other people are also met, local authorities in some New Zealand cities often review project designs at the planning approval stage. This process invites experts, whose work is informed by design guidance, to express their opinions about the design and other urban design related matters. This paper addresses the question of whether the ways places change aligns with public expectations. A mixed methods approach was used to elicit people’s preferences for building and streetscape characteristics, where stimuli were first presented as photographic representations and secondly as real streetscapes in two New Zealand cities. The findings identify the streetscape design characteristics that were best liked by people and the ones that were disliked. Of particular interest was a comparison between the preferences expressed by lay members of the public with those of design and planning professionals. The paper concludes with a brief discussion about barriers that may be limiting the achievement of well-liked streetscapes in the New Zealand context.

Keywords: Urban design review; Environmental aesthetics; Streetscape.

1. Introduction

Around the world, people continue to flock to cities to live, work and play. People come to cities to enjoy civic and social amenities as well as the many economic opportunities that arise when people live more closely together. As populations rise and business owners respond to new opportunities, the built environment also changes. Although a considerable amount of growth takes place around the edges of cities, expanding the area of land they occupy, transformations also reshape existing built-up areas. Carried out over varying scales and timeframes, market demands are made manifest as incremental steps, from single buildings to large scale redevelopment of entire blocks.
In order to help ensure that change outcomes are appropriate, many cities have adopted urban design review regimes. Although projects are carefully scrutinised by the project team during their development, the outcomes sought by an owner can often conflict with those sought by the public (Bentley 1999). This is particularly true where development is undertaken as a business activity. Urban design review is a way of balancing the needs of the public with those of the specific project. Design review can have significant influence on project outcomes and is therefore relevant to any discussions concerning form and content of contemporary cities.

This paper is concerned with urban transformation processes and in particular the effects these have on the visual appearances of towns and cities. Are places changing in ways that reflect the aesthetic preferences of the people who use them? If not, what are the challenges that need to be overcome?

2. Visual preference studies

The paper reports on a part of a project that has evaluated the effectiveness of different design control methods being conducted in New Zealand cities. This part of the project is driven by the question: what are the characteristics of well-liked buildings and streetscapes in New Zealand? There is general consensus that there are significant gaps in evidence based knowledge about people’s aesthetic experience of cities. Most of the existing literature has been developed on the basis of normative theory (Cuthbert 2006: 171-173), reflecting the fact that aesthetics in the visual design fields, from architecture to the fine arts, has generally been the domain of philosophers and theoreticians (Wohlwill 1976). However, since the 1960s a number of critical studies have examined people’s perceptions and judgments of their environments through application of social science and psychology methodologies (Berlyne 1974; Ittelson 1978; Kaplan 1988; Nasar 1998; Stamps III 2000). This research fits with these in the growing area of environmental aesthetics.

A well-known research in this area was carried out by Nasar (1998), who used mapping techniques developed by Lynch (1960) to examine visual preferences of people in two American cities. He set out to identify the general characteristics of likeable places, which led him to identify naturalness, openness, upkeep, historical significance and order as those having greatest significance to people. Findings like Nasar’s, which are based on empiric data, provide evidence on which planners can base design policy and guidance.

This project builds on the findings and methods of earlier visual preference studies. Two studies were undertaken in sequence, one that asked people to evaluate urban streetscapes on the basis of photographic representations and the other inviting them to rate buildings and streetscapes in real life, as they walked along them. The streetscapes were each selected on the basis of the particular characteristics of individual buildings along their length and the relationships they formed with each other. The aim was to present a range of conditions encountered in design review processes.

More than 200 people responded to the representations of buildings along six different urban streets to the first study (figure 1). In addition to contributing robust data to the overall findings, preliminary results helped inform the selection and design of the second study. In this study, different respondent cohorts were invited to visit two streets in Auckland and one in Wellington. At least 40 people participated in each of the three cases, where they evaluated the design characteristics of the individual buildings, the relationships between adjacent buildings and the overall streetscape composition along both sides of the street as they walked along it. To help tease out the key issues that influence the ways people perceive the environment, two focus groups comprising people who had participated in the survey of College Street in Wellington were also held. Meetings of lay participants and of change professionals
were convened separately; the rationale for this being to help ensure robust and fulsome discussion around the issues within each focus group.

3. Research findings

A summary of the research findings is presented in Table 1, with the highlights, relative to design guidance and review, discussed in the following paragraphs. Concerning individual buildings, the research found that the façade design features people liked most are discrete window openings. Correspondingly they disliked buildings with facades that are horizontally banded (such as continuous strip windows). People were found to prefer facades that are monolithic in nature, where the floor levels are implied behind the façade by the window arrangements, and not directly expressed. Such monolithic facades are generally considered to be more traditional, conceptually seen as a wall extending over the full height of the building (figure 2). This finding corresponds well with preferences for discrete windows and a dislike for horizontally banded facades (figure 3). While the majority of traditional, monolithic facades incorporate

Figure 1: Streetscape scene created from photographic images of the individual buildings along one side of a street that was used to stimulate people’s responses to urban streetscape characteristics in the first study.

Figure 2 and 3: The building on the left embodies the building characteristics that people like the best, including discrete window openings, a monolithic facade and brick cladding materials. The building on the right is horizontally banded, a characteristic that people disliked.
surfaces that can be painted, the most preferred surface finish appears to be brick, which can be problematic in a seismically active setting such as New Zealand.

Table 1: A summary of the research findings with evidence sources identified

<table>
<thead>
<tr>
<th>Research finding</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Buildings</strong></td>
<td></td>
</tr>
<tr>
<td>People preferred traditional cladding materials, particularly those that can be repainted</td>
<td>N/A ✓ ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>People preferred buildings with discrete window openings</td>
<td>✓ ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>People preferred building facades that appear clean and well maintained</td>
<td>N/A ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>People preferred street level designs that enable visual engagement with the activities inside</td>
<td>N/A ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>People disliked horizontally banded building facades</td>
<td>N/A ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>The findings were inconclusive about whether contextual fit is considered when people evaluate individual buildings</td>
<td>N/A ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td><strong>Streetscapes</strong></td>
<td></td>
</tr>
<tr>
<td>Relationships between buildings where there was coordinated visual interest across the individual facades were best liked</td>
<td>✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>People preferred streetscapes where building heights vary within a narrow band</td>
<td>✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>People preferred streets where building façades are aligned consistently</td>
<td>N/A ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>Open spaces were found to mitigate potentially negative relationships between adjoining buildings</td>
<td>N/A X ✓ ✓ N/A</td>
</tr>
<tr>
<td><strong>Perception</strong></td>
<td></td>
</tr>
<tr>
<td>People’s understanding of building function was important in aesthetic evaluation of buildings and streetscapes</td>
<td>N/A ✓ ✓ ✓ ✓</td>
</tr>
<tr>
<td>Change professionals’ opinions were influenced by their knowledge of urban change</td>
<td>✓ ✓</td>
</tr>
<tr>
<td><strong>Demographic comparisons</strong></td>
<td></td>
</tr>
<tr>
<td>Lay people and change professionals held similar preferences for buildings and streetscapes</td>
<td>✓ ✓ ✓ ✓ N/A</td>
</tr>
<tr>
<td>The aesthetic preferences of planning professionals and architects differed more than those of change professionals and lay people</td>
<td>✓ ✓ ✓ ✓ N/A</td>
</tr>
<tr>
<td>While there were areas where men’s and women’s perceptions differed, there were no fundamental differences in opinions of buildings and urban streetscapes.</td>
<td>✓ ✓ ✓ ✓ N/A</td>
</tr>
</tbody>
</table>
People expressed strong preferences for buildings that were well maintained. Although not the only factor affecting their preferences, perceived maintenance levels correlated strongly to whether they found the building to be pleasant or unpleasant. Although not specifically a design characteristic, maintenance and the extent to which it is able to be recognised by respondents is clearly influenced through design. The surface qualities of cladding materials, their durability and the ways different construction components are detailed all influence how a building is seen to age.

Another design factor that people responded favourably to was the extent to which they could see inside the building, particularly when they could see into interior spaces at ground level. This response could be linked to a natural sense of curiosity, as discussion within the focus groups suggested that people often project themselves into a space through the activities they see as a means of understanding the building. An example of a well-liked activity at ground level is a bar or café, where perceptions of these activities were linked strongly to levels of transparency into the seating area. While in many cases the two factors of well-liked activities and a visually permeable façade treatment worked well together to enhance people’s perceptions, they were not mutually dependent. For example, the research found that women responded positively to retail activities on the ground floor of buildings even when they could not see into the building. It was found that signage or building typology – such as a shopping mall – were often enough to alert people to unseen retail activities within the building’s ground floor.

At a broader scale, building height relationships that varied within a narrow band of difference was a well-liked streetscape characteristic. Correspondingly, large variations between buildings were generally disliked by respondents. The factor that underlies these preferences is ordered variety, which is a design characteristic known to elicit a positive aesthetic response (Smith 2003).

Continuity of building façades along the street edge was another well-liked streetscape characteristic. However, it appears that spatial definition, in the sense advocated by Sitte (1979) and Jacobs (1993), is not the characteristic people find most appealing. The strong preferences expressed for façade continuity are linked to a dislike of blank and uninteresting flank walls on internal site boundaries. They are also linked to the notion of positive space, where the space between the building facades and the footpath is developed positively for physical and visual enjoyment by pedestrians.

People liked to see coordinated visual interest across the individual facades. Once again, this feature corresponded well with the broadly held aesthetic preferences for ordered variety. Green landscaping and positive open spaces in a street were very well liked streetscape characteristics. These were seen to mitigate the negative visual effects arising through poor relationships between buildings. An example of
this is in relation to large differences in building height. Where these were mediated by open space, even an intersecting road, the poor visual effects that these differences led to in other circumstances were reduced and even became positive.

The second focus of the research links to urban transformation and change processes, and in particular to design review. Most decisions about the shape of buildings and streets are made by professional experts, charged with this responsibility in large part because of their expertise. This part of the research was driven by the question of whether change professionals also speak for the wider public when they make decisions that affect the aesthetic characteristics of the built environment. The research found that the preferences of change professionals to be largely aligned to those of lay people, but with some differences.

There was a consistent tendency for change professionals to be more critical in their opinions about buildings and streetscapes. Although the preferences expressed by both groups were similar, the opinions of change professionals were generally more negative when both groups liked a building or streetscape and more positive when they did not. This may reflect a cultural characteristic of change professionals.

While overall preferences between these groups did align, interesting differences were noted in the way each group formed their opinions about buildings and streetscapes. Firstly, change professionals tended to focus on the design of buildings above ground floor level when making their overall evaluation, whereas lay people tended to emphasise the design at ground level. This also reflects closer attention on the activities taking place within a building by lay people; where activities were perceived positively, the building was also more likely to be rated positively.

Secondly, change professionals incorporated their particular knowledge about how the built environment changes when forming their opinions about buildings and streetscapes. In particular, they appear to have been able to overlook poor design characteristics when they considered these to be short-term effects. The focus group discussion revealed that where a change professional could see opportunities for transformation that might eliminate a currently poor aesthetic condition, they were able to dismiss the condition when making their evaluations and assume a more aesthetically pleasing the future. Whereas change professionals were able to consider future possibilities when making their evaluations, it seems that lay people were only able to make their evaluations on the basis of the present conditions.

4. Design review background

Government administered design review is generally invoked to look after the interests of the public, which can easily be marginalised in private review processes (Jones 2001, Imrie and Street 2011: 16). The avenue for governments to intervene in any private matter is through the field of ethics, which invites those with power to assume responsibility for the Other, the term used in the literature to refer to those sitting outside the circle of decision makers (Radford 2010: 381). Design review is based on the belief that there is a collective good in its application that is greater than the sum of the cost to each individual stakeholder (George and Campbell 2000: 163).

Having first decided to become involved in controlling the outcomes of private development, local governments must also navigate a number of issues that can lead to tensions between different stakeholders and in some cases can diminish the design quality of outcomes. A significant source of tension is the strong culture of individual property rights in Western societies, which appears to be even more pronounced in new world countries such as New Zealand. Indeed, the history of colonial settlement in New Zealand is based largely on subdivision and exploitation of the land by private interests, acting
under authority of the government. As development is largely undertaken by private interests, design review is likely to affect the rights and freedoms of the individuals who have the ability to develop and change the built environment (Lai 1994).

Other important issues that design review must navigate include power and questions of who should be entitled to make key decisions in the process (Case Scheer 1994). Pointing to the law, Case Scheer argued that design review is the only field in which lay people (those not specifically trained in design) are left to rule over professionals in their areas of expertise. There is also the matter of justice, as the reviewer is seen to hold the balance of power. This limits the extent to which a fair hearing is possible (Case Scheer 1994). While this issue might be minimised through the use of written guidelines, these are also considered to be tools that limit freedoms of individual expression. Developers and designers often opt to take the path of least resistance when negotiating design review and they become unwilling to test the limits of guidelines or to appeal unfavourable decisions because of the time and cost of doing so (Jones 2001). As a consequence, designs mimic the approach advocated by the guidelines in order to ensure a favourable decision rather than the right decision.

Tension exists around the matter of aesthetic preferences and whose should be taken into account when it is the public that has to live with the design outcomes. While the present study has found there to be significant alignment between the preferences of lay people and change professionals, the broadly held view is that there are differences in the way these two groups each evaluate buildings and that there are very good reasons for this (Case Scheer 1994: 4, Groat 1994, Stamps III 2000, Pugalis 2009). Professionals are trained in design and aesthetics and hone their skills and knowledge in the field through their work. On the understanding that there are differences in aesthetic perception, Case Scheer (1994) argued that professional views should be privileged when deciding how the built environment is to change.

5. Key challenges for design review

The fundamental objective of design review is to return buildings and urban streetscapes that appeal to all people (Punter and Carmona 1997). This objective would seem to be achievable given that it has been confirmed that the aesthetic preferences of people who design and manage urban transformation are similar to those of the lay public. Why then do we end up with “spectacularly ordinary commercial development”, the conclusion John Punter (2004: 406) came to following his analysis of Sydney’s urban development since the Second World War. If, as this research appears to confirm, those who design and manage changes to cities have similar aesthetic preferences to the lay public, why aren’t the outcomes better liked by all? In order for design control to deliver on its promises, several difficult issues must be confronted.

5.1. Motivations of the producers

The key issue and the reason for design control being introduced in the first place is that those who create and manage the built environment appear to have different motivations than the public do. Since the late 19th Century the built environment has been a source of financial gain in and of itself. Buildings began to be produced not by those who would own and use them in the course of their business activities but as a separate means of income generation.

In light of this, Bentley (1999) notes several constraints that can affect development outcomes. Considered as commodities, buildings are produced according to principles of capitalism, which drives
producers to seek lower building costs wherever possible. Low financial investment in the production phase of development leads to buildings that are flatter, less interesting and prone to ageing poorly (Bentley 1999: 87). At the same time efforts are made to increase market values. To distinguish their product from the competition and make them more attractive to the end buyer, developers encourage visually exciting designs from their architects (: 92). Often making use of shiny materials to make up for lack of interest in the details (which cost money to produce), these designs can struggle to fit in with others around them. As noted above, this is often the effect sought by the designer and their client. So on the one hand we have flat, visually uninteresting buildings and on the other buildings that in form and material use cry for attention. Streetscapes emerging through contemporary development tend toward visual cacophony (Habraken 1998).

5.2. Commitment to control design

Aesthetics is still considered in the manner of Kevin Lynch’s description; that it “is considered like a kind of froth, difficult to analyse and easy to blow away” (Lynch 1976: 68). The history of design control in the United Kingdom demonstrates the extent to which its application is dependent on the political climate (Punter and Carmona 1997). Labour governments have tended to emphasise and support efforts to control design outcomes and, unsurprisingly the more economically liberal Conservative governments has favoured lightly-lightly approaches in this area. The current government, which came to power in 2010, has wound up the Commission for Architecture and the Built Environment (CABE), which has existed in one form or another since 1924. This has signalled a political climate of minimal intervention into the affairs of private landowners (Carmona, Tiesdell et al. 2010).

Aesthetic matters are rarely given the statutory weight of other matters in planning regimes. A study of Wellington’s design control methods found that design guidelines were not effective when used in conjunction with controlled activity status under the District Plan. A controlled activity is where a proposed building or activity cannot be refused, regardless of the aesthetic qualities of the built form. Rae (2004) reviewed 20 completed projects in Wellington’s central area and also found early consultations to be ineffective. The architects he consulted noted that advice given by Council officers in the early stages was inconsistent and conservative. He also found that when it was undertaken, consultation did not take place at a critical, site-specific analysis stage but only once preliminary design proposals and economic budgets had been formed. As a consequence, Council urban design input was unable to prompt significant changes, should they be needed, to improve outcomes. The research also found that the discipline specific approach to evaluating projects could have a detrimental effect on projects when compared to assessment of proposals in a more holistic manner. Changes made to satisfy singular and conflicting advice from heritage, traffic, wind, and urban design advisers had served to diminish the design quality of the outcomes.

5.3. Professional acculturation

Intuitively, an appreciation gap might arise from a professional education, which has been focussed on speculative aesthetics (Devlin 1990, Hubbard 1994). In his study of the development of aesthetic preferences amongst students, Wilson (1996) found that those of architecture students progressed toward those of their professional tutors, and away from their student peers in other disciplines, with each year of study. Patterns of socialisation of preference were clearly evident, particularly in response to architectural style. Differences in opinion could be traced to what each group takes into account when making aesthetic judgements. Non-designers react to and evaluate the environment in associational
terms; to them meanings are of primary importance. Conversely, designers are known to respond in perceptual terms as their meanings, learned and reinforced by education, lie in the physical composition, an abstraction of the building in three dimensional terms (Rapoport 1982).

On this basis, preferences learned during education and training may be expressed in particular cultural settings and in the execution of one’s professional work. Bentley (1999) argues that professional preferences are influenced at least in part by the need to remain in business. This leads designers to become willing to argue in favour of design approaches that enable their clients’ aims to be met including favouring designs that make use of thin, featureless materials and of simple, flat detailing outcomes (figure 3). In this sense, he argues, designers rationalise their approach to aesthetic preference on the basis of economic realities. On the other hand, culturally learned aesthetic sensibilities of designers enables them to push beyond conventions, to explore new aesthetic expressions that over time will find their way into the mainstream. This would seem to present a clear, if somewhat difficult to achieve, need to unlearn culturally specific aesthetic preferences. It may be better to think about managing differences in aesthetic preference in ways that enable compatibility where this is suitable and special expression where this is deemed appropriate.

6. Conclusions

Design review is undertaken by local governments to help ensure that development achieves outcomes appropriate to the needs of all members of the public and not only of those who hold the balance of power in the process. These processes are fraught with challenges, some of which concern the relative freedoms expected by those who own the land, which design outcomes should be pursued by design review and whose opinions should matter most.

This paper reports on the outcomes of research undertaken to identify those design characteristics that people find most appealing and those that they find least pleasant, at the two perceptual scales of individual building and overall streetscape. It was found that people prefer traditional design expressions, comprising monolithic street facades and discrete window openings. This confirms theories that people prefer scenes that provide moderate levels of visual interest within overall patterns that can be ordered. This preference pattern also extends to those expressed for overall streetscapes, where people preferred height relationships between buildings that create variations of between one and three levels over those that were absolutely consistent and over those that had large differences of height.

It was also found that people trained in design and planning disciplines have similar aesthetic preferences to those of lay members of the public. This supports the principle that design review can lead to places that all people like better. With the potential for design review confirmed, the paper went on to discuss possible barriers to achieving this. One is the influence that producers have, firstly on the outcomes themselves by adopting the economic model of ‘buy low and sell high’. In this model, the cost of producing buildings is reduced by eliminating details and surface articulations. As the built environment is seen as a commodity with the potential to generate income in and of itself, the influence of economic motivations is higher than it has been at any time previously. Lower investment in construction leads to buildings that are flatter, less interesting and prone to age more poorly than others. Secondly, those with knowledge of development processes have been found to be willing to rationalise poor designs, motivated to do so in large part by a desire to stay in business. It seems that some circumstances enable fundamental aesthetic sensibilities to be set aside. While design review has the potential to achieve better liked buildings and places it will be necessary to confront barriers such as these in order for that potential to be fulfilled.
References


Learning architecture: supporting positive change

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Abstract: The design of built environments play a significant role in the impact of global sustainable development and the contributions of sustainable design have been informed by research and education programs. However, opportunities to improve the positive impact of global development remain, as lifestyle and use of existing buildings continue to contribute to climate change. This research is part of a larger project that explores how architectural learning can prompt a change in future practice that will support change in lifestyles and behaviours. Developing skills in critical reflection, communication and collaboration encourages change in world view and consequentially change in practice. This paper questions the way in which architectural education is examined and seeks to better understand the complex process of architectural learning. The methods used to examine the physical, social and educational environments enable a broader view of architectural learning to be documented. Tools currently used within architectural practice are developed further in order to document those learning experiences which support skill development and prompt a shift in worldview. This process of examination is presented as a means of better understanding the learning experiences that can support and sustain positive change in architectural practice and future sustainable development.

Keywords: architectural education; learning; experience

1. Introduction

In the last 50 years, the science of climate change has become increasingly known and more widely accepted by society at large, evidenced through publications such as the Silent Spring (Carson, 1963), and the increasing rate of the advancement of climate science research (Le Truet et al., 2007). Technological advances related to the materials, construction and use of the built environment have had a positive influence on the impact of the design of the sustainable built environments on climate change. However, there remain areas for improvement in sustainable development.


The design of the built environment influences, supports and impacts on many of the goals of the Agenda for Sustainable Development (United Nations General Assembly, 2015). While improvements
have been made, accelerating urbanization has increased the need for resources and the consumption of energy, resulting in increases in greenhouse gases and the consequential climate change (United Nations, 2015). While both the negative and positive impact of urbanization is more significant in developing nations, the reduction in negative impact expected of the developed nations has not been realized despite significant technological advances. Increasing levels of wealth and lifestyle are contributing to increases in building energy use, and the long life spans of existing building stock ‘lock-in’ higher energy requirements (Lucon et al., 2014).

In 2012 the Architectural Review published a series of monthly articles with ‘the aim of stimulating new thinking and combative debate’ in response to the global ecological and economic crises (Slessor, 2012). In the ninth of these articles Buchanan argues that architectural education is failing to engage with these critical realities, and that many of the current practices haven’t responded to change, as they reflect those practices of the 1980’s (Buchanan, 2012). Such new thinking requires not only an understanding of the environmental systems. The needs of diverse clients and communities and the potential impact of the use of the built environment, extending beyond the immediate capital costs, must also be understood. The core skills of critical reflection, communication and collaboration are required in order to come to this understanding and to change the culture of practice (Nicol and Pilling, 2000).

Calls for change in architectural education, and the need for the explicit development and improvement in education around these core skills, have been made since 1960. It has been argued that the process of designing can become divorced from practical life (Llewelyn-Jones, 1960). However, when designing takes place in authentic environments, using the specific language of designing as part of a collaborative process, skills in communicating with others are strengthened (Papanek, 1983). It has been recognised that critical reflective practices can serve to make tacit knowledge more explicit, and bring learning to the fore in design practice (Schön, 1983). Suggestions have been made to strengthen the social responsibility of architecture by challenging the hidden curriculum and unstated values within courses (Dutton, 1987). By shifting social relations beyond the formal, supporting critical thinking and challenging commonly held values, students learn to see themselves in the world, and develop a better understanding of the world and others. More recently it has been found that in Australasia architectural educational curricula typically prioritise design skills over environmental and cultural understanding, and that the presence of communication in curricula is declining (Ostwald, 2008).

This paper emerges from previous research that suggests that changes in lifestyles and behaviours are needed to ensure the sustainable use of new technologies and existing environments. It is argued that these lifestyle and behaviour changes are supported by the critical self-reflective practices of designers, design processes that are collaborative, and built environments that meet the needs of diverse clients. As part of a larger research project aimed at identifying how such change can be prompted, supported and sustained through architectural learning, this paper questions the way in which best practice in architectural education is considered. The difference between architectural education and learning is acknowledged. Education is defined as the process of receiving, giving or imparting knowledge and / or skills, (Merriam-Webster, 2016a). This definition implies that knowledge and skills are developed as information is transmitted from one to the other. It suggests that these actions are transmissive in nature and often one directional or non-reciprocal. Learning on the other hand, is defined as the acquisition of knowledge or skills through experience, study, or by being taught (Merriam-Webster, 2016b). The implication here is that knowledge is developed through personal experiences and exchanges that take place through interaction of the participants. Focusing on architectural learning, and more specifically the experience of architectural learning, enables these
interactions, and the outcomes, to be examined more closely, while acknowledging the broader situation in which these experiences take place. As most formal architectural learning takes place within higher education, this discussion focuses on programs in universities.

The methods of examination discussed have been used to investigate transformative learning in architectural education. This research differs from current research into architectural education as it recognises the broader contexts of learning and the role of the worldviews of all participants in interaction and behaviours. This has been determined through a review of publications from the last twenty five years listed in the INFORMIT databases, identified by the keywords ‘architectural education’ in the Education database, and ‘education’ in the Architecture database. The outlines and summaries of these publications were analysed to determine trends in themes, approach and focus using a coding framework, developed as part of the larger research project. The themes identified included discipline specific knowledge and skills; the design of the built environment; descriptions of the learning experience; discussion of the learning outcomes; and pedagogical practices. The approaches used in the research published included case studies, differing methods of analyses, literature reviews, and theoretical discussions.

2. Examining architectural education

Global rankings are often used by universities to promote the quality of their higher education programs. Global ranking systems such as Academic Ranking of World Universities (Shanghai Ranking Consultancy, 2015) and the Times Higher Education World University Rankings (Time Higher Education, 2015) allow entire universities to be compared. Others, such as the QS TopUniversity Rankings (TopUniversities, 2014), rank subject areas and specific programs, such as architecture, within universities. QS TopUniversity Rankings is used here as one example of how best practice in architectural education is considered.

The QS TopUniversity ranking system assesses the four broad areas of research, teaching, professional expectations and international outlook (TopUniversities, 2014). Highest priority is given to research, measured by research outputs of the staff and citations per faculty, followed by teaching quality, assessed using the faculty (staff) / student ratio. Other criteria include assessment of employer reputation, based on a global survey of graduate employers, and the diversity of the learning and teaching community, measured by the proportion of international staff and students. The use of such indicators to assess the quality of architectural education is questioned. It is not clear if the ranking criteria acknowledge if or how research informs the learning experiences within an institution, and practices within the profession. Minimal integration between learning and practice could result in communication skills that are discipline specific, limiting collaborative practices across disciplines and within communities. The preference for low staff / student ratios, small class sizes and individual tuition as an indication of commitment to good teaching reinforces the expectation of high levels of supervision and guidance in architectural education. This may limit opportunities for self-directed development and critical self-reflection. The reputation of the program amongst the profession aligns with the focused discipline knowledge, and development of discipline specific technical skills of graduates. In Australia this alignment is evidenced in the competencies expected of a registered professional (Architects Accreditation Council of Australia, 2015).

Accreditation systems also consider the outcomes of architectural education programs and examine the demonstration of key skills and capabilities. In Australasia, the accreditation process examines the content and structure of the program, the facilities in which the programs are conducted, the outcomes
produced by students, along with staff profiles and student satisfaction. In doing so, evidence of the application of communication and collaborative skills is looked for. Meetings with staff and students are used to gauge the nature of the experiences within the program, and can identify critical and collaborative practices. However, the accreditation process is used not as a determination of best practice, but as an assessment that minimum professional requirements are met. The skills of critical reflection, communication and collaboration are embedded within the criteria, and are employed by students to produce the outcomes examined. The way in which these skills are learnt, and the experiences in which they are developed, is not explicitly addressed.

An alternative method of examination is one that places architectural education within a broader context. This method examines the different environments in which architectural education can occur, the curricula and teaching practices that lead to certain outcomes, and the types of the participants involved and their role. The tools used for this examination do not rely on visiting the institutions, but instead take advantage of information available online, enabling a number of programs to be examined easily, with minimal financial and time commitments, supporting a broader examination of programs.

2.1 Architectural Education Environments

Considering the effects of different educational environments on architectural learning can help to develop an understanding of the experiences outside of formal teaching which may influence student learning. The physical environments are examined by analysing images of individual buildings and the campus, and maps of the campus and the broader, often urban, context. Limiting this examination to a walkable catchment or ‘ped shed’ (Western Australian Planning Commission, 2007) identifies the diversity of the built context, the opportunity to experience natural environments, and the types of everyday activities and situations within walking distance of formal teaching spaces. Examining the broader social environment of architectural education can identify opportunities to connect with and learn in communities beyond the education institution. The type of student accommodation available; it’s location on, near or off campus; and the proportion of students living in this accommodation can strengthen or limit relationships and social engagement within the program. Professional communities, evidenced by the number of nearby architectural industry-related practices, support the engagement of profession in teaching activities, and increase the relevancy of the curriculum. The position of the architectural program within the institutional structure, as a discrete school or as a department within a school or faculty, can influence the level of autonomy within the program. Architecture programs aligned with other built environment studies such as planning or construction, or with other disciplines such as social sciences or engineering, influences the extent to which cross disciplinary activities are supported and this can inform discipline focused and flexible curricula.

2.2 Curriculum, teaching practices and learning outcomes

The examination of architectural curricula categorises the content of the programs into the subject areas or streams defined in the UIA (International Union of Architects) Validation System for architectural education (UIA, 2014). This categorisation enables the curricula of different programs and institutions to be compared and similarities and trends in the structure and content to be identified. It serves to highlight not only the areas of focus for formal and structured learning but also where in the curricula skills are tacitly developed and cross curricula teaching occurs. The types of the classes, such as lecture, tutorial, seminar and studio are used to identify the teaching practices and the types of learning activities within the program. For example, it is unlikely that collaborative studios are conducted in a
lecture theatre, and conversely, delivering information consistently to all is most typically done when the scale of the learning space accommodates entire cohorts. Documentation of learning outcomes online provides evidence of the different ways in which the participants have interacted and communicated as groups or individuals; the focus of learning activities on processes or outcomes, and the types of review and reflection that occurs.

2.3 The types and role of participants

Examining the types and roles of participants involves determining the number of staff and students as well as their background, expertise and roles. The staff / student ratio within the architecture programs is used to determine the density of the immediate social environment in relation to pedagogies and environments. Opportunities for interaction within and between types of participants are also evidenced. Distinguishing between part-time and full-time staff allows for a comparison to be made with regard to the practitioners and researchers teaching in the programs. Teaching staff with professional activities beyond teaching can influence the educational experience. External practitioners, those outside of the formal contractual arrangements for academic staff, often present as guests which broadens the staff / student interaction. Identifying instances of cross-curriculum teaching can also be used to support processes which develop the skills of communication in different ways, and collaboration, especially within multi-disciplinary, project based activities.

This type of examination of architectural education defines the contexts of education, documents how discipline-specific content is taught, and the ways in which the participants involved in the teaching activities may interact and support students as they learn to see themselves in the world, and better understand the world of others. However, it does not address how these environments and activities support the participants to change their values and behaviour, their worldview, in response to change. Re-focusing on the transformative learning experiences within a program can develop different understandings of the dynamic educational and professional environments and how the learning experiences can change, and be changed, through critical reflection, communication and collaboration.

3. Examining architectural learning

In order to explore the dynamic process of architectural learning different methods of examination are used to recognise change in the learning experiences. The ways in which the architectural learning process builds the capacity to support positive change in learning and professional practices can also be identified. As part of a larger research project the methods outlined below have been piloted on a number of case studies in which existing architectural learning experiences have led to sustained change for students, staff or communities. Examining these case studies has provided evidence that has been used to further develop the methods used to document the contexts, experiences and behavior of the programs.

3.1. Mapping contexts of architectural learning

The act of mapping contexts requires the researcher to be ‘in-place’ for a length of time, and in doing so, an understanding of place is built up through direct experience. This enables not only the built and natural environments to be defined but also the social environment as the intended use of the spaces, the definition of the boundaries and transition spaces, and the language used can be documented.
By photographing physical contexts, the built and natural contexts are documented objectively. Panoramic photographs capture surroundings often cropped out of view when photographing specific projects. A sequence of photos, taken at regular intervals along a given path or direction, documents a journey as well as the environment. Documenting journeys made by staff and students regularly, such as the walk from near-by accommodation or public transport hubs to the architecture building, for example, objectively brings environments and situations that may go unnoticed to the fore.

Being in-place allows the changes in the context that may influence how experiences are interpreted to be documented. This is done by visiting places more than once, returning at different days and times of day to observe and document how people are using the spaces, and interacting with each other and their contexts. Making sound recordings, soundscapes, of the environments visited documents non-visual aspects of the environment, acknowledging that environments are experienced with multiple senses.

This process of documenting and mapping requires the researcher to observe, look closely and more objectively. By slowing the pace of the analytical task though reorganisation, distilling and curating the information, the researcher is required to both tighten their focus and widen their view. Reducing the evidence to a series of instances serves to focus on areas of confluence. This is where multiple activities take place, where there is a concentration of activities, or where participants can come together. Widening the view can enable situations and activities that may have gone unnoticed to be considered as part of the learning experience.

The act of mapping, achieved by spending more time in a place, observing and experiencing, deepens the understanding of the contexts and interaction between place and people. This is critical when considering the learning contexts, as these contexts are dynamic, changing over time or through use. These methods of documenting and analysing the contexts accommodate this change by broadening the viewpoint and identifying the ways in which the contexts can influence and interact. Instances of collaboration can be traced, and the movements of participants and their involvement in different actives are recorded over time. This assists with the determination of the factors that support or limit collaboration. The events and activities that lead up to and support collaboration, as well as the situations that sustain it, are also captured.

3.2. Understanding staff, students and communities

Whilst being in-place, interviews provide a way to capture how change is initiated, directed and controlled within the program. Interviewing leadership teams establishes the background of the program and provides a context for analysis for the overall project. This leads to an understanding of how the program has been able to respond to change over time and how this change has been managed.

So that the person being interviewed is able to describe events and situations in their past with minimal prompting and guidance, the interviews are semi-structured. Such interviews typically results in narratives, in which the participant select s, organises, connects and evaluates prior events. These narratives are useful for finding common thematic elements across a number of situations. The format and nature of the interview prompts self-reflection as the person being interviewed constructs their narrative, as opposed to compiling a description. In retelling an experience, the narrator relies on previous experiences, memories, and understandings (meaning) in order to interpret the experience. Such narratives offer insight into how meaning is made, the ‘position’ of the narrator within the retold experience, and the worldview from which the story is told.
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The narratives are used to develop a model of worldviews by mapping the communities involved, and their experiences of architectural learning. When considered alongside other documentation such as the photographs, the knowledge sharing experiences and the outcomes of the learning are analysed in order to determine the nature of the experiences and the interactions that have taken place. In doing so, how different modes of communication has been developed and supported can be identified.

3.3. Observing behaviour

The observations made by being in-place provide insight into the interactions that take place in learning experiences, the roles of the contexts, and the participants. Observations, field notes, audio recordings and photographs are used to establish the nature of the social interchange, the role of the natural and built environments and the effect on the learning experiences, both formal and informal. The aim of these observations is to capture a wide range of behaviour including movement through a specific place or situation; behaviour at specific events; repeated situations or actions; and different interactions or responses in similar situations. In addition, field notes made during observation, and immediately after, provide written descriptions of what was observed, and maps, diagrams, documents etc. gathered while observing. Reflexive journals, which track the conditions in the field, serve also to record the state of mind of the researcher and other variables that affect observation.

The documentation of observed behavior, the field notes, photographs and reflexive journals, provide insights into the interaction that takes place within the learning experiences. Relationships between participants, both individuals and groups, are explored by examining the size, location and diversity of the social groups. The body language evident in these interactions, and the dynamics, such as the teacher-student interaction, and peer-peer relationships are captured and the characteristics of the contexts examined in more detail to explore the role of the contexts in the interactions, and to determine if change or transformation has taken place.

The examination of learning experiences outlined above demonstrates the complexity of the processes of architectural education. The factors that can support experiences of all types of environments by all participants, which in turn can support critical reflection of the impact of these environments, are identified. The types of educational processes that occur, the development skills in multiple modes of communication, and the opportunity to collaboratively reflect are recognised. Defining the role of participants can provide a more detailed understanding of the opportunities to develop and demonstrate skills in critical reflection, communication and collaboration. From this examination, architectural learning experiences can be developed in which the activities and modes of interaction provided can contribute to the meaning that is made of these experiences. Reflection upon these experiences, and the awareness of the benefits gained, leads to new understanding. The sharing of this understanding with other participants can lead to shift in worldview and subsequently to a new way of thinking and practicing.

4. Considering architectural learning experiences

When considering architectural education at high-ranking universities, analysis of the evidence collected on the education environments, the curricula and the participants indicates that architectural education is reinforced by and reinforces current practices within the profession. The pre-requisites and entry requirements of architectural programs identify certain skills that are required and recognise the existing abilities and capacities of these participants. A process of admission that determines the types
of abilities and languages of admitted students is reflected in the discipline-specific language and way of thinking expected. While common language and a set skill level serves to focus the programs and ensure equity when developing the skills further, it can limit the opportunities for challenging current values and prompting a shift in understanding the worlds of self and others. Supporting a diversity of languages and skills encourages different ways of viewing the world and ways of sharing experiences.

It has been acknowledged that meaningful knowledge is built through direct experience (Holt, 1974) (Atkin, 1999), although it is recognised here that the extent to which the world can be experienced directly is limited. This is particularly important when the education focuses on global architecture and the built environment. Through effective communication, sharing architectural experiences with others can influence the way in which others perceive and understand our world, and the extent to which we can understand the worlds of others. The more engaging and effective the sharing by another, and the greater the ability of the self to understand and be inspired, the more likely the motivation to learn (Atkin, 1999). In addition when sharing experiences, if communication skills are not suitably developed or present, or the language used is not aligned with the literacy of others, then it is more difficult for experiences to be shared and the opportunity for learning to challenge current values and prompt change is limited.

Teaching focused on shared experiences that place personal experiences at the core of the learning, and sharing teaching spaces with others, using the same space for teaching different subjects, can support collaboration and the application of multiple concepts to a single situation. Elective or optional units within a program can support a student to direct their own learning. When this direction is based on insights made through critical self-reflection this can become a tool to challenge their knowledge and worldview. Cross curriculum teaching, where staff teach across more than one of the capabilities and skills requires more than one language and can support the development of multiple modes of communication. Recognizing and accommodating diverse abilities and skills can influence the transfer of knowledge and opportunities to learn.

The review of published research identified that when analysing the areas of focus of this research, there are differences between architectural research that focuses on education, and education research that focuses on architectural education. Within the architectural research that focuses on education the common areas of focus include educational content; the learning environments, typically built and educational; and the demonstration of discipline specific skills and abilities. However, whilst knowledge and how others make meaning within the built environment are discussed, the role of worldview, or the epistemological positioning, of the architectural educational program itself is not often explicitly addressed. When there are contrasting worldviews, it can lead to confusion in both staff and student and conflicting assumptions about the nature of knowledge and meaning can result. Education research that focuses on architectural education often focuses tightly on certain elements of the experience. A focus on the relationship between two types of environments, such as the role of the built environment in education, does not place the learning experience in a broader context. A specific event or learning activity, such as the design studio, may focus on discipline skills only. A focus on a particular component of the curriculum such as technology requires discipline specific knowledge and may limit application. The methods of examination discussed in this paper recognise that architectural education relies on a range of abilities and languages to develop new understanding of shared and experienced worlds, and that a different point of view can support the new meaning and a change in position.

New construction methods, innovative materials and the emerging technology require specialist knowledge and equipment and certain situations with regards to client, budget and time. This can serve
to disconnect the users from their environments, through the over-use of discipline specific language, automated controls and limited environmental literacy. It is not only skills and knowledge about the architecture that is being learnt. A contextualized understanding of self and others, through multiple modes of communication, can reconnect designers, users and their environments.

5. Conclusion
This paper discusses how a complex understanding of architectural learning can be reached. It argues that current understanding can be further developed to include the architectural learning experiences, the multiple contexts in which these experiences occur, and the changes in the worldview that enables staff, students and communities to better respond to the complex global changes. It acknowledges the need for core skill development beyond technical skills and discipline knowledge. It is recognised that while these skills are developed during architectural education, and are expected by the profession, the learning of the skills and the experiences in which they are developed is often assumed or tacit. Current methods of determining best practice in architectural education such as those used in university rankings, focus on research outputs, teaching staff, professional expectations and international outlook. However, this focus does not explicitly address the skills of critical reflection, communication and collaboration, which has been repeatedly called for in architectural education nor do these rankings address the complexities of the learning within architectural education. A review of articles published within the field of architectural education has indicated that discussions seldom address learning as an experience or contextualize these experiences. The methods described here adopt an approach, focused on learning experiences. This has enabled insights about these learning experiences that recognise the complexities of architectural programs, and the dynamic nature of architectural learning. Re-examining architectural education in this way can help to make explicit the role of the contexts of learning and the abilities of all participants to design responsibly. However, it is unable to address the processes and experiences required for learning as it focuses primarily on the outcomes of staff and students. New methods of recording learning experiences has enabled the nature of these experiences to be examined and explores how real-world experiences of learning can be shared and understood in different ways by self and others. Mapping the contexts of learning, requiring the purposeful and critical reflection of the situations, can be useful in identifying the key elements of the environments. Examining and understanding the way in which these environments relate to each other and the way in which this can influence learning can be achieved through being in-place for a length of time. By identifying the roles of participants and modes of interaction within an architectural learning process through observation of behaviour the cognitive processes and modes of learning are made explicit. Examining how learning experiences are shared, and the languages and communication used, is a means of understanding the relationships between participants and the interactions that occur that can prompt and support a shift in world view and epistemological position. In doing so, change in the contexts, the participants and the interactions within systems of architectural learning can be captured.

References


Architectural science, creative design and professional expertise

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Abstract: Steven Szokolay acknowledged that some academics consider the term architectural science to be oxymoronic. This paper argues that it is a suggestion worth investigation in terms of how architectural education is to be conceptualised as a future focused program. The notion that the science-based aspects of architecture might profitably be made distinct from other aspects of the profession suggests a constructivist perspective of how architecture ought to be taught. It assumes that architecture is best learnt as an ordered progression through a logically arranged set of subjects, the completion of which will ensure the knowledge and skills the profession expects. As we approach the second quarter of the twenty first century, such isolationist view of domains of practice are increasingly considered to be inappropriate in a profession wherein declarative knowledge is ubiquitous and readily assessable but innovation and creative ideas are few and far between – regardless of the fact that architectural practice ties its reputation to the latter.

Keywords: Architecture, Science, University, Design.

1. Introduction

The assertion that science and art meet in architecture has acquired a substantial and largely unchallenged history, dating back to the subsumption of the profession’s training into the academy. In terms of research and practice, the meeting of science and art in architecture is far from settled because the fundamentally conflicting assumptions and methodologies of creating and evaluating new knowledge favoured by either of the two has caused increasing friction and contestation within both the academy and the professional association. Both the academy and the profession foreground design as architecture’s principle aspect. For example, the first five of the nine competencies required for registration as an architect in Australia focus on design whereas only two focus on project delivery. Universities too focus the importance of design in the standard five years of higher education required to graduate as an architect. For example, in the University of Melbourne, the undergraduate pathway degree to a Master of Architecture qualification will be the Bachelor of Design.

Design is generally seen as the handmaiden of science and engineering on the one hand and as a less salubrious manifestation of art on the (less dominant) other. Science is generally assumed to provide the
A. Onsman

concrete building blocks of design; the incontrovertible factual data that grounds the imagination and stops flights of implausible fancy in their tracks. Regardless of their aesthetic, buildings are argued to require functionality and art is more or less a cosmetic extra. In actuality, new architectural knowledge is more likely to be generated through artistic research than scientific research and this shift in focus is having a discernible impact on how architecture is taught and how architects are trained.

Architecture is an open domain of knowledge that continues to refine and reconstitute its boundaries both in terms of skills and knowledge. It is also a cross-disciplinary domain of knowledge. Practitioners regularly appropriate knowledge from other domains. Design is not a domain of knowledge per se but a strategic framework that ranges across numerous fields of enquiry and expertise. Design is fundamentally the derivation of a tangible solution to a real or hypothetical problem. When confronted with a familiar problem to solve architects draw on what is already known, which is the basis of all expertise. When architects are faced with an unfamiliar problem, they are required to speculate, experiment and innovate. Creativity in architecture expands the boundaries of expertise by borrowing from other domains of knowledge as much as pursuing what-if ideas within its boundaries. Such strategies are the defining characteristics of artistic rather than scientific research but the methods of research used in the sciences are, according to Paul Feyerabend (1993) far from hard. Hard science generally refers to domains which knowledge is derived by way of objective and quantitative methodologies, and includes physics, chemistry, mathematics and so on. The soft sciences – including psychology, biology, archaeology and geology - tend to accommodate a portion of qualitative research. Basically these “soft science” fields of enquiry tend to recode qualitative data as quantitative data in order to perform statistical analyses that resemble the statistical analysis performed on quantitative data in order to give the research a patina of academic authenticity.

There are two major flaws in this largely academy-sponsored development. First is the assumption that soft science research is familiar to most people; that it is to a large extent, common knowledge (Kelley, 1992). It therefore lacks the gravitas of research that is more remote, that requires learned expertise to generate. Second is the lack of understanding that systemic knowledge, the underlying complex structures of theoretical framework generated by the soft sciences to cognitively accommodate complexity in order to predict rather than simply articulate, is in general terms more sophisticated in a real world science that anything pure mathematics can come up with. Nonetheless the lopsided and unevenly funded divide persists. Moreover, there has been a growing tendency to assign the word science to domains of knowledge or fields or enquiry that seem to have little cause for such appellation: political science, social science and philosophical science to name a few. In deed Christian Science has been around since 1875, when an attempt was made to reconcile “received” with propositional knowledge. Some one hundred and forty years later, that reconciliation is still a way off but there are those who remain dedicated to the task. Christian Science is conceptually akin to philosophical science, and it is not at all surprising that Marxist thought has found a spiritual home there.

The existence of an Architectural Science Association assumes that architecture can be scientific; that architecture can be practiced scientifically. According to its website, the Association exists “to promote architectural science, theory and practice primarily in relation to teaching and research in institutions of higher education”1. Where, on the continuum that has hard science on one end and soft science on the other, architectural science places its marker has changed over time. As this year’s conference is titled “Fifty years later: Revisiting the role of architectural science in design and practice”,

1 http://anzasca.net/about/
it seems an opportune moment to consider whether or not architectural science remains useful agency in both the profession and its training.

The Association is “committed to the development, documentation and diffusion of the principles of architectural science and including but not limited to the application of natural and innovative techniques for sustainable architecture”. It promotes “high quality research, practice and education in environmentally sustainable design”. Architectural science therefore has to do with research, practice and education. Sydney University posit that because they have “extensive experience analysing and controlling the physical phenomena affecting buildings, practitioners of Architectural Science have a profound impact on the function, aesthetics and efficiency of architectural spaces”\(^2\). Their Master of Architectural Science has the following majors: Audio and Acoustics, High Performance Buildings, Illumination Design, Sustainable Design, Facilities Management and Building Services, with the last two offered as graduate certificates rather than master’s degrees. Only Curtin University offers a Bachelor of Applied Science (Architectural Science), the prerequisite undergraduate degree for a Master of Architecture degree. The degree consists of two streams: Architectural Design, Science and Technology, and Architectural Culture and Design Communication. Conceptually then, Architectural Science exists in contrast to Architectural Culture. Interestingly Architectural Design is aligned with Science and Technology while Design Communication is aligned with Architectural Culture. Curtin University also offers its undergraduate degree program through Open Universities and various TAFE colleges.

Steven Szokolay defines architecture as ‘the art and science of building’ and argues that without a scientific basis it cannot create built environments that are sustainable. He traces architectural science as a specific knowledge domain back to H. J. Cowan who coined the term in 1954 to indicate the scientific basis of architectural design – mainly in terms of materials, construction and structures - at the University of Sydney. Szokolay articulates how the field subsequently broadened to accommodate the physical science aspects of architectural design and, later, the relevant areas of the social sciences. Eventually the use of energy and resources – sustainability – became the main concern. And there, he argues, architectural science as a discreet field of inquiry should have stopped, registering dismay with those who consider architectural science oxymoronic:

Since then, unfortunately, some extreme exponents of post-modernism came to consider architecture purely as an art-form, denying Sullivan’s tenet: “form follows function”. This has led to the most extravagant, unorthodox, contorted and crazy buildings. The odd few can be tolerated here and there in an existing sober and solid urban context but heaven forbid this becoming the ‘norm’. It is pure formalism, at the expense of function and environmental decency (Szokolay, 2014: viii)

In essence then, architectural science assumes that its knowledge domain has been verified by research that is scientifically valid. The function of research is to add to knowledge. Research involves experimentation, explication, re-interpretation or postulation. Where in architecture does experimentation occur? It is a complex question because architecture has become a blanket term for any human intervention in the built environment – virtually or physically. Richard Hyde (2016) takes what seems to be a more progressive view, arguing that architectural science advances by way of both theoretical and practical research. Earlier (2013) Hyde had posited that convergent methodologies – those that have both quantitative and qualitative methodological frameworks - could have significant benefits for architectural science which hitherto had commonly used only the scientific method to

\(^2\) http://sydney.edu.au/architecture/architecturalscience/
answer complex questions concerning the built environment. Hyde points out that architecture in practice already uses a combination of hard and soft science methodologies, and multi-methods allows for triangulation of findings. In this paper, I am positing the idea that architectural science needs to go even further to remain relevant in architectural research because architecture is not simply about designing what is possible but designing what may be possible. Hard scientific research at best can provide the basis for innovation and at worst stymie experimentation.

This paper is principally concerned with how architecture is conceived as a future focused field of enquiry and practice, and how it is taught as such in the twenty first century. In most degree courses in the western world, the fundamental aspect of architecture education is design, and other aspects radiate out from that fundament. Moreover, that structure is also evident in the professional organization, Architecture Australia. Therefore, it is at this elemental level where research outcome ought to be focused. By way of a nod to the academic zeitgeist, any paper that seeks to consider design as research outcome had better declare what it takes research to be (Balkema & Slager, 2004). The Oxford English Dictionary defines it as:

> Systematic investigation or inquiry aimed at contributing to knowledge of a theory, topic, etc., by careful consideration, observation, or study of a subject. In later use also: original critical or scientific investigation carried out under the auspices of an academic or other institution. The product of systematic investigation, presented in written (esp. published) form. [OED unpaginated]

At heart then, research is the gathering of data and information to be synthesized into knowledge that increases what is known within a domain, usually by way of answering a question postulated to refute a negative hypothesis. Two pertinent issues arise. First, the investigation needs to be systematic. Second, the investigation needs to be original, critical or scientific. Nowadays, there seems to be an assumption that the investigation, and its product, needs to be original, critical AND scientific but despite it being ingrained, that assumption is contentious for two reasons. First, epistemologically there is no historical basis for it and second, functionally it is a contradiction in terms.

In terms of the history of human knowledge acquisition, the scientific method of research is a very recent development. Other methods have substantially longer histories: observation, insight, superstition and religion, trial and error, hermeneutics as methods of knowledge creation have been around a lot longer. None of those involved either a hypothesis or systematic methodology, and whereas science affords them a diminished status as data-gathering mechanisms, they garnered tremendous amounts of knowledge. The scientific method of research (Betz, 2011:22) evolved in the seventeenth century in Europe as an “intellectual conjunction of the research of six particular individuals: a scientific model that could be verified by observation (Copernicus); precise instrumental observations to verify the model (Brahe); theoretical analysis of experimental data (Kepler); scientific laws generalized from experiment (Galileo); mathematics to quantitatively express theoretical ideas (Descartes and Newton); and theoretical derivation of an experimentally verifiable model (Newton). Items 3 to 6 inclusive indicate that the paradigm is based on quantifiable modeling. However, the notion that theoretical ideas can be expressed mathematically is philosophically if not naturallycontestable. Mathematics is a wholly invented paradigmatic framework, and as such allows perfection and closure. Mathematical theorems are proved or disproved within that framework. For example, the conundrum at the heart of Fermat’s Last Theorem (There are no whole number solutions to the equation $x^n + y^n = z^n$ for $n > 2$)
zn when n is greater than 2) remained unsolved for 300 years because more mathematically consistent aspects needed to be constructed by way of reductionist logic (an invariable algorithmic sequence) in order to solve it. Number theory falls under the heading of “Pure Science”, a domain of hypothetical knowledge wholly dependent on if-then relationships that contribute to the set of its defining characteristics, where proof relies on whatever knowledge has already been accommodated within the domain. In the case of Fermat’s Last Theorem, it had to wait until algebraic geometry had built up enough knowledge to allow the puzzle to be solved. The Mathematics Academy generally sees its resolution as proof of the theorem. But both the proof and the theorem are hypothetical fabrications, phenomena that exist only artificially as coherent and systematic conjecture. Such propositional knowledge often forms the basis of hypothesis-driven ‘if-then’ research, as in reconciling the conundrum in Fermat’s Last Theorem. On the other hand, the resolution of such hypothetical speculation can lead to immensely complex algorithms that can operate meaningfully and purposefully in the most complicated contexts. Scientific research can be pure or applied: the former seeking to identify and understand underlying concepts, the latter seeking practical application, most often as a solution to a specific problem. Both seek to yield testable data that can be interpreted to answer a question. Whereas the essence of pure scientific research is that ultimately only self-evident statements are meaningful, the idea of self-evident statements in architecture is not only tautological but fundamentally absurd unless observable phenomena within a design are articulated as constituent elements and conceptually organised as part of an underlying model inherent within that design: it is in effect an exploratory factor analysis of a hypothetical construct.

In a scene in the TV sitcom “The Big Bang Theory” the experimental physicist Leonard Hofstadter responds to his mother (a psychiatrist, neuro-scientist, author and terrible mother) who has asked him what he is currently working on by telling her, “I think you’ll find my work pretty interesting. I’m attempting to replicate the dark matter signal found in sodium iodide crystals by the Italians” to which she replies “so, no original research?” “No.” “Well, what’s the point of me seeing it? I could just read the paper the Italians wrote.” Should anyone decry the use of a comedy show on television to make a valid point about research in architectural science in an academic paper, it should be noted that the highest ranked scientific journal in the world, Nature, reported that the Italian theoretical physicist Professor Rita Bernabei and her team’s claims to have seen dark matter caused controversy and contestation in 2008 (Brumfiel, 2008) but nonetheless set off numerous attempts by teams of experimental physicists around the world to replicate the experiments, mirroring Leonard Hofstadter’s work. For those with an inquisitive mind, the claims are set to be confirmed or refuted in 2016 (Castelvecchi, 2016) because the knowledge, technique and equipment needed to do so are now at hand. The point is that the scene accurately depicts the various and growing concerns with the place of scientific research. Validity in science is based on a hierarchy of reproduction: a single experimental result is only potentially propositional knowledge. Before it is accepted as theoretical knowledge it needs to be reproduced. Before it gains traction as procedural knowledge it needs to be reproduced in other contexts and under other conditions. But there is nothing creative or innovative about reproducing an experiment. Similarly, there is nothing creative or innovative in reproducing a design. For a design to innovative or creative it has to have made a leap into the unknown somewhere in the process.

Hard science is a handmaiden to the imagination: it is very good at providing the mechanisms, data and conceptual understanding to answer open-ended and speculative questions from other domains of

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knowledge. On the other hand, it is not so good at innovation, and as Oscar Niemeyer said, architecture is invention. Bernard Tschumi adds that not only is architecture concerned with creating new things, its ultimate pleasure “lies in the most forbidden parts of the architectural act, where limits are perverted and prohibitions are transgressed”. Tschumi’s work on the New Acropolis Museum serves as an example of limits perverted and prohibitions transgressed (Horacek, 2014). In both his approach to architecture and in the response to it, Tschumi exemplifies the preference of architects to be thought of as artists rather than scientists. On the other hand, no architect can claim to be only an artist. Although Walter Gropius famously said that architecture begins where engineering ends, Louis Kahn was somewhat more pragmatic when he stated that a building must

...begin with the unmeasurable, must go through measurable means when it is being designed and in the end must be unmeasurable. The only way you can build, the only way you can get the building into being, is through the measurable. You must follow the laws of nature and use quantities of brick, methods of construction, and engineering. But in the end, when the building becomes part of living, it evokes unmeasurable qualities, and the spirit of its existence takes over. Architecture has existence, but it has no presence. Only a work of architecture has presence, and a work of architecture is presented as an offering to architecture. (Kahn, 1967: 149)

Architecture according to Kahn is principally an exercise in design: practically informed and parametrically contextual but design nonetheless. But design covers a much greater bailiwick: it includes anything that is based with the contingent rather the necessary, not with things as they are but as they might be (Herbert, 1996). On the one hand, the argument is simple. Architecture is design (Tversky, 2016). Design is not a science but an independent area of thinking and doing. (Cross, 2011). On the other hand, Herbert Simon asserted that there was such a domain as science of design, ‘a body of intellectually tough, analytic, partly formalizable, partly empirical, teachable doctrine about the design process’. Leonard Archer disagreed, stating that ‘there exists a designerly way of thinking and communicating that is both different from scientific and scholarly ways of thinking and communicating, and as powerful as scientific and scholarly methods of enquiry when applied to its own kinds of problems’. Whether or not architectural science is a contradiction in terms seems then to depend upon where you see the divide between architecture and a work of architecture; between the design and the construction of a built environment.

Where nowadays on that continuum does the Architectural Science Association place its marker? The ASA is, according to its website, “an international organization, the objective of which is to promote architectural science, theory and practice primarily in relation to teaching and research in institutions of higher education”. To clarify what it means to “promote” architectural science in universities and colleges, the ASA asserts that it is “committed to the development, documentation and diffusion of the principles of architectural science and including but not limited to the application of natural and innovative techniques for sustainable architecture”. Granted that it contains some fine alliteration, the statement doesn’t actually state what “the principles of architectural science” are. In fact, it is quite difficult to find what anyone understands those principles to be in 2016.

Of all the higher education institutions that offer architectural degrees only the University of Queensland provides a definition of sorts. In Architectural Technology, a course offered by the university’s Faculty of Engineering, Architecture & Information Technology, the course description states that
This course provides an introduction to the principles of architectural science (heat, light and sound), materials science (embodied energy and energy transfer), building services (power, sewer and water) and passive design for sustainable building. Students examine the principles of energy, air, water and climate in activities and assignments that also develop skills in the design of environmentally sustainable small to medium scale buildings.¹

Undoubtedly heat, light and sound are important elements to be considered in the design of a building, as in deed they are in a multitude of other contexts, but they do not at first blush seem to be principles as such, let alone principles of architecture or science.

The problem of tying down exactly what the principles of architectural science – the things that the ASA is committed to develop, document and diffuse – is not contained to the here and now. Nearly two centuries ago the redoubtable J. C. Loudon identified one:

A wall or a house, therefore, can that does not show, either in reality or in imitation, the materials of which its walls are composed, can have no pretensions to architectural expression. This expression can no more be produced in its full effect, than a sentence can be printed without employing the letters of the alphabet. There is not a more important principle than this for the young Architect to bear constantly in mind, in the whole range of the science of Architecture. (Loudon, 1835: 261).

Frustratingly, Loudon doesn’t mention any other principles but at least we have the “most important” one: architecture should not attempt to hide the nature of the materials used in construction because it runs the risk of losing architectural expression. In his preface, he states that “knowledge of the rules of Grecian Architecture, can no more be considered the principles of the science than the art of mixing colours can be called the principles of painting”, which suggests that he believes architecture is a science with rules which are different to its principles. In today’s lexicon that seems contradictory but in 1835 the word ‘science’ meant little more than ‘knowledge’, it had not yet acquired the notion of a specific knowledge domain which parameters were defined and organised by systematic study. With that understanding even Christian Science becomes a reasonable if not exactly rational proposition.

In terms of its pedagogic purpose and place in the university curriculum, the expression of architectural science as a sub-domain of knowledge seems to correlate to an increased pressure exerted by universities on faculties for more research output and more industry engagement. Nearly forty years ago, Otto Koenigsberger proposed the focus of architectural science on problem-oriented research allows it posit itself as an essential component of architecture, organically aligned with construction methods. Koenigsberger equates architectural science with building science, and suggests that university staff are well-placed to take on consultancies to do some original short term research that solves a specific industry problem and with the ensuing publications kill two birds with one stone. Of

¹ https://www.uq.edu.au/study/course.html?course_code=BLDG2120&offer=53544c554331494e
course, post-graduate research work for higher degrees could be directed to some of these problems. In this way the university will be more associated with the building industry, and the affiliation will be mutually beneficial (Koenigsberger, 1978:7). He goes on to point out that there are two rather obvious problems that might provide barriers to such ventures. This kind of research, he concedes, is not really what universities ought to be doing. First, it fits better in technical institutions and industrial facilities. Universities should be engaged in more conceptual research that results in more universally applicable results. Second, the problems of architecture or building are often not confined to the parameters of architectural or building sciences. His solution is that for such research an “inter-disciplinary approach is the obvious answer, a solution that iterates the argument that architectural science rather than a separate knowledge domain is simply the use of data, information and knowledge gathered in the various science contexts to make manifest what has been architecturally designed.

In 2014, Routledge published the third edition of Steven Szokolay’s book ‘Introduction to architectural science: the basis of sustainable design’ in which he offers a defence of architectural science on the grounds that architecture cannot be sustainable without science, and that any architect who claims otherwise is contradictory, possibly schizophrenic and probably fraudulent. Science, he claims, is part of design. And that the “designer can only exercise his/her imagination if the physical basis is understood. Scientific understanding should permeate the intuitive, inventive design” (2014, viii). Here in sum, we have the entire problem with architectural science in a nutshell. Scientific understanding is based on reductionist experimentation, the elimination of possibilities until only one verifiable option remains, the result of “if-then” logic. Architecture on the other hand, in its design capacity functions on “what-if” questions, on increasing the range of possibility, on multiple potential solutions, on cross-domain idea activation; on finding best fits. The designer not only can but should exercise his or her imagination without anchoring it to the known: it is only when a flight of fancy is to be made manifest that science and the other handmaidens will be challenged to make it happen.

But, it ought not to be concluded that this paper has suggested that there is no connection between science and architecture. In fact, it has argued quite the opposite. The manifestation of architecture is possible because of the sciences, engineering, psychology, art and economics. But none of those is architecture. While to question whether architectural science is oxymoronic may ultimately be irrelevant, there is a fundamental purpose in posing it, one that transcends what the ASA purports to be its ambitions. Firstly, it will challenge the place of research both in the academy and in the professions and secondly, it will have impact on design, construction and delivery of academic curricula, and thereby impact on what the architects of the future will be concerned with. The next fifty years will be interesting.

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Colonial modernism and architectural science: Historic developments in Sub-Saharan Africa

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**Abstract:** Formal architectural education in sub-Saharan Africa (excluding South Africa), founded at the height of tropical modernism, a link that embedded a scientific approach to architecture as a key part of the new curricula. Over the years, however, engagement with architectural science has all but vanished, little more than basic rules-of-thumb, which has raised concerns in face of growing awareness of the need for ESD in architecture and architectural education. Seeking answers, this paper interrogates the socio-political events following the Second World War than may have contributed to this state of affairs. The contextual realities of tropical modernism, with roots in the less palatable moniker, colonialism modernism, emerges as a key factor in this discourse. While tropical modernism was initially embedded in architectural education, its historic links to colonialism contributed to it, being jettisoned as part of the Africanisation of curricula as part of post-colonial ideological shifts. Being associated with tropical modernism, architectural science was thus relegating to the periphery of architecture programmes, and may partially explain the continued nonchalant attitude toward architectural science today. Any attempt to revisit this engagement naturally has to come to terms with this reality as an important step in engaging with discourse on architectural science education into the future.

**Keywords:** Colonialism; Tropical Modernism; Architecture Science Education, Africanisation.

1. Introduction

Across East Africa, academics are beginning to query the dearth of architectural science in architectural education (Oyaro, 2011; Olweny, 2013; Kimeu, 2015). While most schools of architecture do include ‘Building Science’ or ‘Environmental Building Science’ as part of their teaching repertoire, there is limited evidence of these being incorporated into students’ design projects, and eventually into new buildings. How this came to be becomes an intriguing line of investigation, given architectural science as a discipline has strong links to Tropical Modernism and the founding of schools of architecture in sub-Saharan Africa during the 1950s. Investigating the developments surrounding Tropical Modernism, which replaced the less than palatable moniker, ‘Colonial Modernism’, may reveal some answers to this question. This paper is part of a re-reading of Tropical Modernism through a post-colonial lens, as
initiated by Lagae (2004), Le Roux (2004) and Uduku (2005). Revisiting the origins of Tropical Modernism and architectural education in sub-Saharan Africa, the paper seeks to understand the rise and subsequent demise of architectural science as a key component of architectural education across the region. This presents what (Okoye, 2002, p. 384) termed a “rich dilemma”, when looking at the future direction for architectural science; taking account of the troubling relations embodied within the Tropical Modernist canon (Le Roux, 2004), and could shed light on the absence of architectural science in contemporary architectural discourse across the region.

2. Tropical modernism

Tropical Modernism emerged after the Second World War as a response to “... climate conditions that were ‘uncomfortable’ to expatriate and westernised bodies ...” with architects seeking to devise ways to modulate “… the passage of heat and light between interior and exterior” (Le Roux, 2004, p. 439). It presented as a systematic attempt to deal with the climate conditions experienced in West Africa, but in so doing, disregarded indigenous approaches, as revealed by the following dialogue purportedly uttered by Maxwell Fry and Jane Drew, early proponents of Tropical Modernism in West Africa:

   Maxwell Fry: ‘A Nigerian aesthetic? On what would it be based that is as solid as the plywood techniques, the old timber traditions of Finland?’

   Jane Drew: ‘If a Nigerian genius were to be born, upon what deeply-felt indigenous art might it not feed – and be better digested, perhaps, than Picasso’s reactions?’ (Ihejirika, 2000, p. 185)

Such positions ensured disengagement with social aspects of architecture, encapsulated in the idea that there was nothing in the region worth considering as precedents (Okoye, 2002). This position was also critical in justifying the use of imported materials and technologies in the new buildings in the quest to tackle climatic conditions described by Fry as “enemies that could be overcome only through design.” (Liscombe, 2006, p. 197). This approach rejected earlier forays into architectural responses for the British West African colonies that “… spoke of the need to rely on exiting architectural and design traditions” (Myers, 1998; 13), traditions which dictated that most daily activities took place outdoors, “with buildings only performing the function of shelter from more adverse elements such as rainfall, and as places to sleep at the end of the day” (Uduku, 2005, p. 402). The uptake of the tropical modernist aesthetic thus presented as a break with the past, installed a largely alien building typology as “the only valid and progressive form of architecture” across the region (Uduku, 2000, p. 50).

The new tropical modernist aesthetic also provided a carte blanche opportunity for the growing number of expatriate professionals to “implement a radical aesthetic” (Liscombe, 2006, p. 193) through their own interpretation of local conditions. Being synonymous with technology “… that mirrored or even represented the western world itself” (Cripps, 2004, p. 473), tropical modernism epitomised developmental progress in the colonies, exhibited through the use of new materials like reinforced concrete, aluminium, glass and asbestos. As use of these new materials and new techniques took hold, it was clear that a more detailed understanding of their performance under tropical conditions was needed, provided through the West African Building Research Institute (WABRI) set up in 1952 in Accra, as an offshoots of the British Research Establishment (BRE). The need for support staff for these institutions was in part a catalyst for the new technical schools and universities in the region, effectively linking early architectural education in the region with a new aesthetic based on scientific rationalism, and a need to be more responsive to local climate conditions. This also linked tropical modernism with
the birth of formal architectural education in West and East Africa, tied to the education of professionals being rolled out across the region for the first time after the Second World War.

It was through these new educational institutions that Tropical Modernism had its greatest visual impact, through the numerous educational buildings built as part of the colonial spatial project, with buildings constructed to accommodate the new institutions acting as a key part of the educational (read civilising) mission. Further, these architectural endeavours had a significant influence on development at an “...economic, social, cultural and philosophical level...” (Uduku, 2000, p. 46). Education itself was a key element in spreading the benefits of modernism and its principles. The use of education as part of colonial policy came late in the life of colonialism in sub-Saharan Africa, having been the privilege of religious missions, and much later by traders and the army. The colonial government only reluctantly came into education, considered “… when medical requirements, labour recruitment, and agricultural needs made officials aware of the lack of skilled manpower” (Beck, 1966, p. 116). Architectural education was only peripheral to this endeavour, emerging as a response to the need for local professionals, given the shortage of expatriates to engage in the large volume of work available as part of a post war construction boom. Pressure had also come from indigenous professionals disgruntled with their own architectural education in the UK, seeking to engage a new generation of professionals with contextual studies that had been promised as part of the post war ‘Africanisation’ efforts. The lack of educational endeavours directed to the needs of students from sub-Saharan Africa had earlier emerged as a challenge for architectural education in the UK, leading to the Tropical Architecture Conference held in London during 1953, with an outcome that defined later approaches to the education of architects for the tropics, and included a unit – Teaching in Developing Countries, offered by the Architectural Association. Architectural science formed a key part of the early architecture programmes, in West Africa, at the Nigerian College of Science and Technology at Ibadan (Nigeria), and later at the Kumasi College of Technology at Kumasi (Ghana); and in East Africa at the Royal Technical College, Nairobi (Kenya). Tied to the post war infrastructural developments, the Tropical Modernism canon was rapidly taken up as an architectural mantra during the late 1950s and 1960s in both architecture and architectural education.

Colonialism largely came to an end during the 1960s, however the immediate post-colonial period saw a continuation of the ‘civilising mission’ embedded in the colonial spatial project, and linked to the development agenda of post-colonial governments. Tropical modernist building typologies, with an “emphasis on abstract form rather than culturally specific symbolism [which] prevented the exclusive appropriation of its signification by the colonial or the colonized” (Liscombe, 2006; p. 200), was taken on as a basis for building the fledgling nations, all of which had diverse ethnic populations for which a single locally derived typology could have been viewed as another colonising element. This appropriation of Tropical Modernism by post-colonial governments, as symbols of the strength and vitality of their newly independent states, was significant in itself, an acknowledgement that the scientific paradigms embedded within this canon were indeed universally applicable, and could act as a unifying element in the post colonial world. This acted on two different levels: first, outward linked to the progressive ambitions of the new nations, many seeking legitimacy and international recognition through engaging with international recognised approaches within the modernist ethos, and; second, inward, providing a message to the country, that the new governments were indeed delivering on the promises they had made as part of the independence struggles, and keen to use the universality of Tropical Modernism as a means of unifying their far from homogeneous states (Hess, 2000; Myers, 1998). Indeed, as it pointed out by Potter and Potter (1984), we have to acknowledge that building:
... is part of nationhood. When a new nation comes into being, its historians are apt to refer to its creators and ‘builders’, and its leaders as ‘architects’. Once independence is achieved, to be able to build is – as any postage stamp collector will vouch – one of the insignia of freedom, no less less vital an element in national self-esteem than the possession of armed forces or one’s own international airline. And the justifiable pride in building is all the more intense if a nation happens to have a local vernacular – and, best of all, local materials – that can be used and developed (Potter and Potter, 1984, p. 13).

Tropical Modernist thus came to simultaneously symbolise the essence of the colonial and the post-colonial, which has come to impact on the very essence of architecture and architectural education across much of sub-Saharan Africa, not least the contradictory claims of “acknowledging the importance of local knowledge, customs and social practices as well as topography and climate” (Liscombe, 2006, p. 194).

3. Tropical modernism in architectural education

Initially, the architecture programmes inaugurated across the region were geared to graduate technicians to work under RIBA registered professionals. These were the Diploma in Architecture stated at the Nigerian College of Science and technology at Ibadan, (now the University of Ibadan) in 1952, and a similar programme at the Royal Technical College, Nairobi (now the University of Nairobi) in 1956. These programmes were upgraded to full degree status shortly after – in 1955 in Ibadan, and 1960 in Nairobi in response to a growing demand for fully qualified architectural professionals, which became even more apparent after independence (Anon., 1969). Although Ghana had gained independence in 1957, the country was also keen to forge its own locally grown architecture school, building the first purpose built school of architecture in 1958 as part of the Kumasi College of Technology, Kumasi (now the Kwame Nkrumah University of Science and Technology).

An important contributor in the establishment of architectural science within architectural education across West and East Africa, was the Architectural Association (AA), in part helped by links it had been built with the London School of Tropical Medicine and Hygiene, and the British Research Establishment (BRE), the latter serving as an aid to “... mainly British Architects in West Africa who needed technical advice on materials and environmental design for the tropics” (Uduku, 2005, p. 398). This link extended into education, with the founding of the AA School of Tropical Architecture in 1954, a response to the need for architects versed in the specific needs of the tropics, and who were also capable in engaging in teaching. Many graduates of that programme subsequently found their way to sub-Saharan Africa assisting in the development of new architecture programmes, most prominent of these being the ‘rebooting’ of the architecture programme at the Kwame Nkrumah University of Science and Technology (KNUST) under leadership of Michael Lloyd. As part of this endeavour, a number of academics and graduates of the AA were seconded to KNUST; including Fergus Nichol, who spent some time there during the 1960s, no doubt influencing his development of the Adaptive Thermal Comfort Model. This link with the AA helped make KNUST the epicentre of architectural education in West Africa during the 1960s and 1970s, and arguably across sub-Saharan Africa, as an offshoot of the AA Tropical School (Uduku, 2005). In East Africa, the link was less direct, with the University of Liverpool responsible for transforming the Diploma in Architecture at the Royal Technical College Nairobi into a fully-fledged architecture programme. As part of this project, Steven Szokolay was seconded to Nairobi, possibly a
consequence of his education under Koeningsberger at the AA, and having completed the Teaching in Developing Countries course offered by the AA (Lu, 2010).

Built around the ideals of Tropical Modernism, these new architecture programmes played an important role in defining the direction of post-colonial architectural education, and post-colonial built environments, more so as a key role involved an evangelising mission, defining architecture in the context of region, and espousing the values and virtues of architecture as a profession, given that it was being introduced to the region for the first time (Potter and Potter, 1984). The new curricula were biased toward architectural science, in line with recommendations of the 1958 Oxford Conference on Architectural Education, which embraced building science as a vital component of architectural education (Chang, 2016). In the context of sub-Saharan Africa, this was also in a belief that this would ensure the acceptance of architecture, based around the provision of comfort:

A large proportion of the theoretical studies must be devoted to the study of architectural science. Architecture in Africa, to be acceptable to the community in terms of comfort conditions, must be designed on a sound scientific basis. Much of this knowledge must rely on controlled experiments with actual buildings in the countries concerned. It is therefore, vital that every school should have an architectural science laboratory with the appropriate equipment (Danby, 1969, p. 31).

The focus on architectural science however, proved to be a double-edged sword: providing a means to quickly engage with the perceived requirements of the rapidly developing post-colonial societies, but ironically providing only marginal links to social and cultural conditions of the places in which the new programmes were located. For the most part, this was a consequence of architectural education itself being based on “foreign pedagogy and its associated cultural ethos, only partially modified to local conditions” (Liscombe, 2006, p. 194), and for the new programmes, still embodying key principles of the colonial spatial project, and this contributing to the paradox that was early post-colonial architecture. This paradox made a significant contribution to the eventual demise of architectural science as a key element of architectural education across the region (Myers, 1998; Cripps, 2004), more so during the second decade after independence.

4. The Post-colonial, and the demise of tropical modernism

Initially embraced as the architectural style of choice by post-colonial governments, tropical modernism, and its embedded scientific principles, shaped many urban areas across the regions. However, a significant shift occurred with the founding of the Organisation of African Unity (OAU) – now the African Union - established in Ethiopia in 1963, and largely with the wider independence movement and fight for self determination across sub-Saharan Africa. A consequential outcome of this galvanisation of Africanism, was a healthy cynicism to anything remotely linked to the colonial era (Myers, 1998), inevitably leading to post colonial governments seeking to redefine what it meant to be African in a post-colonial world (Sian, 2007). This was reflected in writings by novelists such as Wole Soyinka in West Africa, and Ngũgĩ wa Thiong’o in East Africa, questioning the appropriation of modernism in representing the future of Africa, something they regarded as symbolic of colonised minds (Akwang, 2012). Modernism as the vision for the future, a future that was very much like the past, thus came into question. Ironically, questions of this universal applicability of modernism had been questioned much earlier, a result of the general lack of specific design solutions to meet the growing needs of budding professionals in the region, leading them to push for a more ‘appropriate’ architectural education.
Even by the time Fry and Drew completed their educational commissions in 1955-56, the African voice and gaze were only minimally present in the African architectural profession. Non-African paradigms predominated in the education system intended to facilitate Africanization (Liscombe, 2006, p. 2008)

Realignement of social and political ideologies during the 1960s inevitably affected the nature of education, contributing to the eventual demise of tropical modernism as a post-colonial endeavours, and as part of architectural education. Changes were made to the architectural curriculum not only to cater for the ideological shift; dispensing with anything perceived as colonial content. Consequently, the mantra of Tropical Modernism was jettisoned, and for the most part, so was architectural science, although a key aspect was retained, but largely in stand alone courses: an emphasis on science and knowledge as the basis of education, related to a belief that “... knowledge in its pure form [was] considered apolitical and universally relevant ...” (Bouman, 2001, p. 9). In the multi-ethnic nations of the post-colonial era, this was critical, as knowledge could easily translate across cultural divides, and therefore was considered as an important unifying element in the culturally diverse countries. The radical changes implemented were broad sweeping, dispensing with whatever was regarded as the continuation of a colonial ethos. Within architectural education, a new nationalist curriculum was implemented at the University College Nairobi in a newly branded school the Faculty of Architecture, Design and Development. Coincidentally these moves came at the height of the cold war, with African nations aligning themselves either with the West, or the Soviet block. In East Africa, Kenya aligned itself with the West, while Tanzania aligned with the Soviet block, with the inevitable ideological tensions spilling out into the educational realm, ultimately resulting in the dissolving of the multi-country University of East Africa in 1970 (Kithinji, 2012). This had an immediate impact on architectural education in the region, with students from Uganda and Tanzania barred from programmes in the now independent University of Nairobi. Both Uganda and Tanzania struggled to make up lost ground, seeking setting up schools to cater for the lack of access the programme at Nairobi, although it was not until 1989 that Uganda set up its own programme at Makerere University, and 1996 for Tanzania at the University of Dar-es-Salaam.

A key challenge for architectural science in the context of architectural education in sub-Saharan Africa, among other things was a failure to come to terms with its colonial roots. Tropical Modernism, to which architectural science relates had been branded as being part of the colonial spatial project and thus has been discarding as part of post-colonial realignment of programmes, geared to portray more nationalistic agenda. While some fundamental scientific elements had been retained within the new curriculum, having been reframed in order to advance political and ideological goals left programmes as little more than the mere transmitter of knowledge. The ideological imperative effectively served to stifle the role of the university in research and the advancement of knowledge, the very basis for the founding of the science based institutions in the first place. Further, proliferation of post-colonial coups d’état contributed to the demise of scientific exploration, contributing to a suspicion of the educated elite, particularly university instructors, who were viewed as contributing to the unfulfilled post-independence promises. The coups d’état also created knowledge gaps, overtly evident in the delayed completion of EXTEL House in Kampala, originally designed by Richard Hughes in the early 1970s. When the building was eventually completed during the 1990s, it had lost its prominent horizontal solar shading elements, replaced by sheer glass curtain walling in part linked to contemporary trends, but also failure to acknowledge the function these horizontal elements were designed to serve. Although Kenya did not experience a successful coup d’état, the ultimate demise there was cemented by a series of academic strikes during the 1980s and 1990s, which saw the few educators who had received some
education and training in architectural science emigrate – seeking greener pastures overseas, thus relegating architectural science to the periphery of the architecture curriculum.

What then could be the future of architectural science in the context of the changing fortunes of the post-colonial? The ahistorical and Eurocentric values embedded in the tropical modernism, were key factors that contributed to the demise of this architectural canon, leaving the architectural space open for new explorations. The Africanisation and nationalism movements that ensued during the early post independence years stood out as an opportunity to explore indigenous architecture of the region through the various lenses available, including architectural science. Limited explorations were made based around form and materials, with little attention to building performance, be it social, cultural or environmental. Sadly, these explorations have not yielded significant results, and raising more questions than answers with regard to how architectural science could be appropriate to drive new explorations in tropical architecture in the region. A review of the established architecture programmes across East Africa today, there is still limited engagement with architectural science within architecture programmes, specifically in relation to: Environmentally Sustainable Design (ESD); Environmentally Conscious Design (ECD), and; Energy Efficiency (EE) (Olweny, 2013). This could in part be a legacy of the nationalist agenda, but also reflects views of education as being the application of a strict set of rules, and reinforcing the notion that architecture itself is responding to fixity (Olweny, 2016). This could also be a backlash to the imposition of foreign approaches to the detriment of tradition, with a return to tradition itself being a questionable approach, as it effectively requires an erasing of a significant portion of human endeavours, framing any new knowledge as being invalid. While there may be a desire to reengage with architectural science within architectural education, a key challenge is presented by the very nature of architectural education, described by Till (2005) as a prison yard, with “[...] an outer fence policed by the values of the profession and an inner fence policed by the authority of the school” (p. 167).
5. Conclusions

Regardless of the origins of Tropical Modernism, it is difficult to overlook the value and contribution this architectural canon had contributed to architecture and architectural education across Africa, and to the science of buildings across the globe. The contribution of tropical modernism to architectural science knowledge as a discipline was certainly unprecedented, contributing to what Hess (2000) termed a ‘constructed community’, in this case a construction of what came to constitute ‘appropriate’ architecture for the tropics. Shifts in post-colonial ideologies however ensured that tropical modernism, and architectural science as a key part of architecture and architectural education fell out of favour. This left a significant void within architecture and architectural education only just being recognised, and evident through the continued lack of ESD, ECD and EE within contemporary architecture curricula in East Africa. The future of architectural science regardless of the past is increasingly viewed with optimism, coming with a realisation that the potential demand for accommodation over the next fifty years may well exceed the existing building stock, thus having a dramatic impacting on resource consumption. Professionals are increasingly turning to the principles that had previously been abandoned, seeking answers that could enable architecture to address some of the contemporary challenges that are increasingly coming to the forefront of the development agenda. This is seen in a recently held workshop in Machakos, Kenya at which the Machakos Declaration for Sustainability in Architectural Education (UN-Habitat, 2016) was signed. This declaration seeks to engage schools and practitioners in thinking about ESD, ECD and EE, not because they are trending concerns, but because they present a means by which architecture can respond to the contextual challenges faced in the region, and which the Africanisation mission of the early post colonial period had sought to achieve. A key challenge remains, with the question of how the past principles be salvaged from their colonial past and interlinked with contemporary architectural discourse? Architectural science may yet emerge as a defining element in the future of architecture and architectural education in East Africa.

References


Simplified climate information for building designers

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Abstract: Local climate has always been a major factor in the layout of cities and building forms in the past. With the modern technological innovations and climate modifying techniques, building designers often overlook the usefulness of climate design strategies in their designs thus isolating them from the immediate environment. With the availability of affordable and efficient energy modelling tools, designers can assess energy efficiency of their designs prior to construction, but the interactions between various environmental factors at the early design stage are not often clear to them. Only thorough analysis of local climate data can shed light on the effective design strategies for a particular site. Most often, climate data is presented in tabular formats making them difficult to comprehend the inter-relationships between climatic elements and their implication in building design. As a result, climate consideration in conceptual design stage is usually ignored or inadequate. This paper addresses the underlying issues of climate data presentation and uses informative figures and tables to inform local climate in a meaningful way. The information will help building professionals to understand local climate easily and allow them to incorporate climate design strategies in their designs. This paper takes Brisbane as an example to explore a climate design approach. Brisbane climate data recommends minimizing the impact of high humidity in summer and maintaining a comfortable temperature in winter.

Keywords: climate, energy efficient buildings, thermal environment, design strategies

1 Introduction

Response to local climate has always been a major factor in any building tradition and the practice can be traced over the centuries. Socrates and Vitruvius were the pioneers who discussed the climatic influences in layout of towns and the individual buildings. Over time, however, as the technological innovations made it possible to achieve controlled indoor environment, the concept of climate responsiveness was lost in transition from the traditional to the modern built environment. As a result, a lack of consideration of small scale climate variations at the urban and regional scale in most urban planning and building projects led to adverse impact on the environment over the years.

An interaction between climatologists, urban planners and architects is vital to understand the close relationship between microclimate variations and design intervention at urban scale or at building scale (de Schiller and Evans, 1990/91). There has been a significant contribution from Olgyay (1963), Givoni (1976; 1998) and Szokolay (1982; 2008) in advancing climatic design. Nowadays, climate data is easily
available and tools such as bioclimatic strategies and building energy evaluation software packages are available to assist building professionals. However, local climatic issues are often ignored at conceptual design stage and subsequently at detailing stages. This necessitates a further investigation on what could be done to promote integration of climate in design practices.

De Schiller and Evans (1990/91; 1996) identified various factors that prevent the use of climate information at the urban and building scale. One of the major factors was identified as the presentation of the climate data. Most often, meteorological data is presented in raw numerical format which is complex and require further processing before they can be used by the designers. De Schiller and Evans (1990/91) suggested presenting climate information in a clear graphical format that can be easily understood by the building professionals and can easily be incorporated in the early stage of the design process.

The second issue that De Schiller and Evans (1990/91) identified was related to broad climate classification and generalised climate design recommendations for a large geographical region, ignoring local micro-climatic features. For example, the different climate regions of the world are commonly categorized in terms of their thermal and seasonal characteristics i.e. hot-dry, warm-humid, composite, moderate and cold. It is important to note that even within the same climate zone or within a distance of few kilometres, diverse climate characteristics can be found. In order to define local climate more precisely than simply according to the generic typologies, location specific detailed climate information is required such as, air temperature, humidity, solar exposure, sky conditions and wind patterns.

This study aims to bridge the research gap by adopting graphical techniques to present climate information, using informative figures and tables. This information is believed to be easy for the building professionals to comprehend and will help them to develop design strategies without requiring further assistance from the climatologists. This paper briefly discusses current status of the climate analysis tools, presents climate data and recommends few important early stage design strategies for Brisbane (Australia) climate as an example.

2 Overview of the currently available climate analysis tools

There have been a number of platforms available to analyse the climate data. One of the earliest was ‘Bioclimatic chart’ developed by Olgyay (1963) which combines temperature, humidity, solar radiation and wind speed to inform the status of climatic conditions and approaches to achieve thermal comfort by utilizing wind effect or solar radiation. Recently, digital platforms such as, Climate Consultant (UCLA Energy Design Tools Group, 2014) and Autodesk Ecotect (Autodesk, 2016) are extensively used by building designers and architectural students. Both the above mentioned climate analysis tools use graphical approach of presenting complex climate data. Climate Consultant and Autodesk Ecotect present temperature, humidity, sky condition, solar radiation and wind data graphically and recommend building design strategies. The inter-relationships between climatic elements however, are seldom explored; as a result, designers struggle to link two different elements while developing location specific design strategies. For example, the above mentioned climate analysis tools often plot temperature and humidity on psychrometric chart and recommend passive solar heating strategies when outdoor temperature drops below lower threshold of the thermal comfort band. However, the tools rarely cross-examine sky conditions and the available solar radiation in winter daytime which will have significant impact on the solar heating potential. Similarly, recommendations are made for ventilation even though outdoor humidity levels are high and ventilation may not be much beneficial for thermal comfort.
3 The study

This paper explores local environmental conditions using air temperature, humidity, sky condition, solar radiation and wind pattern to understand their impact on comfort and consequently in building design. This study sources climate data used by Nationwide House Energy Rating Scheme (NatHERS) (Commonwealth of Australia, 2016) for Brisbane airport (climate zone #10), which is embedded in AccuRate engine. The climate data used in this study is a Reference Meteorological Year (RMY) weather file prepared by compiling representative months’ weather data from 1967 to 2004. However, it is not uncommon to find a wide range of variation in the locality with this weather file in recent years.

This paper processes weather information and utilizes more informative graphical medium to inform the building designers of the climatic condition at an early stage of designing by analyzing the following items:

- relationship between temperature and humidity for comfort
- status of the cloud condition and availability of solar radiation on vertical walls
- wind speed and direction in different time and seasons

3.1 Defining local thermal environment

A comfortable thermal environment is defined using both temperature and humidity criteria (Olgyay, 1963; Koenigsberger et al., 1974; Givoni, 1976; Berglund, 1998; Givoni, 1998; Szokolay, 2008; ASHRAE, 2013). There has been a greater consensus regarding temperature comfort band which came out of a large scale study (de Dear and Brager, 1998; ASHRAE, 2013); however, humidity thresholds are still contested among professional institutions, thermal comfort researchers and health professionals (Arundel et al., 1986; Arens and Baughman, 1996; ASHRAE, 2013; Jing et al., 2013). ASHRAE thermal comfort band uses absolute humidity of 12g/Kg as a cut-off point for upper moisture level for thermal comfort (ASHRAE, 2013), but without a lower threshold. In general, high humidity reduces the potential of evaporative heat losses from our body surfaces (Jing et al., 2013) and low humidity causes dry nose, throat and skin, and eye irritation (Berglund, 1998). Health professionals have stressed on the impact of high and low levels of humidity for our well-being (Arundel et al., 1986). Past studies used relative humidity (RH) for regulating humidity criteria for thermal comfort, which ranged between 30% RH and 70% RH (Olgyay, 1963; Koenigsberger et al., 1974; Givoni, 1976; Berglund, 1998; Fountain et al., 1999). However, temperature comfort band is often used to define a comfortable thermal environment assuming humidity remains within the acceptable range (de Dear and Brager, 2002).

This study adopts nine environmental conditions based on the combination of temperature and humidity comfort thresholds proposed by Causone (2016) with slight modification on humidity threshold. This study uses a 7-day running mean of temperature (de Dear, 2006) to define comfort band which recognises daily changes in the outdoor environmental condition and its effect in the building occupants’ comfort set point (Figure 1). In this case, the outdoor average temperature ($T_{av}$) is replaced by a weighted running mean of outdoor dry-bulb temperatures ($T_{mot}$) spanning 7 days, as shown below:

$$T_{mot} = 0.33T_{(\text{today})} + 0.23T_{(\text{day-1})} + 0.16T_{(\text{day-2})} + 0.11T_{(\text{day-3})} + 0.08T_{(\text{day-4})} + 0.05T_{(\text{day-5})} + 0.04T_{(\text{day-6})}$$ (1)
The upper and lower 90% acceptable limits can be calculated by using adaptive thermal comfort equations 2 and 3 (ASHRAE, 2013):

Upper 90% Acceptable Limit = 0.31 $T_{mot} + 20.3$  
(2)

Lower 90% Acceptable Limit = 0.31 $T_{mot} + 15.3$  
(3)

Temperature below than the lower acceptability limit of adaptive thermal comfort band ($t_{c,l}$) is identified as the cold condition and temperature higher than the upper acceptability limit of adaptive thermal comfort band ($t_{c,u}$) is considered as the hot condition. Humidity comfort criteria are defined by both RH and absolute moisture content in the air. Humidity comfort zone is considered in between 30% and 70% RH and less than 12 g/Kg. Humidity greater than 70% RH or greater than 12 g/Kg is a humid condition, and less than 30% RH is considered as a dry condition. An intersection of both temperature and humidity comfort condition is defined as ‘Comfortable’ environment. Summer (S) and winter (W) comfort zones are separated according to the comfort bands defined in figure 1. Other combination of temperature and humidity criteria define the remaining eight environmental conditions – Cold & Humid, Cold, Cold & Dry, Humid, Dry, Hot & Humid, Hot, Hot & Dry. Figure 2 shows the boundaries for the nine environmental conditions in psychrometric chart for Brisbane.
4 Understanding Brisbane climate

4.1 Environmental conditions

Brisbane’s hourly temperature and humidity data for the whole year are plotted on two psychrometric charts for conventional summer (December, January and February) and winter (June, July and August) seasons separately. The psychrometric charts have outlined nine environmental conditions (Figure 3). Brisbane is predominantly humid in summer and humidity remains high for 74% of the time and causes discomfort. Winter season is cold and for 81% of the time temperature drops below the comfort range. The classification of thermal environmental conditions (Figure 3) indicate that high temperature is not an issue in Brisbane, as only 2% of the total time, the temperature exceeds the thermal comfort band. On an average, only around 14% of the summer and winter time is comfortable.

![Figure 3: Thermal environmental conditions for summer and winter seasons in Brisbane](image)

The figure 4 presents thermal environmental conditions during four seasons in Brisbane. Thermal environmental conditions are presented according to their occurrence in Brisbane on seasonal basis. Overall, ‘humid condition’ prevails for around 36% of the time in a year with the high humidity conditions experienced in summer. If all cold conditions (Cold & Humid, Cold and Cold & Dry) are grouped together, then cold condition becomes dominant and prevails for around 40% of the time in a year. The outdoor environment is comfortable for around 15% of the time. Spring is the most pleasant season with the highest comfortable period.

<table>
<thead>
<tr>
<th>Season</th>
<th>Comfortable</th>
<th>Cold &amp; Dry</th>
<th>Cold</th>
<th>Cold &amp; Humid</th>
<th>Humid</th>
<th>Hot &amp; Dry</th>
<th>Hot &amp; Humid</th>
<th>Hot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>5%</td>
<td>74%</td>
<td>12%</td>
<td>7%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>29%</td>
<td>6%</td>
<td>39%</td>
<td>24%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>27%</td>
<td>5%</td>
<td>27%</td>
<td>2%</td>
<td>16%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td>27%</td>
<td>11%</td>
<td>29%</td>
<td>29%</td>
<td>3%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Figure 4: Percentage of time spent in various thermal environmental conditions in Brisbane](image)
4.2 Sky condition and solar radiation

Brisbane sky remains clearer for around half of the period during winter daytime. However, cloudy conditions are more common in summer. Spring sky is relatively clearer than autumn (Figure 5).

A north facing vertical surface in Brisbane receives the highest level of solar radiation in winter (Figure 6) which is almost double the amount of solar radiation than that of summer. Winter solar exposure would reduce slightly within 30 degrees on the both sides of the north. East or west walls receive only half the amount of solar radiation compared to the northern wall in winter. In summer, there is a sharp drop in solar radiation on northern vertical surface. The reduction is primarily due to high solar altitude angle in summer as well as pre-dominantly cloudy sky conditions. East and west walls receive the highest amount of solar radiation in summer and spring seasons. South walls receive the least amount of solar exposure throughout the year. Interestingly, north-east and north-west orientations receive the same amount of solar radiation in each season.

4.3 Wind movement

The wind in Brisbane changes its direction throughout the day and remarkably in each season (Figure 7). In summer, morning wind blows from the south, afternoon wind is primarily from north-east and evening wind is from the north and north-east directions. The autumn wind in morning comes mainly from the south and it changes its course towards the east in the afternoon and evening. The winter wind pattern is also similar to the autumn in the morning; however, it blows pre-dominantly from the south at night. The afternoon and evening wind is dispersed and weak. The spring morning wind basically comes from the south and the afternoon wind blows from the north, evening and night wind comes from the north, east and south – east.
5 Brisbane climate overview

Climate data suggests a clear seasonal variation in Brisbane. It is humid (i.e. 74% of the time) in summer and cool (i.e. 81% of the time) in winter. Mostly, the extent of temperature variation in summer and winter seasons in relation to temperature comfort band can be understood using cooling degree-hours and heating degree-hours respectively. This is also used to calculate heating and cooling requirements (Szokolay, 2008). Brisbane has only 186 cooling degree-hours in summer; whereas, 10,036 heating degree-hours in winter season. However, a recent study conducted by CSIRO (Ambrose et al., 2013) found that summer cooling energy consumption (about 6.3kWh/day) in Brisbane dwellings is double than the winter heating energy consumption (about 3 kWh/day). This implies the necessity of addressing discomfort due to humidity in summer.

Autumn and spring months are transitional periods between the two main seasons. Table 1 summarises climatic parameters between summer and winter. The mean daily maximum air temperature ranges between 27.9°C and 20.0°C. The extreme maximum temperature in summer is 32.8°C. The lowest temperature recorded is 2.1°C in winter. The mean minimum temperature ranges from just 10.7°C in winter to 21.2°C in summer. Mean diurnal temperature varies considerably between two seasons, which is 6.7K in summer and 9.3K in winter.

Humidity is high in summer and the early autumn months, but then gradually it reduces from April and remains in the comfortable range until September. In summer, 79% of the time absolute humidity remains greater than 12g/Kg. In winter, around 50% of the time humidity exceeds 70% RH with temperature less than 19°C.
Table 1: Comparison of climatic parameters in summer and winter

<table>
<thead>
<tr>
<th>Climatic parameters</th>
<th>Air temperature</th>
<th>Humidity</th>
<th>Sky Condition</th>
<th>Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Extreme maximum °C</td>
<td>Mean daily maximum °C</td>
<td>Mean daily minimum °C</td>
<td>Extreme minimum °C</td>
</tr>
<tr>
<td>Summer</td>
<td>32.8</td>
<td>27.9</td>
<td>21.2</td>
<td>15.2</td>
</tr>
<tr>
<td>Winter</td>
<td>24.9</td>
<td>20.0</td>
<td>10.7</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Winter daytime sky is mostly clear in Brisbane; whereas, clear sky conditions prevail for around only a quarter of the time in summer. Seasonal variations can be observed for wind conditions. Summer wind primarily blows from the north/north-east during afternoon through to night, but morning wind comes from the south. In winter, strong wind comes from the south-west in the morning. Afternoon and evening wind in winter is dispersed and weak and blows from the south at night.

6 Design strategies

Design strategies are based on climatic parameters and their inter-relationships. The current adaptive thermal comfort model (de Dear and Brager, 2002; ASHRAE, 2013) does not adequately address the issue of high humidity; therefore, winter heating demand in Brisbane seems dominating. However, households use more energy for cooling (using air-conditioners) (Ambrose et al., 2013) to mitigate uncomfortable conditions due to humidity than in heating buildings. To some extent, the building envelope can easily moderate night-time and early morning low temperature, as a result, actual heating energy consumption remains lower than the cooling load in Brisbane (Ambrose et al., 2013).

Table 2: Design strategies based on climate data

<table>
<thead>
<tr>
<th>Outdoor Thermal conditions</th>
<th>Occurrence period</th>
<th>Design requirement</th>
<th>Design strategies/ Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold, Cold &amp; Humid (40%)</td>
<td>Autumn, winter and spring</td>
<td>Heating required</td>
<td>Passive solar heating strategies- maximise solar heat gain from northern facades; use thermal mass; well-insulated walls, floor and ceiling; reduce air-infiltration</td>
</tr>
<tr>
<td>Humid (36%)</td>
<td>Summer, autumn and spring</td>
<td>Dehumidification required</td>
<td>Use moisture absorbing materials; reduce external/internal heat gain and moisture generating activities; minimise direct ventilation; reduce air-infiltration; install energy recovery ventilation (ERV) system (if necessary)</td>
</tr>
<tr>
<td>Comfortable (15%)</td>
<td>Spring and autumn</td>
<td>-</td>
<td>Maximise the use of outdoor air for ventilation and remove heat generated inside the building; reduce internal/external heat gain and moisture generating activities</td>
</tr>
</tbody>
</table>
Table 2 makes broad design recommendations for Brisbane based on outdoor thermal conditions. For more than one third of the year, it is generally cold in Brisbane and may require heating to maintain thermal comfort. Since winter daytime is usually clear, thermal comfort can be achieved by adopting passive solar heating strategies. NatHERS thermal performance simulation (using AccuRate software) was carried out for a typical passive solar house comprised of concrete floor, reverse brick veneer walls with R1.5 insulation, concrete block internal walls, concrete slab with R3.5 ceiling insulation and 15% of the wall area for the north facing window. This thermally massive design achieved 8.5 stars and a total energy load was 20.9 MJ/m² per year. Due to the lack of hourly simulated humidity data in AccuRate software, it was not possible to further analyze humidity impact on thermal comfort. However, a recent CSIRO study revealed that homes with high star rating in Brisbane consumed more energy than that of low star rating homes and higher energy for cooling in summer than heating in winter (Ambrose et al., 2013). This is contradictory to the AccuRate simulation results.

From the climate analysis, it is evident that around another one third of the year, Brisbane is humid and outdoor air is not generally useful for ventilating indoors due to higher moisture content (Givoni, 1976; Causone, 2016). Bringing in humid air indoors will have detrimental impact on the indoor environment with elevated humidity. To deal with indoor humidity, moisture producing activities within the house such as, showering and cooking should be segregated from the living areas as much as possible. Further, breathable building materials would help in moderating high humidity conditions. If there is a need to incorporate some kind of active system to maintain a control indoor environment, a low energy active system such as, energy recovery ventilation (ERV) system can be useful rather than using an energy intensive air-conditioning system. Rasouli et al (2014) demonstrated a significant reduction in cooling energy consumption by using ERV system in humid conditions.

Outdoor thermal condition is comfortable for around 15% of the time in Brisbane. Building design can exploit indoor-outdoor connections and utilize outdoor air directly to ventilate building and remove heat generated inside the building.

7 Conclusion

Buildings should exploit the local climate through design and appropriate construction techniques for energy efficiency. The biggest challenge to the building professionals designing energy efficient buildings is to disentangle interactions between climatic parameters and incorporate them to location specific design solutions. This paper presented complex climate data using informative figures and tables to allow designers to incorporate them at an early design stage. The study assessed local environmental conditions using both temperature and humidity to highlight the implications of the individual parameters in overall thermal comfort. As a result, nine environmental conditions are defined in the psychrometric chart– Cold & Humid, Cold, Cold & Dry, Humid, Comfortable, Dry, Hot & Humid, Hot, Hot & Dry. Other climate parameters such as sky condition, solar radiation and wind data further help in formulating design strategies.

In broader climatic context, Brisbane climate is defined as ‘Subtropical’ and considered favourable for natural ventilation in summer and requiring not much heating in winter (Kennedy, 2010; Reardon and Downton, 2013). However, in contrast to those understandings, this study has highlighted the need to address two different seasonal requirements for Brisbane which are – minimizing the impact of high humidity in summer months and maintaining a comfortable temperature in winter. Thus, this method also eliminates the generalised recommendations based on broad climate zones.
The methodology of climate data analysis and presentation techniques used in this study can easily be extended to other locations. Additional climate parameters such as rainfall, snowfall and other location specific climate parameters will further enhance the quality of design implications.

References


Building performance simulation in the built environment education: Experience from teaching two disciplines

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Abstract: Building performance simulations are increasingly being employed in built environment education to assist in the decision making process including design, operation and management. Selecting the ideal tool for building performance evaluation is challenging for environmental design. Because of the complex nature of sophisticated building simulation software, there are no guidelines on how to teach this most effectively and integrate with the curriculum. For effective learning, there should be a perfect balance between ease of use, interaction, steep learning curve, time constraint, compatibility with other drawing software, and flexibility in terms of on-campus and off-campus access. This paper reviews the building performance simulation tools used in built environment education and discusses the experience of teaching students from two different disciplines in the built environment. The study used student feedback and reflection from teaching staff to review the student experience, course development and delivery. The findings of this study will help in the development of curricula and resources for engaging students and improving their learning experience.

Keywords: building performance simulation, built environment education, quick feedback, flexibility

1. Introduction

Building performance simulations are increasingly being employed in built environment education to assist in the decision making process including design, operation and management. Selecting the ideal tool for building performance evaluation is challenging for environmental design. Because of the complex nature of sophisticated building simulation software, there are no guidelines on how to teach these most effectively and integrate with the curriculum. For effective learning, there should be a good balance between ease of use, interaction, steep learning curve, time constraint, compatibility with other drawing software, and flexibility in terms of on-campus and off-campus access.

Previous studies show that to enhance the use of building performance simulation tools among building professionals, the first step is to incorporate the tools in tertiary education curriculum. This paper reviews the building performance simulation tools used in built environment education and discusses the experience of teaching students from two different disciplines in the built environment, in
a constantly changing learning environment. The main objectives of the study are to identify the factors that contribute to the selection of building performance simulation (BPS) tools for teaching students in two disciplines in the built environment in two different universities. The study used student feedback and reflection from teaching staff to review the student experience, course development and delivery. The findings of this study will help in the development of curricula and resources for engaging students and improving their learning experience. This will provide future professionals with access to wide range of knowledge and resources quickly and enhance the use of simulation tools in the architectural practice.

2. Literature review

2.1 Current status of BPS tools

Simulation allows architects and engineers to test ideas and designs before proceeding to construction. There was lot of effort globally in the past few decades to integrate building performance simulation in the building industry. In 2010, the number of tools listed on the U.S. Department of Energy (DOE) Building Energy Software Tools Directory (BESTD) website reached more than 389 (Attia et al., 2012). Many studies were conducted to develop user friendly tools to encourage their use in architectural practice. However other studies show that it still a long way for this goal to be achieved. In a recent survey conducted among practicing architects in four countries, Soebarto et al. (2015) concluded that improving architect’s knowledge about environmental issues and building performance, whether it is through tertiary education or continuous training in practice, is considered to be the first important step to take. To increase the ability of current and future architects and engineers to use simulation in their work, it is important to develop a balanced and well designed curriculum in universities. Many studies (Strand et al., 2004; Soebarto, 2005; Schmid, 2008) have discussed the experience of teaching simulation in the undergraduate architecture and engineering courses. Hensen and Radosevic (2004) highlighted several issues related to quality assurance in building performance simulation that need to be considered in teaching building simulation. In an attempt to replicate the dominant consultant/architect interaction as found in high-quality architecture practices, Charles and Thomas (2009) note that having undergraduate students work with simulation software can help them understand the iterative design process as well as be aware of various physical phenomena involved in building design. To deliver high-quality buildings, professionals involved in design and construction must work in a collaborative manner. To be truly effective at collaboration, the various consultants must have relevant understanding about the vocabulary and the physical processes that take place inside and outside the building.

2.2 Criteria for selecting BPS tools

There are wide ranges of BPS tools available in the market for the architecture, engineering and other built environment related disciplines. Their selection process is challenging for the industry. Most building simulation tools are not adapted to inform design decision-making in early design phases, but tend to focus on evaluation after decision-making whereas architects benefit mostly during this decisive phase while addressing the building geometry and envelope (Attia et al., 2012). There is no clear methodology or outline to assess BPS tool specifications and criteria for developers, practitioners and educators. A number of studies and surveys have been carried out in the past that were concerned with the criteria and requirements of BPS tools. Hong et al. (2000) suggested four selection criteria including
Building performance simulation in the built environment education: Experience from teaching two disciplines

usability, computing capability, data exchange capability and database support to select BPS tools. Weytjens et al. (2012) analyzed the architects’ preferences for a simple energy design tool through a focus groups study in which one of the three focus groups involved were architecture students. The majority of the participants agreed that default values in function of ambition level are interesting to adapt data-input to early design, but they must be customizable and transparent. They thought that the interface and input method must be intuitive and modelling rules must be avoided. Regarding output, most preferred feedback aspects that are related to regional energy code requirements. Crawley et al. (2008) compared the features and capabilities of twenty major building energy simulation programs based on information provided by the program developers based on 14 categories. In a recent study, Attia et al. (2011) suggested a set of comprehensive selection criteria for BPS tools based on five major topics: usability and Information management of interface (UIM), Integration of Intelligent design Knowledge-Base (IIKB), accuracy of tools and ability to simulate detailed and complex building components (AASDC), Interoperability of building modelling (IBM), Integration with building design process. The results of the survey conducted in this study indicated a wide gap between architects and engineers’ priorities and tools ranking. It was found that architects prioritized the ability to create comparative reports for multiple alternatives above the input quality control and chose the ability to exchange models with 3D drawing packages such as SketchUp and 3DS Max.

In the current higher education environment in Australia, where students are struggling to balance study and work, universities are facing an increasing demand for courses with flexible delivery modes. Student expectation has changed drastically with the constantly changing technology. Academic staff endeavors to adapt online delivery modes while at the same time attempting to sustain their campus-based and face-to-face teaching approaches. This has particularly affected the selection of simulation tools and to achieve an optimum balance between various criteria has become very challenging.

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<th>Year</th>
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<td>FirstRate5, IESVE</td>
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3. Method

This study investigated the application of building performance simulation tools in two different master programs in two universities where the authors were involved in the design and delivery of the courses. First, the Master of Architecture (MA) program at Deakin University and second the Master of Energy Efficient and Sustainable Buildings (MEESB) program at RMIT University. The study used student feedback from surveys and continuous reflection by the teaching staff. 45 students from Deakin University and seven students from RMIT University responded to the survey. The MA programme involves design oriented architecture students whereas the MEESB programme includes students from various backgrounds including architecture, engineering, building science, building construction and management. The course within the MA program was delivered for six years in semester one from 2010
to 2015. The new MEESB program only commenced in 2015, hence the course under investigation was delivered only once thus far. Table 1 shows the various BPS tools used in the two programs each academic year.

4. Results and Discussions

4.1 Architecture Programme

There is a growing need for future architectural practitioners to be equipped for addressing complex problems through environmentally sustainable design by using fewer resources. However, in most schools of Architecture, there is a separation (polarization) between the “core” design studios and the “supplementary” lecture classes in technology (Oakley and Smith, 2007). Building performance simulation is a good tool for architecture students to investigate alternative design solutions during the concept development phase of a new project. Taking time away from their design endeavor to learn the software tended to impact their design process negatively. This is not a desirable outcome in a studio environment in which the emphasis is above all on authoring a good design (Charles and Thomas, 2009).

In a design centred curriculum, students’ abilities to apply understanding from their technical coursework in their design work is limited and many researchers have proposed the need for a new curricular model to overcome the limitations of this division. So the main challenges that were faced by the teaching team were “How BPS tools can be taught effectively to architecture students? How do the design oriented users interact with simulation tools? Is there a tool available that can tick most of the boxes?”

The course under investigation is a core unit within the environmental stream called “Building systems and environments” which students undertake in the fourth year of their MA studies. The simulation part was only one third of the whole course extending to a period of four weeks out of the total 11 weeks in the semester. The learning outcomes include “evaluating and appraising the appropriate selection of environmental systems to enhance thermal comfort” and “improve energy efficiency and apply computational methods and software to make informed judgments in relation to their role as built environment professionals”. When the course was delivered for the first time, students were asked to choose any existing building which may not have been constructed in the era of sustainable or energy conscious design or any of their previous year’s design studio project as the case study. However, students seemed to be disengaged with the project once their design studio kicked off. Therefore, for the subsequent years, the studio project ‘Architectural Design in Urban Contexts’ was used as the case study project.

Over the years, a number of software including Ecotect, Energy 10, Comfen and Sefaira were introduced to the students. Each software had advantages and disadvantages associated with them; the limited time period associated with the academic calendar was one of the main challenges. With its highly visual approach to building analysis and simulation, Ecotect (Marsh, 2006) seemed to be very popular among the students. However, students tend to spend too much time in building spectacularly detailed geometric models which can result in numerous potential errors or warning messages that will be very difficult to track down. Some academics feel that there is really no need to waste time having students generate their own models. Instead, a model can be given to them so that the students can concentrate on the interpretation of the results. For the students to better appreciate the benefits and limitation of the modeling tools and to better understand and interpret the results, it is important that
they get involved in the modeling and understand the relationship between the model size and running time as well as the assumptions and simplification of the model.

ENERGY-10 program automates many of the time-consuming tasks in geometry building and shortens the time required from hours or days to minutes. Building descriptions are created automatically based on defaults (Balcomb, 1997). The program facilitates quick evaluations and automates the process of both applying and ranking a variety of energy efficiency strategies. The graphical output greatly aids the process of assimilating and understanding the results. One problem reported is that some users have a difficult time going beyond the automatic model building stage as it is quite easy to get started with a shoe-box design. However, during the preliminary design stages, the user must compute wall, roof, and window areas and enter these numbers into the appropriate dialog boxes and this is seen as a barrier by the students. The access to these two tools has always been an issue as the students had to come to the university and use a machine in the computer lab which is often heavily booked for teaching purpose. As flexible delivery became part of universities strategic goals, more and more off campus students enrolled in the courses as a result of which access and licensing became problematic. As the teaching staff has to make sure there is equal opportunity for all the students enrolled in the course, a computer lab based licensing did not work as off-campus students were not required to attend the classes. As a result of the student feedback, COMFEN Program that calculates the heating and cooling energy use, and visual and thermal comfort, of commercial building facades, from the Lawrence Berkeley National Laboratory was implemented in the subsequent year. COMFEN is very simple software freely available for download, however its use was quite limited as we can model only one space with single external wall. The students had to choose one space/zone in their design that has only one wall facing outside. It took quite a while for the students to simplify their design to be modelled in the software. The flexibility and access issue was resolved. Even though, the simplicity of the geometry allowed for substantial time for the students to analyse and interpret the results, the overall perception was that “The software is not capable of modelling my whole design and one zone is not enough, I want to have windows on all the four sides.” Don et al. (2009) state that traditional simplified design tools are typically too limited to be of much use, even in conceptual design and proposed proposes an approach to the creation of design tools that address the real information needs of designers in the early stages of design of non residential buildings.

As a result of the feedback, Sefaira (2016), a cloud based software, specifically built for conceptual design was trialled in the subsequent year. Recently Sefaira released new plugins for most widely used building information management platforms such as SketchUp and Revit. After completing the course, the students were asked to complete a survey about their experience in using the software. Among the 46 students responded to the survey, 42% have used some form of BPS tools before. Majority (83%) of the students agreed that Sefaira helped them to achieve the course learning outcomes. 86% of the students felt that Sefaira helped them in better decision making with regards to their design studio project, with 20% strongly agree and 66% agree. The comments from the students mainly reflect that the software is an easy tool to understand and use and very good for early design stages. Particularly, Sefaira for SketchUp plug in helps to get immediate feedback on design decisions. The quick feedback with the real time analyser (RTA) and the ability to benchmark against the 2030 challenge was a major advantage. The 2030 challenge is global architectural challenge, issued by architecture 2030, that aims to get to carbon neutral buildings by the year 2030. Furthermore, it minimizes the number of inputs required to get meaningful results which greatly increases the ability of the architect to use the software.
Six performance metrics including energy use intensity, annual carbon emissions, spatial daylight autonomy, annual sunlight exposure, annual operating cost, peak cooling/heating load were displayed as the output. Figure 1 shows a view of the output from the RTA.

![Output from the real time analyser](image)

The main problems encountered by the students were the geometry limitation as Sefaira could only simulate a model in Sketchup which has less than 1500 planes. For detailed analysis and to control the baseline parameters further, the SketchUp model has to be uploaded in the Sefaira Web App. The SketchUp model file then must be uploaded on Sefaira’s online site in order for Web App simulation to be conducted. The building parameters for space use, zones, HVAC systems, occupancy patterns and loads were then assigned, and simulations were run. While Sefaira’s RTA plugins allows for rapid geometric design iterations and a highly visual energy analysis including daylighting visualization, with the Web App, users can gain a higher level of control over baseline parameters and the ability to utilize response curves to create strategies and bundles to further optimize the RTA geometric iterations. The Sefaira Web App also allows users to quickly compare multiple mass options against each other. Like any other applications, the running time increased with the number of planes in the geometry. In a previous study comparing actual and simulated energy between two softwares (Vasari/GB and Sefaira) energy data from Vasari/GB was significantly higher than the actual data, while modeled energy data from Sefaira is close to the actual but did not follow the same monthly energy consumption pattern as the actual data (summer loads were lower than the winter loads) (Abdullah and Cross, 2004).

The students were not satisfied with the thermal comfort analysis in Sefaira. The thermal comfort analysis seemed less advanced; the output was in the form of number of occupied hours for temperatures between 18°C to 28°C (see Figure 2) instead of the conventional PMV/PPD plots displayed by other tools such as Ecotect. Students expect to have thermal comfort outputs displayed for various seasons rather than aggregated annually. As noted by Weytjens et al (2012), line-graphs and histograms are not preferred mode of output among architects for design feedback. Students also found the Web App confusing as it seemed it required them to upload the model after every small change they make on the model. Some suspected this is because of certain bugs in the software. This year Sefaira swapped Fulcrum engine with industry standard EnergyPlus in its new "SYSTEMS" product and hopefully the bugs
will be eliminated. Similar to other softwares, the students found there was not enough time to learn the software and required more tutorial classes.

The tool “Sefaira” seem to be addressing most of the current challenges faced by the students as well as academic staff involved in teaching large classes. The purpose of Sefaira was to get quick results with minimum number of inputs and compare the general impact of different strategies rather than to get the scale of details achieved by compliance models. An advantage of Sefaira was that it is a plug-in of Sketchup and Sketchup is already used widely by architects in the early phase of the design process.

4.2. MEESB Programme

The MEESB program is a new specialised master program developed by the School of Property, Construction and Project Management at RMIT University. The program is developed with close industry input as a result of the need identified in training graduates with expertise and capability in analysing and evaluating energy efficiency in the building sector. The course that was investigated is ‘Building modelling and simulation’ a second year core subject for the master program. The course is designed and delivered as a ‘blended mode’ course in which one-third of the content is delivered face-to-face through workshops and the rest is delivered online. The course aims to develop specialised skills and knowledge required to carry out complex simulation and modelling tasks, developing professional capabilities in multiple modelling platforms including thermal, energy, air flow and lighting simulation. The course teaches students the importance of validating the quality performance of a building simulation tool through the BESTEST (Building Energy Simulation Test) method and the introduction of both residential and commercial building simulation tools commonly used in Australia.

A regulatory building simulation tool for residential, FirstRate 5, was introduced to students to understand the important parameters that govern the performance of residential buildings in Australia. FirstRate 5 is a residential thermal performance assessment software used to rate the energy efficiency compliance of residential buildings to the minimum 6-star standard under the National Construction Code of Australia (NCC). The NCC standard applies to all new homes and major renovations and extensions carried out in Australia. The software tool generates ratings based on the NatHERS
(Nationwide House Energy Rating Scheme) star rating system on a 0-10 star scale for homes. In addition, a commercial whole building simulation tool, IESVE (Integrated Environmental Solutions Virtual Environment), was used to develop students’ understanding and expertise in building modelling and delivery of sustainable buildings. IESVE is a building energy analysis and performance modelling software which could be used to test various design options and help to identify sustainable building solutions through in-depth analysis on energy use, CO$_2$ emissions, occupant comfort, light levels and airflow impacted by different building constructions. Figures 3 and 4 show the view of a model and the occupancy schedule in IESVE. Students purchased their own standalone license for a reasonable price and installed the software in their PC which gave them enough flexibility to work off campus.

Figure 3: IESVE Building Model with surrounding buildings

Figure 4: IESVE weekly occupant profile
The feedback from the first cohort of students in the course was mainly positive. Students found that the learning curve for FirstRate5 is manageable but required much effort in mastering the IESVE software, which is expected as IESVE is a much more complex software in terms of its capabilities and inputs requirement. Online tutorials were provided to the students to learn the software on their own time before the actual assessments commenced. Students found the online tutorials and materials provided are of great help in their understanding and learning of the software. For IESVE, students will need to incorporate appropriate building design requirement such as heating and cooling settings, usage profiles, lighting usage, internal heat gains, etc. These requirements are closely linked to regulations and standards which students will need to understand the codes and practices governing certain types of building design besides learning how to model using the software. Most of the students have experienced using some kind of simulation tool such as EnergyPlus before taking this course. They found that the IESVE software provides good user interface, ease to use and certain degree of accuracy in building modelling. Students are happy with the capabilities of IESVE in terms of the versatility of results generations and agreed that the software helped to achieve the learning outcomes of the course. The software also helped students better understand the expectations of the related profession such as ESD industry. Even though the tool can be used to understand the parameters in relation to building performance, for in depth understanding of some of the complex relationships between parameters, one should spend substantial amount of time exploring the tool. Students think that the weather files provided in the software could be more comprehensive in covering more regions in order to provide more accurate simulation results. The capability of the software in accepting and exchanging different CAD drawings and models will also need to be improved.

5. Conclusions

The application of building modelling using computer simulation tools plays an integral role in the design and evaluation of energy efficient and sustainable buildings. Architects, engineering and construction management professionals use building simulation to understand and assess building performance. The results of building modelling and simulation are required at multiple stages of the design process and need to be evaluated, critiqued and communicated to multiple stakeholders, including clients, architects, engineers and regulatory bodies in order to deliver a sustainable building outcome.

Selecting an ideal tool for building performance evaluation is challenging for environmental design. The two cohorts of students investigated in this study had considerably different expectations regarding the use of simulation tools and this is quite similar to how the building industry actually operates. For architecture students, creating the geometry closely resembling their design was very important. They prioritized the ability to exchange models with 3D drawing packages and preferred fast performance feedback that is fully integrated into their design environments. The flexible delivery, which is often overlooked in architecture, was highly desirable for students who have competing time demands and are struggling to balance study and work. Recently developed cloud based tools such as Sefaira were well suited for flexible off campus delivery, however the accuracy and reliability of the simulation engine need improvement. For the specialist master program, established tools such as IESVE provided a good platform for whole building performance analysis. The delivery of this building modelling and simulation course could be further enhanced and improved by introducing more hands on sessions to help students to get a deeper understanding of the use and capabilities of the software. Industry experts could be invited to present the practical experiences and implementations of the software in real life situation to the students. These improvements to the course will certainly help to expand the horizon of application
of building simulation tools in the industry and better equip students to gain professional employment in the future.

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Four value propositions for architecture education

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Abstract: This paper proposes four managerial and business techniques that architects and their practices can benefit from. The 2008 global economic downturn and follow up financial crises has triggered the author to engage with small scale design firms to becoming more productive in the production of architecture. The overarching value proposition is that professional practice needs to stay relevant in today’s economy and for better ways to educate architects. To this end, four managerial competencies and business capabilities familiar to the author have been brought into the design studio space including: (1) Value Management, (2) Stakeholder Management, (3) Building Information Modelling and (4) Reflective Practice. These are key elements among the emerging set of competencies put forward in this paper.

Keywords: architecture practice; strategic thinking; domain competencies; professional development

1. Management for Architects

The image of architecture is well engrained as the art and science of creating spaces and environments for humans to inhabit. An architect is defined as the chief and builder from its Greek roots (arkhi-, chief; tekton, builder), as the person who plans, designs and oversees the construction of buildings. However, in a contemporary sense architects are losing professional ground and competencies. The need to increase practical, technical and academic advances in the training of architecture is important, especially in a fast changing world. The overarching value proposition in this papers calls for the need to uptake, and in other cases to reengage with, professional competencies that can benefit architects and their clients. There are also emerging technological competencies such as Building Information Modelling (BIM) to embrace emerging work paradigms in the 4.0 revolution such as those discussed by Susskind & Susskind (2015); and Kuprishka (2014), in order to harness competencies and capabilities in a rapidly changing economy (Rifkin 2011; 2014 and Schwab 2016). This paper looks at internal practice competencies and capabilities such as those discussed in Heintz and Aranda-Mena (2012 and 2016) rather than looking towards business development and marketing plans.
2. Project Management for Architects

Tracy (2013) defines PM as the discipline of initiating, designing, planning, executing, controlling, and closing the work of a team to achieve specific goals and objectives within a project vision. Effective decision-making is also a core component in PM practices. Nevertheless, there is an aspect to management which is less linear and more organic, especially when dealing with people, their values, preferences and idiosyncrasies and that is why management is beyond a mechanistic or predictable set of rules or events. Today’s knowledge about project management directly applies to the practice of architecture and this paper addresses the challenge to bridge PM into mainstream architectural discipline. While, in the non-English speaking European context, architects might naturally apply PM principles and techniques, and accept that much of it is learnt “on the job”, in the English-speaking world, such as in the UK, the USA and Australia, PM is more often seen as outside the architectural domain, in education, practice and research. Thus arises the value proposition on bringing PM across to architecture in the latter context.

PM research embraces techniques from the social sciences. In other words, many of the PM investigations are about people and processes, and the results linked back to projects. Keywords often seen in PM research include decision-making, risk, work packages, with PM research findings being about team performance, knowledge management, reflective practitioner reports (Schön, 1983), knowledge transfer, creative cognition, which are all areas as much aligned with the human condition, as with to how to harness projects and to successfully deliver them.

A good point of departure would be to tailor and integrate PM into design thinking, for instance looking at Lawson’s seminal work on the psychology of architects and designers (Lawson 2005) and design in mind (Lawson 1994). Architecture practice takes place, not only with the internal practice managerial aspects but also externally in client and stakeholder management. How architects could engage with these aspects will be discussed with the aim of encouraging the adoption of better management methods, tools and techniques. However, what might work for defence, telecommunications or manufacturing projects might not be the best fit for architecture projects in which artistic sensitivities also play a role, although care must be taken to avoid using the artistic stance as a defensive ploy to avoid change. For every example of a difference between the practice of architecture and another discipline, there are probably many more examples to be found of inherent similarity. Architecture has the opportunity to expand its domain by moving away from a self-image of exclusivity.

2.1. Value Management

Edwards (2013) refers to value management (VM) as the set of principles that help to maximise project outcomes not simply in terms of costs but in the overall project value. VM as part of a management technique can be useful to architects. VM can help all stakeholders to (1) establish a shared-clear vision of project requirements and outcomes, and (2) identify clear objectives so as to (3) guide teams to achieve common goals and maximise project values (Edwards, 2013). Examples of VM (and thus value creation) are about maximising project outcomes, thus generating more value for each stakeholder. VM is just one of several management techniques used in Project Management. The decision to undertake a project has far reaching consequences including time, effort and money. The objective is to produce valuable assets or services (Edwards, 2013). In the case of large scale or government projects this aim is known as achieving Value for Money (VfM) (McCully 2014)
Project clients expect their project teams, including consultants and contractors, to deliver VfM. Contrary to common understanding, VfM in not solely about cutting costs but identifying and achieving project value through ensuring mutual understanding of:
- The value being sought
- How the value is to be achieved, in other words the objectives to be fulfilled.

In some cases, better VfM can be achieved by actually spending more; although this is admittedly a rarer occurrence. McCann et.al (2016) argue that better value can be achieved by clarifying objectives; and then exploring alternative ideas or solutions and testing the ideas against pre-determined criteria before finally implementing the best value option. Smith et.al (2001) defines three priorities to satisfy client needs and thus, manage expectations:
  - understanding the project priorities and business objectives;
  - providing advice which assists client to gain competitive advantage;
  - being client oriented rather than project focussed.

Since the 1990’s the Royal Institution of Chartered Surveyors (UK) has highlighted the importance of the strategic stages in the development of project solutions; advising institutional clients to engage with advisers who are willing to challenge the status quo including understanding of the project priorities and objectives; providing advice which assists clients to gain competitive advantage; and being client oriented rather than project focused (Cook and Chatterjee, 2015). Although a radical departure for architecture and design professionals, there has been a level of acceptance in this area including a shift from project/design values to social/client values. Clients will eventually validate the question of VfM and its criteria; however they can also be short-sighted and look for short-term high-gain solutions that are not necessarily in the best long-term public interest (Smith 2001).

A common threat risk factor in projects is the lack of clear vision, clear objectives and adequate project definition. Institutional clients may launch a competition or call for Expressions of Interest (EOI) to which some architects might respond without questioning the quality of the briefing documents or the clarity of client objectives for the project. For both public and private projects, briefing documents have been found too often be too open – lacking specificity; misleading or vague and in cases incomplete. Whether or not this is true for any project, it clearly shows that better understanding about clients and their needs is paramount. Developing better understanding through briefing documents and architectural programs using better technologies such as Building Information Models is an area architects could embrace. For instance, in architectural public sector development and interventions, Volker (2010) investigated ‘deciding on design quality’ for public commissions in the European context. Her work investigates the way architects are selected in public design competitions and the decision making processes of adjudication panel members - often a ‘black-box’ aspect to clients, the profession and the general public. In her results issues of transparency, objectivity or equality clearly emerge; identifying the following problems at various project stages:

(Pre)selection phase:
- unclear selection criteria
- high/too many requirements
- too many candidates
- careless request for participation

Tender phase:
- No/little financial compensation for design work
- No/little interaction between client and designer
- Delay during procedure

Award phase:
- Unclear/not well considered award criteria
- Indistinct user and citizen participation
- Mixture of politics and procedures
- Negotiations after announcement of winner

(Volker, 2014)

On the other hand Silberberger (2012) found that architectural competitions often overlook the value proposed by many of their entries as competition juries are often biased and decisions are made subjectively. In his work Silberberger investigated techniques to assist the jury panel to profoundly scrutinise and challenge the assumptions on which the competition brief is based, thus allowing a fit-for-purpose solution space in the competition. The resulting revision would allow a revision of the brief in itself through the jury’s interaction with the entries. It is argued that in this way the client, stakeholders and the panel itself will better achieve expectations, value for money and honourable responses back to the submissions (Volker, 2014 and Silberberger 2012).

In the private sector development, more tangible benefits are demanded as clients usually want to achieve VfM outcomes (McCann, 2016). However, best value and VfM concepts and definitions are often misunderstood as value is not the same as cost. A low cost that delivers a low value project outcome often ends up as a loss for its sponsor (although possibly being highly profitable for some stakeholders). Lowest cost commensurate with highest value is the solution space that clients want to be in. However, this may not be good for the private sector as it pushes contractors to build quickly, often at less quality and with lower safety standards. A mid-range cost and high-value is a scenario objective which can help to bring a project to a more successful outcome. Architects traditionally focus more on the quality of the end-outcome, than the other factors such as risk, process, project duration, although increasingly on life-cycle sustainability. In less conventional projects, such as heritage or sustainable projects, other criteria may also be important in achieving VfM including: abstract/intangible values e.g. heritage, appearance including aesthetics, status, and marketability. In the case of operational values, aspects of life-cycle and key performance indicators (KPIs) are taken into account including: environmental performance, return on investment, productivity/functionality.

**VM into action:** Edwards (2013) provides a framework for a VM workshop/process, which typically is developed over two to three full-day workshops. In practice the VM workshop might usefully extend longer as there are cases when it is important not to rush decisions. More often than not, however, such workshops are limited to one day or less. The VM workshop structure might incorporate four initial phases including:

- Information phase: What is it? What does it do? What does it cost? And what is it worth?
- Speculation phase: What else would do the job?
- Evaluation phase: How well does that work?
- Development phase: How much will that cost?

These are followed by presentation of findings, decision-making and implementation. During the initial information phase, the client and the team try to clarify objectives. What is the client trying to achieve with this project? These are the “To...+ verb + object ...” statements.

In class workshops, students are encouraged to address the questions systematically:

1. What is it? E.g. is it a gallery + cultural precinct
2. What does it do? E.g. identify and establish primary function using a verb + noun approach, e.g. transmit (verb) and light (noun) as the required function for a window.

3. What does it cost? E.g. a monetary value to represent the cost of the component in the finished project.

4. What is it worth? E.g. here is where value for money sits (wherever possible expressed as a cost per unit of delivered function or as a unit of delivered function per $1 of cost).

During the early design process speculative alternative ideas are proposed, but these are not discussed or formally assessed until the VM Evaluation Phase is commenced. The VM evaluation phase will explore each alternative idea through three initial assessment filters including Level 1 Filters: Objectives (does this alternative satisfy the objectives?), Level 2 Filters: Functional Performance (does this alternative deliver better, or the same, performance as any other?), Level 3 Filters: Unique implementation constraints (what prevent the adoption of this alternative on this project?). Cost assessment of alternatives is undertaken in the following Development Phase of a VM workshop, where economic considerations are brought to bear, and the functional worth of alternatives is established so that comparisons can be made between them and with the original design solution.

Procedure: As part of the VM process one purpose is to maximize the creation of alternative solutions in order to identify those, which provide better VfM for the client. In this way the Value Management process aims at establishing primary objectives, secondary objectives and desirables. Speculation is then invited to provide alternative ways of achieving those objectives. Judgement of these options is left to a later stage, however the initial stages are ‘inductive’ from particular points to generic points in a way that team members are pushed to think outside the box, either individually or in teams. Contrary to the common belief and even practice, brainstorming (as the best technique for speculation) can also take place individually as the result of introspection and reflective thinking. Creative thinking also take place in moments of tension or constraints for instance, some of the students mentioned that economic recession encourages (and in some cases forces) industry to be more creative and more productive, preparing ground for innovation – “necessity is the mother of invention” (Belski et.al 2016).

2.2. Stakeholder Management

The concept of the stakeholder was initially conceived by ‘the Stanford Research Institute’ in 1963. A seminal publication by Edward R Freeman in 1984 defines the concept of stakeholders as those individuals or groups who can affect or may be affected by a project. In successive years there has been some contention as to how to define stakeholders, debate has ensued regarding some definitions (IPMA 2011). Mitchell, Bradley & Wood (1997) progressed the stakeholder concept further by identifying three main characteristics that stakeholders must hold; (1) power to influence; (2) legitimacy of relationships; and (3) urgency of the claim, which then reads as a group or person with a vested interest in the success of a project and the environment in which it operates. Stakeholder management is about the arranging and dealing with the combination of people and processes to deliver a particular project. People or project teams would typically include members of a consortia, client or client representatives and external or third parties such as members of a particular community or ‘end-users’ to a project or facility. Bourne (2016) investigated stakeholders and risk. Her major contribution is the technique she calls “The Stakeholder Circle”. Although the technique is effective, the guiding principles are not always clear, teaching studios encourages students to re-design the Stakeholder Circle in meaningful ways (to
them) and the mapping of their projects. In this way the original work and Circle diagraming techniques developed by Bourne & Walker (2005) have been adapted for the purpose of education. 

The stakeholder circle diagraming technique (Bourne and Walker, 2005) develops a visual mapping tool to demonstrate how stakeholders impact at a project through various project stages thus defining the level and probability of stakeholder impact during project delivery. Additionally they point out that the larger the project, the more complex the planning and analytical techniques required.

Although the importance of stakeholders and their contribution to project success seems to be well covered in the literature, along with a number of ways to identify and categorise stakeholders, Missioner and Loufrani-Fedida (2014) claim that there are a number of limitations to the subject matter, namely: a lack of methods and tools to identify stakeholders and their interests; and a lack of appreciation for the dynamic nature of both stakeholders and the project throughout its lifecycle. 

Notions of project success evolved in the 1980’s and 90’s to include aspects of the project team and the relationship between the strategic management and the operations of the project, however still missing was the inclusion of the implications of the external stakeholders (Missioner and Loufrani-Fedida 2014). Current perspectives are developing a stakeholder-focused assessment of project success. Turner & Muller (2003) developed four key success conditions for projects:

1. Success criteria need to be confirmed with the key stakeholders prior to the start of the project and repeatedly throughout the project.
2. A collaborative working relationship is needed between project owner and project manager.
3. The project manager should have enough authority and flexibility to deal with unforeseen circumstances as they see appropriate.
4. The owner should take an interest in the performance of the project.

Turner and Muller (2013) suggests that current theories regarding stakeholder perceptions of success are insufficient and do not provide the industry with usable tools and methodologies. Mok et.al (2015) suggest that a stakeholder’s perception of success may have little to do with the project’s performance regarding budgets, schedules and quality levels. Assessing the success or failure of a project is typically done just after completion, however it is important to realise that there are many stakeholders who will assess the project time after completion if that is the case project success would have a completely new set of *project values* e.g. other than time-cost-quality, particularly if intended as KPIs. Architects can certainly drive the agenda for project success by increasing competencies in coordination projects including stakeholder management with institutional clients.

### 2.3. Building Information Modelling

Building Information Modelling (BIM) has made great advances in the architecture profession, especially for architectural programming, spatial needs analysis, overall project documentation and coordination. BIM certainly is plying a key role in the way the architecture profession is transforming, it only takes a glance at job advertisements in the profession to see that BIM is a must for new recruits.

BIM is rapidly evolving and software applications are quickly emerging as cloud services rather than stand alone applications. On the other hand, traditional document management, local storage and revers will disappear. Interfaces for document and project management solutions have taken ‘a large chunk’ of the commercial market, at least in the architecture, engineering and construction (AEC) industry sector. In the public sector Volker (2014) discusses the need to improve value matrices to increase transparency and accountability for public commissions. One way to do this is by bringing more
project metrics and building information (parametric) modelling is one way to do this, in the shape of better and more accurate design documentation and early project analyses such as cost, energy and space planning. BIM can save architects time at early project stages allowing time for exploring creative and value propositions and testing them concurrently with other team members or project stakeholders. To achieve high design standards and architectural outcomes, the profession needs to protect the time that it takes to develop and test ideas at the early schematic project stages. BIM can facilitate this and then become the practical vehicle for project information delivery to stakeholders.

The use of BIM across projects is still to see its wider adoption not just by the architecture profession but also by engineering consultants and construction contractors. One of the barriers to more widespread adoption is the need to develop managerial and technical competencies. The perceived tendency by designers, architects and creative professions is to protest that BIM hinders creativity and inventiveness, and that BIM “locks” architects to come up with preconceived forms and ideas. This is not the case. In fact, a larger number of architects have continued to improve their creative output by embracing BIM at a much earlier stage in the design process and allowing changes and variations to take place without taking a toll on project delivery criteria (Aranda-Mena 2016).

2.4. Reflective Practice

An adaptation of standard steps for reflective practice into architecture would include (1) explanation of basis of assessment, (2) general summary of significance, (3) significance of individual or discretionary components from landscape (or cityscape) to architectural elements and building parts and, (4) the more recent drive to catalogue and protect the non-tangible heritage where the empty spaces and the activities that happen in them are what is to be protected (O’Keefe and Prott 2011).

RP is a generic term, which explains a method by which professionals engage to explore their projects, jobs and life-experiences in order to lead to a new understanding and appreciation. Reflection involves a number of skills (such as observation, self-awareness, critical thinking, self-evaluation and taking others’ perspectives) and has the intended outcome of integrating this understanding into future planning and goal setting (Mann et al., 2009). Different models of reflection described in the literature are usually iterative (a particular experience triggers reflection and results in a new understanding or decision to act differently in the future); or vertical (describing depth of reflection), or some combination of both.

What is the evidence base for reflective practice? How do students engage in the process of reflection? In addressing the final question, four methods of facilitating reflection will be outlined: journal reflection, reflection on a critical incident, reflection following professional development, and reflection on a clinical encounter. As early as the 1930s, the educator Dewey stated ‘there can be no true growth by mere experience alone, but only by reflecting on experience’. However, it was only much later in the 1980s that reflective practice (RP) started to be widely discussed following Schön’s seminal work (Schön, 1983). There is now a growing body of literature supporting the importance of reflective practice (RP) across professional fields including architecture. This paper highlights the importance of introducing deep reflection as part of teaching pedagogies in architecture education. Allowing adequate reflection time as a job routine in such a way that becomes a habit of professional practice and for life-long learning.
3. Game Changer for Architects

Four “game-changers” can be detected. On their own, none of the following is innovative, or provides new thinking. A different story emerges when combining all of them and integrating them with traditional architecture design studios. By doing this, architects are forced to think more carefully about project governance; project processes; project appraisal; and project delivery. Conclusions point towards a potential “game changer” with respect to the competencies of emerging architects, including the ability to identify value add potential for no added cost in projects via Value Management (VM), to engage and manage complex client organisations via Stakeholder Management (SM); to improve project documentation and life-cycle design via Building Information Modelling (BIM) to effectively use and appreciate digital modelling tools and technologies in order to survive in an increasingly competitive market and finally, to engage in Reflective Practices.

1. On value management (VM) there are a number of opportunities for the architecture profession to embrace the use of Value Management techniques. The author will continue working on adapting Value Management techniques for use by architects, urban planners and designers. The economic and rational thinking of the VM process does not need to overshadow the creative, innovative and idea generation processes with which architects are familiar but to support it. On the other hand the tools and techniques from across disciplines should complement each other.

2. On stakeholder management (SM) including project communications. The clear and direct applicability of SM and similar techniques to better coordinate and manage projects was presented and discussed, firstly within the project team, then to better understand the clients and requirements, and finally to better co-ordinate and communicate issues with a wider audience. Stakeholder and client Management will continue to be an area in which architects need to excel. Stakeholders will be the extension of the client-body, in other words, client organizations will continue to become more complex and architects will need to develop better and stronger communication capabilities and people skills to deliver projects. Moreover, architects will need to lead on this front if they want to see their designs being built.

3. The area of Building Information Modelling (BIM) is not just a technological innovation, but is revolutionising the way architects practice and collaborate with team members. BIM is finding its way into core professional competencies in the UK, the USA, Singapore and Australia (AIA, McGraw-Hill report). The benefits of using BIM include a better and more accurate approach to designing for life-cycle; increasing the level of understanding and accuracy of how a project might perform (or not) from a number of dimensions such as thermal, lighting, acoustic, ventilation and safety performance, functional aspects such as accessibility, durability; and assessing and improving more subtle, non-performance aspects such as occupier preferences. The use of BIM is a very exciting technological advancement for architects and its full potential has no reached its peak. Rapid improvements on display such as augmented virtual reality (AVR) technologies smart phones and tablets could for example, easily show what is to happen to an building, locations or old structure for instance. Coupled with 3D laser scanning via a drone and 3D printing for an actual set of models as the resulting outcome. Finally, BIM platforms are rapidly moving to the Cloud, meaning that architects, engineers, contractors and clients will be collaborating on line in an “integrated” fashion and concurrently. This is a particularly exciting area for architecture as BIM brings the architect back to the driving seat, in
other words, it is increasingly clear that the entity which controls the information, controls the project. However, the race is on, and disciplines such as Knowledge or Information Managers are emerging and taking-on these roles.

4. Reflective practice might be a way to effectively adopt and integrate the above three value propositions. Reflective practice strategies present relevant ways to integrating this as to understanding the future of the profession (Mann et al., 2009). Different models of reflection described in the literature are usually iterative (a particular experience triggers reflection and results in a new understanding or decision to act differently in the future); or vertical (describing depth of reflection), or some combination of both. What is the evidence base for reflective practice? How do practitioner and students engage in the process of reflection? Using a metaphor: ‘reflective practice would be like looking into the rear mirrors while driving in order to safely move forward’.

This paper has presented three management techniques to bring architectural practice into alignment with current, expected standards, and has suggested that reflective practice might be the means of practical integration for them. This could benefit the progression of the architectural profession, not only in the practice sense but also in terms of architectural education. Each of the methods and tools discussed in this paper is not new in its own right. What is innovative is the integrated approach in merging them all together and adding them into traditional architectural curricula. Traditional design practices are certainly valued but should also be challenged. This paper has highlighted that management techniques and technology platforms should be more widely embraced in architecture education.

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References


A simple method to significantly lower daylight simulation time

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Abstract: A significant barrier to routine use in early design of Climate-Based Daylight Modelling (CBDM) is the relatively long time that it takes to run full annual simulations – potentially many hours for more complex models. Quick checks of design ideas are inconvenient, and this discourages examining large numbers of design options or carrying out routine sensitivity analysis. One way of reducing required simulation time is to not simulate all the daytime hours of the year. The downside is that this would seem to undermine the entire point of CBDM. This paper demonstrates that taking smaller samples of random days throughout the year can significantly reduce simulation time with acceptable levels of error in standard daylighting metrics. Simulating only 10 days/month introduces at most ~6% error in performance estimates – a level of error well within accepted tolerances. This can be further improved by using a selection process to filter “representative” samples of hours, enabling simulations using 5 days/month to provide estimates with only ~5% error.

Keywords: Climate-Based-Daylight-Modelling, daylighting, simulation, methodology

1. Introduction

The case for Climate Based Daylight Modelling (CBDM) has been made forcefully by many (e.g. Mardaljevic, 2013; Heschong, 2011; IESNA, 2016). It is reaching mainstream practice as evinced by the 2013 decision by the Education Funding Agency in the UK to make CBDM compulsory for the evaluation of designs in their “Priority Schools Building Programme” (EFA, 2014) and the similar moves in 2014 by the US Green Building Council for their LEED v4 building rating scheme (Reinhart, 2015). The case made for CBDM is that it examines the performance of a building during all the hours of daylight, and all the types of daylighting condition in a year, not some simplistic cloudy sky condition, plus perhaps some ‘representative times and days’. The limitation for people wishing to complete a CBDM is that the approximately 4000 hours of daylight calculations take a long time to complete. There is a very real risk that this sophisticated and insightful approach is reduced to a compliance check at the end of the design process, not an integral part of the design conception because it takes too long to calculate the performance of a range of design options and thus to discover the best design. This paper explores how this calculation load can be reduced.
Experience of teaching undergrad daylight classes over the past 20 years has demonstrated that there is no better way than CBDM of demonstrating the link between window design, task and room illumination and solar radiation. CBDM offers a nuanced study of all the hours of the year incorporating both diffuse light from the sky and the direct light from the sun that students readily incorporate into analyses of multiple design options. With artificial sky and even simplistic hand calculations evaluation of more than one design option was not the norm in undergrad classes. A further, unsung benefit of the computer-based CBDM is that these technologies allow the designer to break free of the tyranny of the ubiquitous ‘working plane’ grid and focus on quality of luminous environment in far more holistic manner.

The content of this paper has arisen from a teaching programme within a School of Architecture for 200+ undergraduate Architecture, Building Science and Interior Architecture students each year for the past 5 years. The lessons learned from this process are offered here as suggesting a means by which Climate Based Daylight Modelling (CBDM) may become mainstream, instead of a minority activity. The approach is based upon the use of the 3DS Max Daylight Tool, an approachable interface to a validated (Osborne, 2013) simulation tool which makes the basics of daylight calculation more accessible to undergrad students and practitioners than the more widely used multi-phase Radiance approach (McNeil, 2013) for which the requisite Unix scripting knowledge creates a huge barrier for the student. The approachable interface allows the student practitioner to focus on the significant daylight issues, not the mechanics of running the simulation program. The performance methodology explored in this paper makes CBDM calculation of multiple design scenarios feasible during a class design exercise. It has broader application beyond the classroom.

2. Methodology

This paper examines a simple question: if CBDM conducts an analysis based on a reduced number of hours is there a significant loss of information? There are 4000 or so hours of reasonable daylight in a year. If we simulate only, for example, only 5 days/month, ensuring many more design options could be explored, is there a major cost in reliability of design decisions?

2.1 Modelling

![Figure 1: Basic model appearance and dimensions](image)

Daylight simulation was carried out using Autodesk® 3ds Max® 2016, which has been validated against CIE test cases, measured data, and Radiance (Osborne, 2013; Reinhart & Breton, 2009). The models
were based on a simple test cell, which was then varied on all the combinations of 5 different parameters in order to create 48 different designs covering a range of different designs. These variations were designed to represent large changes (Table 1).

The models were placed on a ground plane with a reflectance of 20%. The window frame and mullions had a reflectance of 15%, and the glazing was Pilkington clear 6mm, with a reflection colour of RGB(0.078, 0.082, 0.084) and refraction colour of RGB(0.863, 0.898, 0.884) (Berkeley Lab WINDOW v7.4, 2015).

Table 1: Summary of model variants

<table>
<thead>
<tr>
<th>Model parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reflectance</td>
<td>Wall, floor, and ceiling reflectances varied: Light: Ceiling/walls: 80%; floor: 40% Dark: Ceiling/walls: 20%; floor: 10%</td>
</tr>
<tr>
<td>Depth</td>
<td>Depth of room varied: Shallow: 2.5m deep, 1x window head height Deep: 10m deep, 4x window head height</td>
</tr>
<tr>
<td>Shading</td>
<td>Simple shading added over window: No shading: no overhang Shading: 1m overhang added</td>
</tr>
<tr>
<td># of facades</td>
<td>Varied number of facades with windows: Single: windows on one side of room Double: parallel windows on both sides</td>
</tr>
<tr>
<td>Orientation</td>
<td>Varied orientation of models, facing them North, South, East, and West. Note that for the double-facade models the north/south and east/west models are redundant with each other, which is why there are 48 models instead of 64.</td>
</tr>
</tbody>
</table>

Following IESNA recommended guidelines (IESNA, 2016), the measurement points were placed at ~600mm intervals, with the edges of the grid 300mm from the walls. This produced 32 measurement points for the ‘shallow’ models, and 128 points for the ‘deep’ ones. The height of the measurement plane was set at 900mm. The number of diffuse bounces was set to 6, as is recommended for spaces with average surface reflectances of this level (Osborne, 2013). The weather data for Wellington, New Zealand, was sourced from NREL’s EnergyPlus weather file database, and run using the Perez (Perez et al, 1993) sky model. The model was run for the hours of 8:00 to 18:00 – a total of 3,650 hours over the year (IESNA, 2016). Additionally, to calculate Annual Sunlight Exposure, the model had to be run a second time with the sky turned off, and the diffuse bounces set to 0, in order to isolate the direct sunlight component.

2.2 Analysis

Daylighting performance was examined using Daylight Autonomy (DA), Annual Sunlight Exposure (ASE), and Useful Daylight Index (UDI). These were chosen as examples of popular and recommended
daylighting metrics used by climate-based daylight modellers. Daylight Autonomy (DA) is the percentage of time that a point gets over 300 lux of illuminance during the year (IESNA, 2016). Annual Sunlight Exposure (ASE) is the number of hours that a point receives over 1000 lux of direct sunlight (IESNA, 2016). Useful Daylight Index (as used here) is the percentage of the time that a point gets more than 100 lux and less than 3000 lux (based off suggested limits in (Mardaljevic, 2013).

The sampling and analysis process was done using R (R Core Team, 2016). First, we generated 100 random samples of unique numbers from 1 to 28. Then, we extracted the days that matched those numbers from the results, and used them to estimate the DA/UDI/ASE. For example, if a sample was [5, 19, 3, 24, 23], we would extract the 5th, 19th, 3rd, 24th, and 23rd day of each month. By taking days from each month, we are trying to ensure that we capture the variation of the sun over the course of the day and year, and so get more accurate results than if we just took 500 random hours from the year. This was done for sample sizes varying from 2 to 20 days/month.

3. Results

3.1 Error by sample size

Perhaps the most basic way we can look at the error is by looking at the potential error observed in individual measurement points (Figure 2). We see that error can be substantial at low samples, potentially as high as 17 percentage points for 2 days/month samples. At the other end of the scale, at 20 days/month, the error is at most ~3.5%. In controlled daylighting validation studies it has been argued that differences in DA/UDI of less than 4% show very close alignment, and that error between 4-11% is small compared to the differences between designs that are actually significantly different from each other (Reinhart & Breton, 2009). On these grounds high samples of 15-20 days/month show good accuracy, with the highest measurement error of a point being 3-4%. 10 days/month would be reasonable at ~5.5% max error, and even 5 days/month could be defended with ~10% max error (though that may best be kept to early concept design). The mean error across a model is, of course, less than that of the worst measurement point and at worst is roughly half of the maximum measurement error.

![Figure 2: Measurement error in estimates of daylighting statistics for different sample sizes. Lines show the maximum, 99th, 95th, 75th, and 50th percentiles of error for all individual measurement points.](image-url)
We may also observe that ASE shows slightly less error than DA and UDI – the median error in particular is much lower, being practically 0 at all sample sizes. This is because of lower levels of ASE, and the many points that get no direct sunlight, and hence will always have an ASE of 0 no matter what the sample. This point will be returned to later.

There are, however, other ways of looking at daylighting error. The question we want to be asking is how likely is it that the error would change our interpretation of a model’s performance? In daylighting analysis, a common approach is to aim for a specific target threshold across as much of the room as possible. For example, we might be aiming for 80% UDI across 80% of the room. The Spatial Daylight Autonomy criteria recommended by IESNA is 50% DA across 80% of the room, and ASE is 250 hours across no more than 10% of the room (IESNA, 2016). In this vein, we may measure error as the error in the estimated proportion of the room area above the threshold (Figure 3).

Error here is, in percentage point terms, significantly larger than the basic error of the measurement points. Even at samples of 20 days/month we see error as large as ~10% for DA and ASE, and as much as 20% for UDI. Also, UDI appears to have significantly more error than the others. While for ASE it’s just a continuation of what appears to be a general tendency towards less error, what about DA? The answer is that the difference between the two graphs is simply a function of their respective thresholds.

![Graphs showing error in estimated room area above threshold for DA, UDI, and ASE.](image)

**Figure 3:** Error in estimated room area above threshold. Thresholds are 50% DA, 80% UDI, and 250h ASE. Each point is the maximum error induced in a model by each sample.

The lower threshold of 50% DA is easily met by most of the models – indeed, over half of them get that over 100% of their area and see no error because they are so far over that threshold that even error of 20% would not lower their points below it. In contrast, the points over the 80% UDI threshold require much less error to fall below it. If most of the points above the 80% threshold are at ~81-84%, then even a small amount of error will drop them below that threshold and dramatically change the proportion of the room above the threshold.

So, does this mean that differences of ~20% or more in the estimated room area above threshold are misleading, and are not actually a problem? It depends. If we look at sample sizes of, say, 15 days/month, then the maximum measurement error is ~4%. Looking at the models with the “worst” error we can see that large swings in threshold area are merely due to many of the above threshold points being close to the threshold, and do not actually reflect large changes in performance (Figure 4).
10 days/month, with a maximum error of ~6%, still does not make the results look significantly different (Figure 5). 5 days/month on the other hand does start to look significantly different (Figure 6), and with a maximum error of ~10% may suggest significantly different interpretations – though it may still be fine for identifying and dealing with major problems during concept design.

<table>
<thead>
<tr>
<th>Area</th>
<th>True value</th>
<th>Worst error</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;80%</td>
<td>75%</td>
<td>55%</td>
</tr>
<tr>
<td>&gt;50%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Figure 4: Examples of “worst” error in UDI results for 15 days/month samples. Annotated numbers denote the proportion of the room > 80% UDI (top) and > 50% UDI (bottom).

<table>
<thead>
<tr>
<th>Area</th>
<th>True value</th>
<th>Worst error</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;80%</td>
<td>58%</td>
<td>34%</td>
</tr>
<tr>
<td>&gt;50%</td>
<td>84%</td>
<td>85%</td>
</tr>
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Figure 5: Examples of “worst” error in UDI results for 10 days/month samples. Annotated numbers denote the proportion of the room > 80% UDI (top) and > 50% UDI (bottom).

<table>
<thead>
<tr>
<th>Area</th>
<th>True value</th>
<th>Worst error</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;80%</td>
<td>58%</td>
<td>34%</td>
</tr>
<tr>
<td>&gt;50%</td>
<td>84%</td>
<td>88%</td>
</tr>
</tbody>
</table>

Figure 6: Examples of “worst” error in UDI results for 5 days/month samples. Annotated numbers denote the proportion of the room > 80% UDI (top) and > 50% UDI (bottom).
To sum up: sample sizes of 15 and 10 days/month look like they could reasonably be used for daylighting design without significantly distorting the results. This would allow simulation time to be cut by 50% and 67% respectively.

There are, however, two further points that offer scope for improvement:

- Some models are substantially less error prone than others. Understanding why may allow better interpretation of the likely accuracy of results. Also, if we could predict this, we could run lower samples on models where it won’t matter.
- Some samples are better than others. If we could predict which samples will be more representative, we could reduce error, and enable use of smaller samples.

3.2 Model characteristics and error

The main driver of error appears to be level. For ASE, the higher the ASE, the greater the error (Figure 7). This works out very well for it, as it means that you have the highest levels of error for the points that don’t really need to be that precisely estimated. Target levels of ASE are very low (250h = ~6.8%). Hence, having high error on points that get, say, 50% ASE doesn’t really change our response to them. 30%, 50%, and 70% ASE are all basically the same result – far too much direct sun penetration. This means that we can use low sample runs to quickly identify major problems that need to be fixed, and then move on to higher samples to confirm and refine details when the design is performing well. Also, of course, points that never get direct sun have no error associated with them.

Unfortunately, this works less well for DA and UDI. As shown in Figure 7, error is lowest when DA/UDI is very high (~90%) or very low (<20%), and it is highest in the mid-ranges. It is those mid-ranges in which we will often be working and perhaps be most interested in carrying out daylighting simulation (the IESNA guidelines for instance target 50% DA). In contrast, when performance is terrible, high error is not necessarily a problem. It doesn’t really matter if your DA is 0% or 20% - either way it’s terrible. Similarly, while it is not a bad thing for points with very high performance to be accurately assessed, it is also of more limited value than it would be at the mid-ranges. If a design is getting ~90% DA or UDI, then it is clearly performing very well – and would still be performing well even if that estimate was 10 percentage points too high. That being said, it does depend on what you are aiming for. This could be valuable for someone targeting a very high level of daylighting performance.

Figure 7: Measurement error as a function of metric magnitude for samples of 5 days/month (all sample sizes show the same pattern, though with different levels of error)
For ASE, we can see that for 5 days/month samples if a point has at least 12% ASE it is almost certainly over the 250h target. Thus, until we have removed the major sunlight problems, and refined it to the point that we care about managing areas below that level, 5 day samples are perfectly adequate for checking designs’ ASE (similarly, if areas are below ~3% ASE, they’re almost certainly fine).

3.3 Predicting sample accuracy

Perhaps unsurprisingly, some samples produce less error than others. Importantly, some samples produce consistently less error across the different models. If we could predict these “good” samples ahead of time, we could reduce the potential error and use smaller samples.

One way of doing this is to look at how representative a sample is of the underlying climate data. How closely does it match the distribution of illuminance levels provided over the year? Logically, a sample that has a distribution of illuminance levels similar to the “true” distribution would be expected to provide more accurate results.

To describe the distribution of light levels we extracted the global illuminance data for the relevant hours from the weather file. We then binned the light levels and counted up the proportion of total light levels in each bin (Figure 8). We repeat this for each sample. We can now calculate how well each sample represents the year by calculating the difference in the size of each bin between the sample and the whole year. We take the sum of the absolute differences (|difference|) as a measure of how representative a sample is of the year. If the summed difference was 0, then a sample would perfectly match the distribution of light levels over the year. This is, of course, not possible for small samples.
Plotting this against the maximum error produced by each sample, we see that more representative samples tend to produce less error ($p<.001$) – though it is not a perfect predictor (Figure 9).

To test the application of this process we generated a larger set of 10,000 random samples and then selected the 30 ‘best’ samples to check how well they would work when applied to the models. For these samples we randomly sampled different hours from different days in each month. So, rather than simply randomly sampling 5 of the same days from each month, we took the 9:00 hour from 5 random days, and then the 10:00 hour from 5 random days and so forth. This was to create a greater variety of samples, and to see if there was the potential for particular combinations of hours from different days to provide better samples than if they were constrained to being on the same days.

As shown below, using this process to select the samples cuts the potential error by almost half. Selected 10 days/month samples have less potential error than 15 and 20 days/month random samples. Selected 5 days/month samples perform better than random 10 day samples, with a maximum error of ~5% DA/UDI, opening up the possibility of using them for quick performance sketches.

![Graph showing comparison of potential error from randomly selected and predicted “good” samples](image)

**5. Conclusions**

The strategy of random selection of hours from a file with hourly climate data can produce predictions of daylight performance that are within error bounds considered acceptable in the validation of daylighting simulation tools. This conclusion remains valid across the wide range of design scenarios tested. It is reasonable to presume that this is evidence that the conclusion is valid even beyond the tested range of building form and room reflectivity scenarios.

As a consequence, it is feasible to speed the calculation of daylight performance by a factor between 6 and 3 times just through randomly selecting a small number of hours per month from which to complete a daylight calculation. For the scenarios assessed, samples of 10 days/month produced at most 6% error in CBDM performance indices, or 10% for samples of 5 days/month. Furthermore, the analysis has revealed that it is feasible to create a simple weather data selection process that avoids the larger simulation errors – roughly halving the potential error. Using this guided sampling process, we can get reliable predictions of annual DA, UDI, and ASE even with samples as small as 5 days/month.

The implication of this analysis is clear: for quick analyses of a large number of design alternatives, the selection of small number of hours each month enables accurate design decisions. This suggests that the following would be a reliable design analysis process in the classroom (or consultancy): 1) running a full-hours design analysis for a single design alongside its reduced-hours counterpart can establish a
baseline error range; 2) design analyses based thereafter on a series of reduced-hours simulations can provide a reliable design decision process; 3) a confirmatory full-hours analysis of the final design to confirm the results of the reduced-hour analyses.

The next stage of this research is to look for further speed reductions while retaining this level of accuracy vis-à-vis the full hour simulation. Measurement grid size is an obvious target. In the geometrical construction of a curved line, such as a DA/UDI contour, just 5 points are all that are needed to establish the shape of a curve. Grid spacings that use between 5-10 points to define a grid (25 to 100 total points) seem likely to be sufficient for most situations rather than dense grids of 250mm (EFA, 2014) or 600mm (IESNA, 2016) spacings.

After this grid size examination, the process needs to be calibrated on a far wider set of climates and of model complexity. And finally, it is planned to automate the process of random hour selection to enable all to use it, not just those who can run statistical analysis packages.

Acknowledgements

We would like to thank Stewart Milne for his invaluable support and assistance in running the simulations on the School’s rendering machines.

References


Daylight illuminance calculation model and process for Building Integrated Photovoltaics (BIPV) Systems

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Abstract: In this paper, we propose a Daylight Calculation Model and Process (DICMP) for Building-Integrated Photovoltaics (BIPV) systems. In the field of solar energy application, BIPV system is being incorporated increasingly into the construction of new buildings in recent years. The trade-off when using BIPV technology is that it has the risk of diminishing the daylight availability that is useful for natural lighting, which is yet another valuable resource for minimizing a building’s energy use and adding to its sustainability. Our research presents a calculation and process study for assessing the daylighting illuminance (DI) contributes to interior space when BIPV systems are used. Though, there are already common tools and software programs for calculating daylight illumination inside buildings, they either lack of accuracy or are very complicated to compute. And they are either not adaptive for manual calculation or BIPV system. This paper focuses in discussion of development and application of DICMP for BIPV system. This calculation model and process is important because the BIPV systems are semi-transparent, which allows them to admit natural light while also absorbing much of the solar energy to generate electricity through the PV panels. Our DICMP combines the addresses various sky conditions and takes into account light reflections of ground and opposite buildings. For verification, we have done computational simulations theoretically. According to our initial comparative studies, though there are some flaws in the clear sky condition, the simulation result has proved the effectiveness of DICMP. Especially for the overcast situation, the calculation results can match the simulation closely. For further study, a variety of equipment can be installed for measurement on an experimental prototype house. The calculation will be improved by adjusting its parameters. In sum, the paper summarizes our findings offering a valuable method taking practical factors from many aspects for designers of how to calculate DI for BIPV systems accurately and quickly.

Keywords: Daylight Illuminance; calculation model; BIPV System
1. Introduction

As energy crisis and sustainability issues have caught attention globally, solar energy is one of the best solutions introduced into different fields. Photovoltaic materials are used to replace conventional building materials in many parts. With the ability of generating electricity from sunlight, Building Integrated Photovoltaics (BIPV) system is a technology applied photovoltaics-materials architectural components in parts of the roof, facades of buildings. BIPV are being incorporated into the construction of new buildings increasingly. BIPV systems contribute enormously to a building’s ability to generate electricity which can lead to Net Zero Energy Buildings (NZEBs). However, using BIPV has the risk of diminishing the daylight availability that is useful for natural lighting, which is yet another valuable resource for minimizing a building’s energy use and adding to its sustainability. The BIPV materials are semi-transparent. They can generate electricity for the building, but they also reduce the indoor daylight level because of their opaque solar cells within the panels. Hence this may lead to increase the energy consumption of artificial lighting. Because of this, a methodology that combines the evaluation of indoor daylight level and then artificial lighting energy consumption also needs to be included.

![Figure 1: Some of the images have shown the details of the experimental house of BIPV system on the roof of the building. There are two rooms and two windows in the house. Some of the images have shown the details of the photovoltaic panel. There are two different kinds of photovoltaic panels which are installed on the two windows. So a comparative study is possible.](image)

This study is part of the BIPV system project. Our work aims to develop a method for estimating the average indoor daylight illuminance for the BIPV system, which is intended for manual calculations (also available for implementation in a computer spreadsheet). It is detailed enough to take all sky conditions (overcast sky, partly cloudy sky & clear sky) and the light reflected from the ground and opposite buildings into account.

2. The Overview of Daylight Calculation

Daylight calculation methods have been studied for decades. The common methods of Daylight Illumination (DI) calculation include ‘Lumen Method’, ‘Daylight Factors Method’ and other sophisticated software tools such as ‘Radiance’ which can handle complex conditions for detailed calculation. There are mainly two common approaches including ‘the Daylight Factor Method’ (the DF method) and ‘the Lumen Method’. By using a daylight factor DF, the DF Method can calculate the illuminance of any point...
in an interior space theoretically based on a known luminance distribution sky. The main problem with these approaches are low precision (IESNA, 2000) and the inability to calculate the direct sunlight situation. Similar to the DF Method, the Lumen Method is simple enough to allow manual calculations. However, it assumes an over-simplified room geometry (Saraji and Mistrick, 1993). Being the same as the DF method, it excludes the direct sunlight situation.

A number of sophisticated software tools such as ‘Radiance’ can handle complex room geometries and sky conditions for detailed daylight calculation. Though they are able to model complex room geometries and visualize the interior illuminance distribution, their computing time is too long (Vartiaenen, 2000). Therefore, relatively simple and sufficiently accurate approach is needed for our research in BIPV system.

3. The Calculation Process of the Daylight Illuminance

3.1. The Calculation Process of the Three Components

After modifying and improving usability and accuracy of previous methods, we applied a Daylight Illumination Calculation Model and Process (DICMP) for our BIPV systems research. Several constants, such as the extraterrestrial solar illuminance (measured at the earth’s mean distance from the sun), are applied as parameters in the calculation process. The three components include: Illuminance due to the direct sunlight and the diffuse sky (Ew(sk)); illuminance due to the ground (Ew(g)) and illuminance due
to the opposite obstructions (Ew(o)). They are the preconditions for indoor DI calculation in DICMP. Therefore, aimed for the three components. Our calculation starts from sun position, then daylight availability, sun and sky illuminance and reflected illuminance of vertical facade.

<table>
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<th>Table. 1 Parameters Explanation</th>
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<td>Eg</td>
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<td>Ew(g)</td>
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<td>Ew(sk)</td>
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<td>Ew(o)</td>
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<td>( \rho_{sg} )</td>
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<td>Cf( \omega )</td>
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<td>( \rho_w )</td>
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In this section, how to estimate the three components of DI will be described. By using these illuminance together with the transmittance of window, the mean interior illuminance can be determined. Figure 2 shows the calculation process of the three components of the daylighting illuminance. The following sections show how the three components of daylighting illuminance can be calculated based on the process in Figure 2.

### 3.2. Daylight Availability

This part of calculation aims to evaluate the amount of light from the sun and sky by concerning a specific time, date and sky condition at a specific location. Because the daylight comes from sun, when concerned the amount of light from the sun and the sky, the position of the sun has to be specified first. Then the illuminance of the direct sunlight can be quantified. The parameters in these calculations are come from Diasty (1998).

Variation of the distance between sun and earth should be taken into account because it may lead to variation of extra-terrestrial radiation flux in the range of \( \pm 3\% \) (Duffie and Beckman, 1980). Edn, corrected for the attenuating effects of the atmosphere, can be estimated from the extra-terrestrial solar illuminance. So we use equations for calculation with the parameters from IESNA, 2000. For diffuse light from the sky, it is an important component which depends on the conditions of the sky. The sky cover method is utilized to evaluate the amount of cloud cover. The total horizontal illuminance due to diffuse skylight Ekh can be expressed as a function of the solar altitude.
3.3. Sun and sky illuminance on the ground & vertical facade

Whether the ground receives direct sunlight can be determined by the following instructions. The equations have been generated for the situation when the ground is partly sunlit when meeting the conditions. The equation shows that the window will receive direct sunlight if the associate conditions it can be satisfied. The situation when the daylight from the diffuse sky blocked by obstacles around has also been addressed in the calculation. In the end, the total illuminance of vertical window from direct sunlight and the diffuse sky can be evaluated.

3.4. Reflected illuminance of vertical facade

Two sources—light reflected from the ground and the light reflected from the opposite façade—contribute to the reflecting light on the vertical façade. Ew(o)—the illuminance on the vertical window from the light inter-reflected between façades can be calculated.

In the end, the three components of DI of the reflected illuminance from the ground (Ew(g)), the total illuminance on vertical windows caused by diffuse sky and direct sun light (Ew(sk)), and the illuminance on windows from the light reflected between facades (Ew(o)) are all calculated for our system. These components can be used for further calculation in the following sections as the luminous sources on the vertical windows.

3.5. The calculation of illuminance on work plane (ceiling, window wall, working plane)

By utilizing the three illuminance components and taking the transmittances of windows into concern, the mean illuminance on work plane can be evaluated (Tregenza, 1995). Ac, Av and Ap are respectively the area of the interior surfaces of different parts of the room. For semi-transparent BIPV modules, Aw is the area of the whole module excluding the solar cell area. The above formulas are the direct interior illuminance on the individual surface. The window transmittance parameters and their typical values for all scenarios are given by Tregenza’s paper. By using the three illuminance components (Ew(g), Ew(sk), Ew(o)) as the luminous sources, the mean direct illuminance on the receivers of the room surfaces of ceiling, walls and working plane (Eci, Evt, Ept) can be calculated.

The mean illuminance over all room surfaces from inter-reflected light Er can be calculated by using the mean direct illuminances of Eci, Evi and Epi. Then the final illuminance on various working planes Ep can be calculated by making sum of Epi and Er. Therefore, the average illuminance on the working plane can be determined.

4. Results and Discussion

Through programming, the calculation methodology described above can be implemented through spreadsheet program. The role of the spreadsheet program can be used in the further experimental research. The calculation results can be the reference to the simulation and experimental data for comparison.

Since the project is located in Wuhan, China, we use the local information and conditions for calculation. By entering into a spreadsheet software the primary parameters of day numbers, hours, latitude, the hourly indoor daylight illuminance can be calculated.

In this stage, for comparison and insurance, another computational method by applying the software tool DIVA-for-Rhino is introduced. DIVA-for-Rhino is an optimized daylighting and energy modeling plug-
in for the Rhinoceros - NURBS modeler. The plug-in was initially developed at the Graduate School of Design at Harvard University and is now distributed and developed by Solemma LLC. DIVA-for-Rhino allows users to carry out a series of environmental performance evaluations of individual buildings and urban landscapes. The simulation core of DIVA comes from the well-known software tools Radiance, which has been widely recognized as a suite of programs for the analysis and visualization of lighting in design.

Figure 3: The daylight simulation in DIVA-for-Rhino. Display of the 3D model and horizontal illuminance from the daylight simulation results in DIVA-for-Rhino

Figure 4: The comparison of indoor daylight values in DIVA, DICMP and Hourly Illumination (daylight hours only, Climate Consultant, Data source: SWERA)

First, the models for simulation are generated based on the experimental BIPV house. Second, we download the local climate files (Eqw format) from the weather data website of Energy Plus. By entering the primary parameters, the hourly indoor daylight illuminance can be calculated in DIVA (Figure 3). The simulation result can be used to compare with the results of daylighting illuminance from the calculation spreadsheet. From the comparison, the simulation results in DIVA is consistent with the spread sheet programing result of daylighting illuminance.

After several rounds of simulation in DIVA, for the overcast situation, the calculation result of our DICMP can be well matched to the analysis of DIVA. This has been shown in the Figure 4. We calculated and simulated the daylighting illuminance (lux) on the time of 2 pm on the 15th day of every month from January to December. The blue line presents the illuminance results simulated by DIVA, and the orange
one shows the results from our DICMP calculation. We can see that the differences within these two is quite small. Moreover, by comparing them with the Hourly Illumination (Climate Consultant, Data source: SWERA), we can find them have the same trend from the 1st month to the last month. This can further prove the rationality of our calculation and simulation by comparing the detailed illuminance density. Another aim has been achieved is that, DICMP

Though lots of tests have verified the DICMP, we have to admit that there are flaws for the situation of clear sky condition. The main problem we find is that the DICMP results can’t match the simulation in summer months. The DIVA analysis can match the results for the first three months. However, following DIVA results have shown that the illuminance has the trend to decrease in summer time, which is opposite compared to DICMP. This will be our future study to find out the exact reasons. For now, we proposed the cause can be the differences of calculation method. For outdoor daylight illuminance, it goes up from January. It usually reach the peak in the midsummer. The simulation from DIVA goes down should be the reason by taking account of the shape of the test room and the window position. As the altitude of sun becomes higher, the sunlit area in the room becomes smaller. Though the density of sunshine increases, the mean illuminance of the room decreases. For further study, a variety of photovoltaic panels and devices will be installed for measurement on an experimental prototype house. The DICMP can be improved by adjusting the parameters.

8. Conclusion

In this study, our purpose was not to investigate the principle of daylighting model in details and develop an entirely new daylighting illuminance theory. Instead, we set up a suitable DICMP as an important part of the energy performance of the semi-transparent BIPV system. Compared to the previous methods, DICMP is not only simple enough for manual calculation, but it also allows for computer spreadsheet programming by taking different sky conditions into account.

In the project, the method of assessing the DICMP for BIPV systems have been discussed for the modules. It can estimate the average indoor DI by taking the direct daylight, the diffuse daylight, the reflected light (from the opposite building and ground) and all sky conditions into concerned. The DICMP enables researchers to calculate the hourly indoor daylight illuminance by implementing a spreadsheet program in a short time. As power saving is an important component of BIPV modules, DICMP enables estimating the power saving of the artificial lighting due to the daylight utilization.

According to our comparative studies, though there are some flaws in the clear sky condition, the simulation result has proved the effectiveness of DICMP. It will be our future study to improve it further. Our findings offering a reference and valuable overview for designers of how to calculate DI for BIPV systems quickly, simply and accurately. It is also an essential part for evaluating the performance of the BIPV modules which is sufficient for the requirement of the project.

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References


Facilitating change: the modular format in the design of prefabricated homes

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Abstract: This paper examines the modular format as a tool for systematising both computational design rules and building assembly methods. Its focus is a live case study of a 3 storey prefabricated apartment block. The goal is to explore the utility and effectiveness of this tool and its ability to facilitate change. A parametric model of the apartment block is made and various aspects of the modular format are applied to its assembly and components. Combined as a computational design and building assembly tool, the benefits of the modular format may be exploited. Thus flexibility, adaptability, changeability and reusability are maximised. Whilst fully interactive integration of the modular format may not yet be possible, it is hoped that its incorporation into the complexities of the architectural design process may at least result in more authentic outcomes.

Keywords: modular format, design rules, parametric modelling, prefabrication

1. Introduction

Architects find the implementation and conceptual structure of computational design methods challenging. More easily understood and flexible expressions of design rules are required to stimulate engagement with its tools, and it has been urged that these rules should be expressed in ‘modular’ format (Mitchell, 1989). Although this reference is made to the design rule as computational expression of a procedure delineating design requirements as input and the result as output, the notion of the modular format assists with comprehension of all complex artificial systems, including building assembly processes. A modular format denotes discrete but connectable components, well-defined interfaces, reusability and shareability, in contrast to integrated formats which have no clear division between components. This paper provides understanding and demonstrates implementation of the modular format and its ability to accommodate change, a ubiquitous feature in the practice of architecture. The modular format as expression of a computational design rule and as a means of building assembly is examined in relation to a case study of a live architectural design project.
2. Methodology

The AP14 project is a 3 storey 26 apartment development in Brisbane, Australia. It is both a commercial development designed by Fairweather Jemmott Architects and a research project, funded by the Queensland Government Accelerate Partnerships program and designed by Aquatonic, to compare prefabricated assembly with traditional building methods (Figure 1). A hybrid prefabrication strategy proposed by the research team was confirmed by Bligh Tanner’s structural engineers. Thus, the building assembly’s modular format might be described as the integration of hybrid components - panellised floor, wall and roof elements, volumetric bathrooms pods, and clip-on balcony components.

![Figure 1: AP14: unit type in section & whole scheme in axonometric](image)

The study uses parametric modelling tools to explore expression of design rules in modular format: a ‘component based modeller’ (e.g. Autodesk Revit, ArchiCAD and Microstation); a ‘design development program’ (e.g. CATIA, PTC’s Creo and Solidworks) (Schodek et al., 2005); and a visual data flow graph (e.g. Grasshopper, Autodesk Dynamo) to further examine the design rules in both modular and declarative formats. The modular format has guided the creation and implementation of discrete but connectable components, well-defined interfaces, reusability and shareability. Its intelligibility, ease of use, flexibility and adaptability to change will also be discussed.

3. The modular format

The key characteristics of the modular format are defined above, however more generally it may be described as the decomposition of a system into parts as a means to understand and manage complexity. Furthermore, the concept of connectability by means of well-defined interfaces acknowledges the dynamic nature of interrelationships between these parts.

The modular format as a computational expression dealing with complexity has developed from discourse in other fields. For example, von Bertalanffy’s General Systems Theory (von Bertalanffy, 1950) captured a growing tendency in the science of its time to recognise the importance of dynamic interaction in all fields of reality, marking a shift from a mechanistic and static understanding of systems to one recognising their organic and dynamic tendencies. Simon (Simon, 1969), whilst disagreeing with the abstraction of these characteristics of complex systems to general principles, reiterated the need for hierarchy and the decomposition of complex systems into functional parts. These insights are useful in
consideration of the nature of all complex artificial systems, including computational design and building assemblies. But the modular format has been defined in alternative ways in the computational design and building assembly fields. There follows a brief account of these definitions, followed by a description of a strategy which utilises and integrates the modular format in these fields.

Rudolph Schindler in the early twentieth century, proposed use of a modular unit as a regulator of architectural proportion and building assembly, and indeed, Le Corbusier’s Le Modulor was a sub-set of Schindler’s ‘universal set’ of modular ratios (March, 2003). These modular units represent early development of computational methods to manage the modular format and significantly, the attempt to mentally compute proportional and scalable modules. Schindler firmly believed that the modular unit was a ‘reference frame in space’, the most important mental computational tool in the architect’s toolbox (Park, 2005). His proposition presaged Christopher Alexander’s work on patterns, which was more characteristic of a modular format as it described discrete connectable components, but with a similar conviction that computation is a mental process dependent on the understanding and integration of subdivisions of the whole (Alexander, 1964; 1979).

Although a major flaw in Alexander’s work was a mechanistic assumption that a set of design requirements can be listed at conceptual design stage (Lawson, 2005), nevertheless interactions between these descriptions of patterns and computer programmers of the time became the basis for a branch of object-oriented programming (Lea, 1994). Furthermore, software engineers developed structured programming in the 1960’s, focused in particular on the benefits of the modular format, a strategy adopted as a response to increased complexity in computer program flows (Davis, 2013). Computational designers, in turn, absorbed lessons from software engineers. In 1963 Sketchpad (Sutherland, 1963) introduced parametric modelling to the CAD world, enabling dynamic interrelationships between elements to be represented, and their manipulation by ‘light-pen’ and keyboard. As techniques of parametric modelling have developed the modular format has been proposed as a method for ensuring models remain disentangled, thus it should be expressed as self-contained chunks of code, shareable, reusable and debuggable (Davis et al., 2011).

Building assemblers, by the mid-twentieth century, had developed their own definition of the modular format, which found expression as a volumetric form which endures today (Garrison and Tweedle, 2008). In the USA it is epitomized by ‘transportable’ or ‘manufactured’ homes which are shipped to site on a flat-bed truck, such that 2-4 modules may be joined together to form a whole house (Steinhardt et al., 2013). These possess some characteristics of the modular format - discrete envelope, reusability - but they are essentially mechanistic and static representations with limited consideration of interface connections between modules. Encouraged by observation of the manufacturing industry’s products these modular homes are assembled from standardised parts at the end of a chain of production, thus facilitating limited potential for customisation (Carpo, 2011).

However, this volumetric form is only one interpretation of the modular format in the field of building assembly. A Swedish study (Jensen et al., 2012) takes this discussion further by focusing on an industrialised building system and the customisation of its floor components, which were enabled by their modular format and configuration. In this study it was the interface between modules, the enabler of connections - ‘slot’, ‘bus’, ‘sectional’ - which more meaningfully defined the nature of their modular format. Furthermore, these interfaces facilitated sharing and reuse, characteristics common to modular formats in the computational design field. This prompts consideration of strategies which make best use of the modular format in both fields.
An effective strategy in the design process, which utilises the modular format, is to move beyond high design content with its extravagant outcomes to a low-design content, non-repetitive design strategy, “... an elegantly minimal, tightly disciplined response” (Mitchell, 2005). For example, ‘Kilian’s roof’ is a computational design exercise which has successfully demonstrated this strategy as follows: a framework is defined to lead sub-division of the complex whole; then a point collection is created to assist with location of a proxy object; finally module components are associated with the proxy object (Woodbury et al., 2007). A built example of this strategy of low design, in-context complexity, incorporating non-repetitively designed modules is the British Museum’s Great Court roof, London, UK designed by Foster and Partners, in which the varied shape of roof panels and structural members is controlled by simple rules and parameter values (Figure 2).

Figure 2: ‘Kilian’s roof’ design exercise (image source: Daniel Davis’s PhD thesis, RMIT 2013) & the Great Court roof, British Museum (photo copyright: Ben Johnson).

4. Case study – AP14

Aspects of the modular format - discrete but connectable components, well-defined interfaces, reusability and shareability - are examined in the context of the AP14 project, focusing on the design of panellised wall components and the building’s assembly. Incorporation of the strategy outlined above - low-design content, non-repetitive design - is also considered.

4.1. Modular format wall panels

As noted above, Schindler’s approach pre-dated modular computational programming and found a way to maximise mental computational ability by defining the modular unit as a subdivision of the whole which could be held in mind throughout the design process. However, computational parametric ability made the design of proportional and scalable relationships a simple and perhaps reductive exercise. Nevertheless, his concept of a ‘reference frame in space’ echoes the process by which a parametric model is set-up. With parametric modelling, Schindler’s reference frame becomes a reference plane to which geometry is aligned. This has been described elsewhere as set-up of the ‘design domain’ (Burry, 2007) with which, by association, geometry updates as dimensional parameters change. The modular format may thus find expression in the AP14 project as a timber engineered wall panel suitable for all situations predicted (Figure 3).
This is an example of the strategy of low-complexity, non-repetitive design as this panel may be instantiated as many different types to suit material and engineering requirements so that it might be notched, un-notched, solid, have openings, and have bracket fixings automatically located (Figure 4). These panels are then loaded into the unit’s group for scheduling and creation of shop drawings, a method which is extensible, flexible and able to accommodate change.
4.2. Modular and declarative format programs

Mitchell (Mitchell, 1989) urged use of modular and declarative formats to express computational design rules to make them more easily understood and more easily modifiable. The benefits of this combination have been demonstrated in structuring parametric models and include, flexibility in accommodating change and the ability to defer design decisions to later stages (Aish and Woodbury, 2005; Davis, 2013). In this exercise using a visual data flow graph (Autodesk Dynamo), the modular format is illustrated on the left with clear naming, identification of inputs and outputs, operations encapsulated in nodes, plus a description of its purpose (Figure 5). The declarative format is also illustrated on the left by its wires and nodes describing what is wanted but not how it is achieved, in contrast to imperative formats which describe in script form each step to achieving the desired outcome. Separation with the instance illustrated on the right facilitates deferral of design decisions.

![Figure 5: Modular & declarative formats defining wall & floor panels (Autodesk Dynamo)](image)

The associational and logical relationships represented by this modular and declarative format certainly assist with understanding of the design rule – the procedure stating design requirements as inputs and outputs. However, this is a relatively simple design task and recently it has been argued that the declarative format in particular does not scale to more complex logic, and therefore to more complex building assembly models. One solution to this problem may be to combine declarative visualisation with imperative programming incorporating iterative looping and higher order functions (Aish, 2013; Janssen et al., 2016).

4.3. Modular format building assembly

This next exercise focuses on setting up several flexible models to reduce design complexity by incorporating pre-assembled components. It has been demonstrated, in an experiment using a design development program (CATIA) to test the flexibility of a parametric model whilst structural elements were being optimised, that set-up of an “... all-encompassing flexible model... is not advisable”, because parameters affected by optimisation interfere with the hierarchical and logical structure of the model (Holzer, Burry & Hough 2007). It has also been demonstrated, in another computational design test of a visual data flow graph’s ability to design ‘Kilian’s roof’, that several modular reusable nodes are preferable to a single complex node (Janssen 2016). Both these examples suggest that set-up of computational design rules should follow a modular format.
However, reduction of the design complexity of the building assembly should also be considered. This can be achieved by use of prefabricated or pre-assembled elements in which a degree of design content is inherited (Mitchell 2005). It has also been proposed, with reference to assemblies of components and identifiable sub-systems of buildings, that ‘composition’ as a computational design tool should be ‘internalised and operationalised’ by designers (Aish, 2005) – a description which might further be seen as an echo of Schindler’s and Alexander’s earlier ambitions. Thus the modular format of the building assembly may be more closely interpreted by the modular format of the computational design set-up to reduce design complexity overall and improve flexibility and adaptability to change.

As noted previously, in the AP14 project the prefabricated elements are engineered timber floor, wall and roof panels, whilst the pre-assembled elements are bathroom pods and clip-on balconies (Figure 6).

The modular format is defined by these elements - self-contained with connectable interfaces, reusable, shareable, - and their relationship or assembly. A component based modeller (Autodesk Revit) is used to assemble a unit type’s elements: thus combining these elements into a ‘group’ clarifies interface connections whilst maintaining their discrete properties; ‘group’ amendments are non-repetitive as a change to one instance propagates to all; a ‘group’ may also be linked to the main model and amended in isolation by another design team member thus enhancing shareability. The unit type ‘group’ itself is constrained to the vertical (grids) and horizontal planes (levels) of the main model’s framework. If a grid or level is changed the unit and its ‘group’ geometry changes (Figure 7).
It should be noted that with component based modellers, the terms ‘part’ and ‘assembly’ may have a meaning different to common usage in the manufacturing field. Therefore a ‘part’ may be a wall layer in a ‘system family wall’ (Autodesk Revit), rather than a discrete, connectable modular entity. Whilst ‘assembly’ (Autodesk Revit) may simply refer to the arrangement of elements into a 2D shop drawing. Component based modellers’ focus on building information modelling (BIM), organising information for availability over the life of the building, whilst the geometry of the structure and components - the realm of computational design - often remains inaccessible to the architect.

In contrast, a design development program with full parametric capabilities (Digital Project/CATIA), deals with parts and assemblies in a hierarchical and logical manner, in a way familiar to the manufacturing industry. Its hierarchical tree represents the organisation of the model: a framework sketch defines grids and levels; and parts are assembled within a ‘product’ file as illustrated here (Figure 8).

Thus, the modular format may be more logically represented using design development programs compared with component based modellers. However more discipline is needed to set-up its hierarchy of frameworks, parts and assemblies and more cognitive effort is needed to define parametric relations and constraints between geometrical elements.
5. Conclusion

In summary, architects are keen to utilise computers to their best advantage, and they want their tools to be intelligible, flexible and adaptable if they are to cope with change amid the dynamics of the design process. They are also aware of, and eager to harness, the direct link between these new design tools and better ways of fabricating and assembling buildings.

The results of these experiments confirm significant implications for integration of the modular format in the fields of computational design and building assembly. Modular formatted wall panels demonstrate that the strategy of low-complexity, non-repetitive design is extensible, flexible and able to accommodate change. However, more research is needed to explore the advantages such a strategy might have when focused on other modular and prefabricated components. It is also important to further examine the nature of self-contained, connectable interfaces, and their ability to be reusable and shareable.

It has also been shown that modular and declarative formatted programs improve intelligibility and ease of use. But more testing is needed to examine the capability of declarative formats in dealing with greater complexity, and to determine the extent to which the imperative format should be integrated with these other formats.

Examination of modular formatted building assemblies also highlighted synergies with modular formatted computational design tools. Furthermore, it was shown that design complexity can be further reduced by incorporation of pre-assembled and prefabricated components thus improving flexibility and adaptability to change. If design development programs are also utilised then representation of the modular format is enhanced because of their inherently hierarchical set-up and ability to deal with complex logical relationships.

This paper has interpreted the modular format as an expression of design rules in computational design and as a feature of building assembly models. The modular format facilitates change by systematising the complexity of the design and assembly processes and, far from being a static or mechanistic concept, the modular format combined with parametric modelling tools becomes part of a dynamically controllable association of parts to the whole. If computational design methods and building assembly strategies adopt the concept of the modular format then, subject to the further research identified above, its full benefits might be exploited: flexibility, changeability, reusability, and shareability.

To be worthwhile and effective the modular format as a computational design tool should also enable the architect to progress fluently from concept design to fabrication-ready information, from simple to complex building models. And it should also be acknowledged that increasingly, rather than traditional documentation outputs, minimal geometrical information may be needed for fabrication-ready information. Therefore, the modular format should not only operate smoothly from concept to fabrication but should also reflect this new form of design which is ‘open-ended’ (Aish, 2013), and therefore in harmony with current tendencies favouring flexibility, adaptability and participation.

A corollary of incorporation of the modular format across architecture, not just in its design tools, might be a better response to the demands of complex conditions. Rather than the “seduction of the surprising” it might give rise to a more, “authentic architecture of the digital age” (Mitchell, 2005).
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Daniel Davis, thanks for permission to use Figure 2 (‘Kilian’s roof’), PhD thesis, RMIT 2013.
Ben Johnson (copyright), photo 1705118/img3, Foster & Partners, Great Court roof, British Museum, UK.

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The feasibility of implementing ‘building performance sketching’ within the building design process through the use of the distributed model method

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Abstract: Performance Sketching is the act of assessing the performance of an architectural sketch through the use of detailed building performance simulation (BPS) tools in the early stages of design. BPS tools offer tremendous potential for informing design to improve the passive performance of a building, but are inhibited by limitations and barriers to their use in the early stages of the design process – where the most influential design decisions are made. This paper presents an exploration of the views and perceptions from the New Zealand building industry on the feasibility of performance sketching using the plug-in, Honeybee for Rhinoceros/Grasshopper, as an example of a distributed modelling method (DMM). The study concluded that DMM cannot currently address all wants and wishes of users established in literature, but has potential. Future research efforts are required to focus upon: creating industry specific templates for building types; developing these templates to be adaptable for the different modelling operators of the proposed workflow demonstrated to the participants within this study; and developing quality assurance standards for modelling and guidelines for model validation. Finally, the study concluded with future work required beyond tool development: improving education of architects; and introducing legislation.

Keywords: building performance sketching; design.

1. Introduction

Imagine the following scenario: an architect is approached by a client to design a commercial office building. The client asks for a ‘sustainable’ building, with high energy efficiency and excellent indoor environmental quality. How can the architect as a designer ensure that the building will perform as intended?

Recommendations from literature suggested that the first step should be to ensure the ‘architectural sketch’, or design concept, will lead to good building performance (Granadeiro, Duarte, Correia, & Leal, 2013; Jacobs & Henderson, 2002). The use of detailed building performance simulation (BPS) tools is
contended to be the most reliable means of informing design decisions (Granadeiro et al., 2013; Jacobs & Henderson, 2002). Building performance simulation (BPS) enables the comparison of a broad range of design variants to understand the usability of a design, and the interactions between design parameters and the occupant comfort. However, in our scenario, the use of BPS tools to ensure the design will perform as intended has a number of challenges which discourage its use.

Over the past three decades, tool development focused on the architect has not been successful in encouraging the use of building performance simulation (BPS) in the design process. BPS modelling software is simply too technical, complicated and cannot be considered ‘architect-friendly’ due to the differences in language, modelling processes and visualisation of results (Attia, Beltrán, De Herde, & Hensen, 2009). Architects and designers have difficulty in using even the most basic BPS tools. Hence, BPS does not lend itself well to the casual user, but rather requires the input of an expert who can ensure reliable and robust performance predictions.

Thus, the proposed answer for the architect in our scenario is to look for an approach to ‘sketching’ the performance of their design concepts. This is suggested to be with the aid of the expert engineer in a partnership, using detailed BPS tools to provide high levels of accuracy, in a quick and easy manner.

1.1. Defining Building Performance Sketching

We propose this approach to be early design stage performance modelling called ‘building performance sketching’. The ‘Building Performance Sketch’ is described by Donn et al (2012) as a building performance analogy for the architectural sketch. The architectural sketch roughly outlines key design features which distinguish the potential end product, but does not solidify any design ideas. Thus, the architect is able to choose between possible paths of development. The key principle of the performance sketch is thus mirrored in that by roughly modelling the basic design concept with minimal, but most influential, levels of detail, the likely performance of the concept can be simulated and evaluated in a quick and easy manner using detailed BPS tools.

Thus, accuracy becomes a high priority in performance sketching. Unlike the architectural sketch, the performance sketch cannot leave precise details of elements such as windows or shading for later stages. In the absence of confirmed design parameters, unknown parameters in a performance sketch are defaulted to a range of low, typical or high scenarios using real-world building data. Building performance sketching uses this data in sensitivity analysis to analyse the cloud of design potential that a concept could be developed into. This approach does not require the burden of creating a detailed representation of the building, but rather looks to develop ways of modelling the richness of the human experience of interaction with buildings through the use of detailed accurate performance simulation tools in conjunction with building ‘sketches’.

For building performance sketching as an approach to early design stage performance assessment to be plausible, the same barriers against building performance simulation integration in the design process must be overcome. In literature, several studies exist which outline these barriers faced within developed countries and their building industries. The studies outlined in literature used user feedback from surveys to determine the barriers present in industry, and established user requirements as recommendations to tool developers. Negendahl (2015) proposed the theory that the answer to the problems faced in industry, and a means to address all recommendations, is by considering the integrated design process (IDP) approach by the application of the distributed model method (DMM).
2. Research Design

Despite the many theoretical advantages of DMM within the design process to integrate BPS, there were no studies which could prove its feasibility. Furthermore, it seemed inadvisable to create yet another tool which did not meet the wants and wishes of the current building industry professions, on the theory that this method could encourage building performance sketching in design. Thus, before blindly launching into tool development, the study aimed to first understand how and why DMM could or could not make building performance sketching feasible within the design process to guide future tool development. This would test the hypothesis that DMM could meet the wants and wishes of building professionals for tool development.

To achieve this aim, the study established the need to approach the ‘players’ of the scenario (the architect and the engineer) of a building industry which: a) designs buildings similar to the majority of the building industries in the world; b) does not currently implement building performance sketching in practice; and c) is growing into a building industry with a focus on ‘sustainable’, high performance building design. As an unproven concept, no building industry in the world currently implements building performance sketching as common practice. New Zealand’s building design and construction industry is largely trained in the same manner as in other countries. Therefore, the study focused upon the developed building industry of its location, New Zealand, to provide indicative results of the building industry.

The study had a unique problem in that DMM was not a commonly established method of design. There was no case example to question the professions for feedback on the use of DMM as a means to make building performance sketching feasible within the design process, thereby gaining feedback was a near-impossible research task.

The study took the approach of demonstrating an example of building performance sketching using DMM by creating a conceptual template workflow for the commercial office building type within an example tool, Honeybee/Ladybug for Grasshopper/Rhino (Sadeghipour Roudsari & Pak, 2013).

2.1. The Building Performance Sketch Workshop

The participants were invited to ‘play’ within the program, Honeybee, in order to get a sense of the practical use of such a workflow within parametric design and the speed of its interoperability features directly before the focus group session. A computer room facility was made available for use through the Victoria University of Wellington’s Architecture Department. The workshop was conducted over a period of three hours for each participant group, in which the participants were provided with a brief presentation on the context of building performance sketching, the processes of DMM and its unique features which differ from the methods they were familiar with. Participants were allowed to ‘play’ within the selected program for this study, Honeybee/Ladybug as plug-ins for Grasshopper/Rhino, within a structured tutorial exercise. The workshop was finalised with a demonstration of a workflow created within Honeybee which illustrates the application of building performance sketching on an example building form.

2.2. The Building Performance Sketch Workflow

Due to the scope of the study, a conceptual workflow was created in Honeybee to provide a means to test theories from the recommendations made by literature on the participants of this study, and
provide a basis for recommendations to be made for future development. The aim of the workflow was to address the recommendations from (Donn, Selkowitz, & Bordass, 2012) in using detailed simulation engines and real-world data, along with enabling sensitivity analysis at the early stages of design to ensure reliable and useful results for the users.

Figure 1 illustrates the workflow’s Honeybee components visible in the Grasshopper interface and demonstrates the significance of the features made available through the interoperability of the DMM.

We acknowledge that this workflow has not been created to be robust or for immediate use within the industry, but rather a concept to provide feedback and explore options for future development. The workflow has been set out with two main themes: full transparency of how the model is created, and the defaults of certain components; and minimising necessary inputs. Everything which requires user input is grouped at the start of the workflow in the ‘Parametric Inputs’ area as a means to simplify the required input for the architects. Where the users wish to edit any particular part in creating the models, they are able to do so, given they follow the correct processes to link the change into the workflow. This therefore requires expertise from the engineer. Therefore, all features were created at the most conceptual level to demonstrate their use, however particular attention was given to the creation of:

- The ability to add any geometry to the beginning of the workflow and have the geometry be converted into Honeybee Zones to run simulations - This saves valuable time during the early stages of design, as the design team do not need to rebuild the design model.
- The ability to parametrically run simulations for sensitivity analysis
- The ability to edit all parameters and have full control over the creation and processing of the models
- A user library specific to New Zealand from real-world data provided by BEES (Amitrano et al., 2014) - The construction data specific to New Zealand commercial office buildings was taken
The feasibility of implementing ‘building performance sketching’ within the building design process through the use of the distributed model method and converted from (Cory, Gates, & Donn, 2011) into a Honeybee user library of constructions and materials.

- The ability to run both a thermal and daylight simulation with the same model - In the workflow, using Honeybee to connect DAYSIM and EnergyPlus together within the same interface, the same model is used for both. Therefore, any change for daylight analysis would be automatically made for thermal/energy analysis.

With these processes of the workflow outlined and described to the participants of the study, the participants are provided with a foundation to provide feedback. This workflow in particular focused upon demonstrating to the participants how the DMM can address the recommendations for future tool development in literature and how the method can provide rapid comparison of early design concepts “with flexibility, ease and speed” (Donn et al., 2012).

2.3. Data Collection: Focus Group Interviews

A group interview method was chosen to obtain feedback from the New Zealand building industry in regards to their views on the feasibility of building performance sketching using the distributed model method (DMM). Three recorded focus groups were conducted after their respective workshops to provide the participants of each group the opportunity to answer structured, open-ended questions as feedback which formed the main means of data collection for this study.

This study was particularly interested in the feedback provided by the professions within the building industry who directly work within the design process of the early stage of design. The study thereby had homogeneity in the first two focus groups, with the intention that the information from each group could be compared against another group of a different profession. The final group consisted of a mixture of both to explore the emergence of data and to test whether or not the same issues would be raised by the respective parties given the presence of the other which may argue the answers.

The determination of the ‘appropriate’ number of focus group participants did not have an aim of being statistically ‘representative’ of a given sample. Rather, the research method relied upon ‘qualitative sampling’ in order to compose a structured rather than random sample. In focus group design, this is often due to the need to mitigate the disadvantages of the focus group method such as having domineering or quiet participants. The study followed the recommendations from Morgan (1995), where it was stated that fewer participants would provide more opportunity to both tell and compare their stories in detail. In respect to this, each focus group within this study aimed for four to five participants in each group, resulting in five participants in each.

Hence, the focus groups were split into three categories: five Architects (Wellington); five Engineers (Wellington and Auckland); and a mix group of two architects and three engineers (Auckland).

4. Results

The data from the focus groups were coded into categories established for tool development in (Attia et al., 2012) and was analysed via Directed Content Analysis (DCA). The analysis used a six-category coding scheme to deductively code transcripts from the focus groups. This section presents a brief summary of the results of the study from the three focus groups.

The architects discussed four main reasons why they do not implement performance sketching: the time and cost provided by the client/stakeholder; the perception of time in relation to understanding
the program interface; their prioritisation on architectural aesthetics and method of design; and their lack of expertise as a user. They discussed the only ways in which they perceive these to be overcome would be if: the interface would be made adaptable and educational; they could see the value in performance sketching in informing design decisions; if they would be provided with training; and if the client could see the value in the process in order to allow for more time and money.

However, they noted that architects cannot be fully trained to the point where they would replace the expertise of the engineer. Therefore, the groups suggested the need for a partnership with the engineer in order to facilitate the creation of easier, but accurate, interfaces. Hence, the barriers of the engineer need to be overcome along with those for the architect. The engineers believed that their barriers are: time of engagement within the project; effective communication between team members; the use of programs which do not make their assumptions and calculations transparent; the inability to continue models through into different phases of the design process; and the assessment of design parameters for their accuracy. The engineers indicated within this study that all but the barrier of engagement can be overcome by the use of the example, Honeybee, using the DMM.

The barrier of engagement was rooted in the ‘Old School’ market attitude of ‘We just don’t do it that way’. Engineers and architects alike suggested that in order to overcome the current market attitude, building performance sketching should become mandatory and the new generation of architects should be trained to design using performance sketching within their process. Thus, the designer would include comfort in their list of priorities, and the client would be required to include performance sketching within the early stages of design, thereby allocating cost and time to the process.

**Figure 2: Mapping Concepts and their relationships**
The feasibility of implementing ‘building performance sketching’ within the building design process through the use of the distributed model method

Figure 2 illustrates the relationships indicated by the participants between various concepts/categories brought up in their discussions. This mapping exercise illustrates the means in which recommendations made by the participants overcome the barriers they have established which prevent the implementation of the building performance sketch.

In creating the category connections through mapping, the categories which described the participant’s established barriers were firstly identified in relation to their descriptions by the participants and which concepts represented the recommendations made by the participants to ‘overcome’ the barriers. This means of summarising the results through mapping an operational model diagram highlights four areas for future development and discussion, and are highlighted in blue borders: Legislation; Education through training and available resources; improvements of the interface; and features specific to quality assurance using DMM.

5. Discussion and Conclusion

The distributed model method (DMM) was hypothesised within literature as the best means to overcome the challenges within the integrated design process (IDP) approach, to enable effective design team collaboration and to provide the capabilities to address quality assurance barriers. The data of this study from the focus groups is sufficient to conclude that the distributed modelling method (DMM) cannot overcome all barriers preventing the implementation of building performance sketching. This study has shown that architects and engineers within New Zealand’s building industry consider some external influences on the design process to be barriers which the DMM cannot overcome on its own. These include barriers such as the client and current ‘set in their ways’ attitude of the market. However, the architects and engineers of this study believe the DMM has high potential to address all the wants and wishes for future tool development made by current literature, including their own.

The architects concentrated on how the workflow, and the use of the DMM, could be feasible in the industry’s Building Information Management (BIM) processes. The engineers focused their discussions and feedback upon the matter of quality assurance. They expressed their concerns in having the inexperienced simulator as the designer creating simulation models. The mixed group commented upon both, BIM integration and quality assurance, but focused their attentions on the feasibility of implementing a new tool such as the example tool Rhino within their design studio. Their comments surrounded the idea of competitive fees and ‘backing the wrong horse’ – viewing a new emerging tool as a gamble to invest in:

“We’d have to back one horse but if it’s not Honeybee and Grasshopper, it’s something else”.

“It will improve the level of analysis that we can provide early on. I think internally, our biggest barrier might be lining up all this software, to be honest. Actually getting some of that 3D business, and making sure it interfaces well with Revit” – Engineering participant.

These considerations are not clear in literature, and raise a need for further exploration into business decisions surrounding the adoption of new tools within the design studio. These comments suggest that the implementation of new tools should focus upon not only making the use of the tool easier and efficient in a design team context, but must also consider interoperability to current tools used in industry. This would increase the likelihood of adoption within the design studio. It would be seen as a
means to improve current operations rather than demanding a radical change in processes which would take time and training to implement successfully. Their lasting comment was that future development should focus upon furthering the processes in the DMM to implement building performance sketching for the future.

“I think it opens up a whole new round of possibilities that to me didn’t exist five years ago. I’ve been a consultant for a bit more than 10 years. When I first started, programs like IES were relatively new and they offered a level of computing power that wasn’t there before. I feel like it’s stayed about the same, most of the time that I’ve been working. But the ability to run numerous iterations and parametric simulations like that, is a new thing I think that wasn’t available and I can’t see it going away” – Engineering Participant.

The DMM was seen by the participants as a means to aid in overcoming the barriers against the implementation of building performance sketching by increasing design team communication, reducing time taken during the design process for simulation, and enabling means for quality assurance and effective team collaboration. Before building performance sketching can become a reality within the future, this study concludes with three main features which must be addressed by future development and research. These features were:

**Standard modelling guidelines and templates specific to New Zealand:** The participants liked the workflow created within this study, and requested the conceptual workflow to be developed into a standard workflow with templates specific in modelling building types for the New Zealand building industry which contain New Zealand specific building data. Participants also requested the creation of modelling guidelines for their use in DMM for design. These templates should include benchmarks for their respective building type and uncertainty reporting to inform the user of the validity and reliability of their results in the building context.

**The development of adaptable graphical user interfaces for different users of these templates to meet their level of modelling expertise and priorities:** Architects wished for the number of inputs to be simpler, as the current example is “too overwhelming”; engineers wished for the templates to provide full control and transparency of assumptions, along with the ability to simplify the interface for the architect to ensure the interface is not “too point and press”. Thus a template workflow should be created which allows the engineer to quality assure the workflow for the specific building, ‘cover the hood’ and hand over a template which the architect can trust to provide reliable performance predictions, enabling them to focus upon what they are trained to do.

**The development of the user interface of the workflow structure to be educational for a non-simulation expert to understand the processes of building performance simulation** – The interface given to the architect from the engineer mentioned above should be visually appealing in order to communicate the value of building performance simulation and encourage continual use. Furthermore, it would help the architect in remembering the process if they had been disconnected in its use for a long period of time due to the scope of a project.

Other recommendations from the participants of this study go beyond tool development, focusing on means to address the external barriers on the design process such as: the level of expertise of the architect as designer; and the traditional ‘set in their ways’ attitude of the current market.
5.1. Education

A continuous underlining theme of this study has been lack of understanding, knowledge and value awareness by the industry and designers. The participants believed that an approach to overcoming the issues of expertise in modelling for quality assurance, and the Old School attitude of the market was to educate the ‘old’ and ‘new’ architects of the building industry. Thus, the study concludes the need for:

**Tertiary education of architects to integrate building performance sketching in their design processes:** The problem faced in this recommendation is that architects are currently already taught some form of building performance simulation in their education. However, it was clear from the participant recommendations that architect graduates should be taught the value of BPS to design. This would encourage the educational and the professional design studio to include building performance sketching in their routine assessment and dialogue in designing.

**The creation and sharing of publicly available resources for upskilling professionals within the field:** The barrier of expertise and knowledge of performance simulation prevents a willing architect from building performance sketching within their design studio. Thus, tutorial workshops, and online documentation should become more readily available to the industry to encourage designers to continue their professional development within the industry and implement better ways to inform their design decisions to designing high performance buildings.

5.2. Legislation and Standards

The participants in this study believe that the greatest driver to change is legislation. In referring to the category map diagram of Figure 2, the participants believed that legislation could demand the education of architects and more engineers. Furthermore, engineers believed that the priorities of the architects, and the time allocated to them by the client and/or project manager, would be changed if it were made mandatory to implement building performance sketching within the design process. Thus we conclude with the following recommendations if legislation were to be used as a driver as suggested by the participants:

**Legislation made through expertise:** Where it is made mandatory to performance sketch a building design, the quality assurance process of building performance sketching should be followed carefully and by an expert within the field.

5.3. Future Work

All participants believed that future work should focus upon developing the Distributed Model Method (DMM). The limitations of the scope of this study can be addressed by future academic studies which focus on the use of the DMM. Features which were unable to be tested due to the scope of this study are:

**The comparison between Honeybee/Grasshopper/Rhino vs. Dynamo/Revit** – At the time of this study, Dynamo/Revit was not at a state which could provide reliable coupling between the design tool and BPS tools without requiring some difficulty in translating model geometry. The comparison study may however provide grounds for a new research project investigating the interoperability between the DMM and central model method used in BIM. The participants of the study did ask regarding the interoperability between Rhino and Revit, “Taking just the building out of Revit, what’s that sort of step putting that into this, is that very hard?”, to which an example plug-in (Grevit, 2016) was briefly
described however this interoperability was not the subject of the research therefore was not demonstrated.

Validation testing of the translation of languages between programs in the DMM – e.g. the translation of geometry from Rhino to Grasshopper to Honeybee to the building performance simulation engine is coded and may contain a bug within the code. This issue was briefly raised by the engineers of the study in relation to the open source quality of the example Honeybee for the DMM. Due to the DMM process using VPL as a middleware program to translate from one program to the next, this program must be validated.

Focus groups exploring the views of the client to such a process of design – We note that it would be beneficial to hear the perspective of the ‘other side’ – the client – to understand their wants and wishes for visual communication and expectations of the use of such a process to design.

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Games technology and building performance analysis

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**Abstract:** Modern games technology has advanced rapidly in the past few years. This is true of both open source and commercial games engines, both of which provide an infrastructure for the real-time visualisation of complex geometry with dynamic lighting, shadowing and texture effects, together with support for sound, animation and responsive user interaction. Games engines are extremely flexible – just as capable of rendering flight simulations, battleship flotillas, urban car chases or the interiors of spaceships and dungeons – all whilst overlaying detailed user interface elements and dynamic contextual information. This paper describes the first stage of a research project that aims to utilise this new technology for better representation of building performance analysis information and concepts. The initial work of building the frameworks required for visualising and interacting with this kind of data is presented as well as how gamification concepts have been used in the development of some preliminary online educational tools used to demonstrate and test it.

**Keywords:** Games engine; gamification, visualisation; simulation; analysis.

1. Introduction

Gamification refers to the application of games design principles and techniques to other contexts that are not typically games-related. This definition is quite broad, but an important point is that it does not always mean turning something into a game. In many contexts it can simply mean exploiting game elements that stimulate engagement, motivation, playfulness and a sense of achievement. In the context of the research presented here, gamification is used to mean the creation of highly interactive application environments in which quantifiable performance goals and progress towards them are elevated to the forefront and the means of further progress or achievement are obvious from the controls and interactions made available to the user.

This research is in its formative stages as there is significant initial work required to develop even the most basic and experimental framework for visualising and interacting with building geometry and performance analysis data. The term ‘experimental framework’ is important here as there is no obvious blueprint for what this should be or how it should work. Popular games vary markedly in their visual interface design and the types of user interaction and manipulations they offer, even though they are
generally considered to be visually appealing and quick to learn (Chou, 2015). CAD, BIM and 3D modeling applications have more similarities in their visual interfaces and user interaction, but are typically more complex and have much steeper learning curves. Thus, developing ways to bridge these two paradigms is expected to be an iterative research exercise involving significant trial and error.

This paper outlines the rationale behind the first set of these iterations and introduces some educational tools that have been created to demonstrate and evaluate parts of this work. As such, it touches only on the first of what will be a three-phase research project. Only Phase 1 is currently being worked on. Phases 2 and 3 will commence when the infrastructure is sufficiently developed to support them.

The three phases of the overall project have the following aims:

1. To develop core frameworks and control elements that allow building geometry and analysis data to be visualised and interacted with from within a range of games engines and platforms,
2. To objectively assess the most effective and informative visualisation and interaction techniques for the many different types of building simulation and analysis data available, and
3. To develop more advanced frameworks for the gamification of common building performance analysis processes and their integration into architectural design workflows and best practices.

2. Approach

Recognising the iterative nature of the first phase, the approach taken has been to create a series of educational tools that can serve as both realistic short-term development goals and a means of investigating, demonstrating and assessing different aspects of the problem. The intention is that these tools gradually increase in complexity and scope, with the utility and robustness of the shared code base gradually accumulating with each one.

The first of these tools were used as a means of mastering the various technologies and techniques involved and to gain implementation experience. However, the most recent tools have begun to include more sophisticated visualisations, user interactions and some preliminary gamification techniques. Three of these tools are discussed here, each shown in Figure 1 – the first focusing on solar position, the second on the relationship between location and shadows and the third on room daylight distribution.

Figure 1: Screenshots from three of the educational tools developed as part of this research.
In addition to their role in the development process, the aim of these educational tools is to illustrate and demonstrate specific aspects of building performance analysis in a way that is engaging and that encourages deliberate investigative play. The game elements identified as being key to achieving this are highly interactive analysis models with dynamic visual feedback and low latency between user action and model reaction. This basically means being able to physically manipulate the main parameters that govern a model’s behavior and have the visual analysis update in as close to real time as possible.

3. Why games technology

There are a number of characteristics that make games technology interesting from an architectural science perspective. The primary one has to be dynamic interactivity. It is certainly possible to use 3D modelling or rendering applications to create pre-rendered images and animations that show building geometry overlaid with simulation and analysis data. However, it takes time to set up and render new images so the process of iterating, investigating and even changing direction as each visualisation feeds back new information into the design process can be very slow.

Educationally, reducing the duration between model change and analytical feedback can greatly assist the development of a more intuitive understanding of causal processes (Lowe and Schnotz, 2008) such as building performance. The ideal is obviously instantaneous feedback as the cause and effect relationships are immediately obvious. Not all physical processes can be viably simulated in real-time, but some can and games technology has the potential to wrap those into very useable and useful educational tools.

For those that can’t, games technology alone is no solution. However, providing tools to make exporting and re-exporting models to an environment in which they can be freely navigated or examined as the viewer desires is the first step. Providing simple and intuitive ways to select, control and compare different analysis results and how they are mapped over the model is perhaps a further step. The final step is devising insightful visualisations and animated data displays that can be navigated or examined just as freely as the model itself.

The following is a brief discussion of the features of games engines, how they contribute to dynamic interactivity and why they provide a proven base within which to take these steps.

3.1. Rendering speed

Games engines are typically engineered for very fast rendering of complex and often dynamic geometry at high frame rates. The primary reason for this is that most players prefer detailed and visually rich game environments that they can move freely around in without noticeable flicker. Also, they prefer actions and other characters within the game to be animated smoothly and realistically, again without noticeable flicker. Serious gamers will invest significant amounts in high quality hardware to achieve this and research has shown that this preference extends well beyond just gamers (Gonzales, 1996).

Compared to the complex dynamic environments of many modern games, the requirements for architectural and analytical visualisation are relatively modest. For architecture, this technology allows even highly detailed building models with extensive texturing and shading to be interactively rotated or navigated around very smoothly. It also allows for rich animation of camera views, building geometry and even overlays such as data points, analysis grids and volumetric information. This contrasts significantly with the focus in almost all CAD and BIM tools on static plan, section and elevation projections as well as stored camera views.
Research (Bederson, Boltman, 1999) suggests that interactive animation when navigating a 3D environment or spatial dataset helps users maintain their sense of positional constancy without having to rebuild their understanding of where things are after a view change or position shift. Even for two-dimensional data, work by Microsoft Research (Heer, Robertson, 2007) shows that animating between different chart projections or graphical representations allows users to more easily track both individual data values and the complex relationships that exist between different values.

When working with large spatial datasets that can also change over time, the ability to maintain positional constancy and track complex relationships as views, values and scales change is critical to being able to both assess and understand such datasets. The rendering speed of games engines enables this, as well as the potential to use a wide range of new and dynamic data visualisation techniques. The raw graphics power of modern GPUs makes viewing large volumetric data possible even on a tablet or phone. Easily swiping or transitioning between multiple result sets in the same view also becomes possible, which makes better use of the ability of the human visual system to readily spot areas of subtle difference or slight change.

3.2. User interaction

Graphically intense games typically involve complex user interaction. Responsive and realistic action and reaction with low latency is often the key to how challenging a game feels and how much perceived skill or experience a player must develop in order to master it. Whilst CAD and BIM tools also involve complex user interaction, it is entirely different in nature and primarily aimed at facilitating data entry and the creation or editing of model geometry.

The benefit of using a games engine over a CAD or BIM tool is that pretty well all user-generated events and gestures from a wide range of input devices can be customised to almost any purpose or requirement. This includes touch and motion events as well as head and eye movements from sensors within a VR headset or glasses. This opens up significant opportunity for more involved and immersive interaction with both models and data, as well as the design of user interfaces that are highly customised to very specific tasks or types of analysis.

In their joint thesis, Fagerholt and Lorentzon (2009) researched game user interface design and introduced terms for the different types of interaction components they encountered based on how they related to both the player and the game environment. Whilst very games-oriented in definition, their concept of diegetic and non-diegetic interaction elements is still a very useful characterisation for some of the user interface elements being developed as part of this work.

Diegetic interface elements refer to parts of the 3D model that can be interacted with and manipulated within 3D model-space coordinates. Non-diegetic refers to 2D elements overlaid on top of a 3D model that are interacted with and manipulated within flat screen-space coordinates.

Figure 2 shows some of the interactive interface elements of each type developed as part of this research. These developed from extensive internal testing with touch, mouse and stylus inputs over a range of platforms and screen sizes. Phase 2 of this research will involve a more formal objective assessment of their utility and intuitiveness within different simulation and analysis processes, however the aim at Phase 1 is to explore the technology and techniques required and gain important experience with their implementation.
3.3. Visual abstraction

The graphic styles of different games can vary quite markedly. Thus games engines need to be very flexible in both the types of geometry they can handle and how that geometry can be rendered. Whilst some CAD and BIM tools can be flexible in the types of geometry they can handle, they are often very inflexible in how it can be rendered and then included within the visible building model.

This flexibility in games engines comes mainly from providing direct access to the Graphics Processing Unit (GPU). This means being able to use custom low-level shader programs to control how individual objects within the scene will be rendered or to apply complex pre and post processing effects to the whole scene. This is not possible within CAD or BIM tools as they completely control the render process and the appearance of individual objects within a scene is governed entirely by the particular material parameters each tool provides.

The main benefit of custom shaders is that they allow for potentially unrealistic but useful visualization effects that might provide additional insight or understanding that a traditional photo-realistic render may not. The display of shadows is a particularly illustrative example of this.

3.3.1. Shaders and shadows

Most CAD and BIM tools can display the shadows cast by a building model and do a very good job of dealing with transparency and material effects. However, it is typically not possible to customize their shadow projections in any meaningful way; such as choosing a different colour, selecting specific surfaces to cast and/or receive shadows, or even differentiating the effects of only part of the geometry.

However, the flexibility of games engines allows for a whole range of potentially innovative shadow visualisations, such as:

- Using custom shaders that can display multiple shadow maps created from different parts of the model or even generated at different times of the day or days of the year,
- Using multiple shadow maps to identify which geometric object is shadowing each pixel in the rendered image and then colouring it to highlight the effects of individual shapes in the model,
- Selecting the shallowest shadow map value at each pixel, making it possible to very effectively isolate the full extent of shadows cast and/or received by a particular object,
- Selecting the deepest shadow map value instead to see only the additional shadow created by a particular object when compared to a given base condition,
- Separating the shadow generation process entirely from model rendering, allowing the use of more complete or even completely different geometry to be used to create the shadows which can then be mapped over just a subset or even a different representation of the model, and
- Using a remote server to generate a highly detailed shadow map using the full building model and its surroundings, and then downloading that to a mobile phone or tablet device for mapping over a much simpler building model.

Figure 3 shows some examples of the types of shadow visualisations that custom shaders allow. These shadow images do appear similar to those already available using Ecotect (Marsh, 2003), however differentiating shadows with different colours and on specific surfaces is only possible within Ecotect’s canvas-based ‘3D DESIGN’ tab, not in the OpenGL-based ‘VISUALISE’ tab. In this work, all shadows are generated in OpenGL and WebGL so the core technology involved and the potential for even greater innovation and control represents a significant extension.

Figure 3: Examples of custom shadow visualisations. The left image shows a traditional shadow projection whilst the middle shows isolated shadows from just the two highlighted towers. The image on the right shows the same isolated shadows for each hour of the day from 9am to 5pm.

3.3.2. Access to the GPU

The creative potential of custom shaders cannot be overstated. Even a cursory browse through a website such as ShaderToy (Beautypi, 2016) will reveal all sorts of fractals, fluid dynamics and noise functions feeding into procedural textures and even highly detailed programmatic geometries. The computational capabilities of modern GPUs means that a whole range of physical effects that were previously only available in high-end rendering tools can now be simulated in real-time. Also, shaders can be used to interpolate between multiple vertex attributes or even morph an object between different geometric forms, allowing for smooth transitional animations and streaming dynamic data.

Having direct access to the GPU also means potentially using tools such as CUDA and OpenCL to perform complex analytical calculations as well as rendering. As modern GPUs are massively parallel processors, there are many building performance calculations that could potentially be performed much faster or even in real time. This is not quite as easy in browser-based games engines as there is no access to CUDA or OpenCL, and the new WebCL standard is not yet widely supported. However there are still ways to achieve something similar by co-opting standard WebGL shaders and obtaining results by extracting them from rendered textures (Github Inc. 2016). This is the technique that was used in the real-time GPU-based daylight analysis tool presented here.
4. Gamification

To stimulate engagement and deliberate investigative play in these initial educational tools, the gamification elements concentrated on most have been the generation of highly responsive visual feedback and an attempt to make the metrics of each analysis as prominent as possible within the user interface.

4.1. Responsive visual feedback

The ideal of instantaneous feedback requires significant optimisation of every aspect of the modelling, analysis and rendering pipelines. As an example, just to dynamically move a window within a wall and update the spatial daylighting requires the following steps:

- Check that the window is not overlapping another or moving outside the wall boundary,
- Update the window position and then regenerate, re-tessellate and update the mesh geometry of the wall and its apertures on the GPU,
- Recalculate dimension lines then regenerate and update their meshes on the GPU,
- Compute new daylight values at each grid point then update the colour and position of each vertex of the grid mesh on the GPU,
- If contours are displayed, recalculate each contour line or band boundary and again regenerate, re-tessellate and update their meshes on the GPU,
- Compute the binned value of the histogram/cumulative value chart and update its SVG path, and
- Update any textual data values visible within the user interface that may have changed.

The primary optimisations over which an application developer has most control is the computation of daylight values over the grid and the calculation of contours and dimensions. Using a games engine makes the process of updating geometry meshes on the GPU relatively trivial and, depending on individual implementations, also their regeneration and re-tessellation. However, this can still involve a lot of data transfer between the CPU and GPU so is not without its own time cost.

To achieve a refresh rate of 30 frames per second requires that all of the above steps be completed in around 33 milliseconds. Depending on the computing power available on the device running the application, this can place restrictive limitations on the resolution of the analysis grid and the complexity of the dynamic model. To overcome this, there is growing potential to utilise multiple threads on the CPU and the large number of parallel processing units available on the GPU.

As one of the aims of these educational tools is to provide experience in the implementation of new technologies, a custom shader has been developed for the computation of daylight values across a spatial grid. In its current form, this is based on the BRE Split Flux Method (Hopkinson, Petherbridge and Longmore, 1966) with a rectangular-shaped room and any number of simple frameless apertures. Though a simplified method (Kota and Haberl, 2009), a detailed comparative analysis of results from Radiance on the same simple room models with the same window layouts will soon be published and shows high correlation. This means that the method accurately captures the relative variations in daylight level when the room size or window layout is changed.

The main point at this stage of the research is not the accuracy or otherwise of the particular algorithms implemented in each tool. It is that these kinds of algorithms are implementable and that visualisation frameworks can be developed to allow for real-time interaction with them. Future work or
work by others can refine these algorithms or implement newer more appropriate methods within the frameworks being developed.

4.1.1. Accurate numerical input

Another issue highlighted by this work is the importance of accurate numerical input. Analysis algorithms require accurate numerical data for their key parameters in order to get accurate results. Yet at the same time, gamification requires the ability to easily and dynamically manipulate parameter values as a way of quickly exploring relationships within a model. Usability testing showed that invoking the onscreen keyboard on many mobile devices in order to enter a numeric value was disruptive to investigative play and that dragging a slider made accurate data entry too difficult, especially in a touch-based environment and for parameters that have a wide potential value range but which may be sensitive to changes within multiple decimal places.

The adopted solution has been to create a standard numerical input block that includes increment/decrement buttons, a formatted edit box and a customised dynamic slider, as shown in Figure 4. Large comparative changes can be done using the slider whilst exact known values can be entered using the edit box and system keyboard. The buttons allow for the value to be more slowly and deliberately changed in known increments. The slider needed customisation to significantly widen its track area as, in a number of browsers, the standard HTML5 range input slider track is quite small which touch-based control difficult.

![Figure 4: Examples of the standard numerical input block developed to allow both interactive manipulation and accurate input of numeric parameter values.](image)

4.2. Quantifiable performance goals

The solar position and location/shadow tools focused primarily on fast visual feedback whereas the daylight analysis tool provided the opportunity to prominently display statistical information derived from the calculated spatial dataset.

There are many metrics for quantifying daylight availability (Kota and Haberl, 2009). The Split Flux Method calculates the daylight factor, given as a percentage of the total natural light available from an unobstructed overcast sky that reaches points on a work plane within a room. This is a relatively simple metric, but it provides a useful relative measure of the effect of the room design and layout without requiring detailed location-specific weather data.

The main aim in designing for daylight is to maximize daylight values in those areas of the room that require lighting, with the typical tradeoffs against aperture size, construction and layout restrictions. Thus, the key metric is the actual spatial distribution of daylight levels across the workplane. Secondary metrics are the maximum, minimum and average values, as well as the percentage of the total area above or below different values.
To display this information, a two dimensional grid of calculation points is arrayed at a configurable height above the floor to represent the work plane. Values are colour mapped across this grid and contours lines and bands can be superimposed. In addition, a histogram chart displaying the percentage area of the grid within each contour band is displayed immediately adjacent to the main legend, as shown in Figure 5. It is also possible to switch this to a cumulative distribution chart.

4.2.1. Daylight design target

In some cases, a daylight design requirement involves the specification of a minimum percentage of the work plane area that must be at or above a given daylight factor. This information can be derived from both the histogram and the cumulative distribution, but it is more effective if it can be directly visualised within the model.

To do this, a daylight design goal can be set which causes a percentage area marker to be displayed within the histogram chart and the exact area of the work plane at or above the target value shown as a contour within the context of the model. Figure 5 shows an example of this. The target value can be interactively manipulated using either the numeric input block in the popover or by dragging the percentage area marker in the histogram chart.

![Figure 5: The display of dynamic statistical information about the daylight distribution and, on the right, showing the percentage of the work plane area at or above a target daylight value.](image)

5. Next steps

The first phase of this research is now well underway with most of the core framework in place and functional implementations in Java, JavaScript, C# and C++ to support multiple games engines. Generators for a range of charts and graphs have been developed that can be fed data from the output files of several different analysis tools, as well as a set of interactive manipulators and user interface elements for controlling and interacting with them. Now that the solar geometry and spatial analysis components have been developed, the next set of educational tools will explore the visualisation and quantification of temporal overshadowing and solar availability.

One of the most challenging parts in the development of the next set of tools has been obtaining user-generated building geometry in a form suitable for visualisation and technical illustration styles that require both surface facet and outline edge information. Whilst it is relatively simple to obtain detailed triangulated geometry from a CAD or BIM model, accurately determining the boundary outline of each planar facet is often much more difficult.
An initial solution has been to develop a native export plugin for Revit and code for parsing gbXML files as these allow the one process to extract triangulated mesh as well as surface facets and edge data. The next step is to include Industry Foundation Classes (IFC), which are currently handled by storing them in a BIMserver (BIMserver.org, 2016) database and then using a Render Engine plugin to produce the required geometric data. These three sources are critical as they also allow for the extraction of analytical models with more detailed spatial, zonal and material data which can be used to drive many of the external building analysis tools that generate building performance data.

In addition to the dynamic interactivity that games engines allow, direct access to the model rendering process has been the most compelling feature of this technology. The ability to write custom shaders has already allowed this research to generate a range of analysis, visualisations and non-photorealistic technical illustration techniques that would not have been possible without it.

This now forms the basis for the next phase in which these visualisations and techniques are objectively assessed.

References


Abstract: Architectural science aims to understand the complex relationships of architectural systems to their environment. Environmental scientists can infer a species’s ability to adapt to different environments through a knowledge of the species and detailed data about its environment. Developmental biologists can then untangle how the organism developed from its DNA genotype to its adult phenotype. Furthermore, researchers in evolutionary development can tell us how the species evolved to support its self in that environment. Revisiting these terms in the face of radically changing architectural design and practice is necessary to evaluate their appropriate use in current digital workflows and their potential impact on the source theory in the domain of biology. Morphogenetic prototyping (MP) positions the evolutionary development of biological systems as an analogue to understand complex hierarchical systems in architecture and their relationship to their environment. In this way MP provides a framework for us to understand the implications of architecture’s adaptation throughout its historical development, framed in its vernacular context. This paper proposes a multi-directional methodology for the phenotypic and genotypic description of the A3 Adelaide house to support morphogenetic prototyping of environmentally homeostatic architecture at a genotypic level.

Keywords: Morphogenetic prototyping; Typology; Architectural phenotype; Architectural genotype

1. Introduction

Architectural science reveals the complex inter-related systems that make up architectural designs and their relationship to their environmental context. In parallel, Biologists seek to understand the systems of the natural world. The generated understanding can then be represented as rules and knowledge that can be used to provide a greater global understanding of our natural world. It would therefore seem attractive to incorporate theory from these domains into architectural discourse to better understand architecture as a system strongly related to its environments. However, the process of appropriating external theory into architecture is fraught with challenges. Ostwald (1999) defines three methods (Figure
by which architecture appropriates external theory in order to construct ‘architectural theory’. These include ‘uni-directional’ appropriation; where the theory is taken from the source discipline and then appropriated in architecture. The main challenge with this approach is that the source theory ‘loses its original meaning in the process of translation and translocation’ (Ostwald, 1999). At the same time the appropriator dangerously believes that the original theory is ‘pure’ and ‘untainted by contact from other disciplines’ (Ostwald, 1999). Another concern is that even if the meaning is preserved, the source concept could change or be disproved in the future with new research in the source discipline. Biomimetics (Menges, 2012) (Gebeshuber, Gruber, and Drack, 2009) (J. Vincent, 2014) provide an example of the typical focus of taking ideas from biological systems and integrating these solutions in architecture.

As Pedersen Zari (2010) discusses in depth, biomimicry on an ecosystem level provides a fertile opportunity to mitigate climate change through the adaptation of the built environment. It is therefore essential that we find ways to appropriate these ideas without the limitations of uni-directional appropriation. Alternatively, hybrid appropriation creates a new hybrid theory from both the original source and architectural theory. The challenge with this approach is that the hybrid theory loses its connection to its original discipline. Ostwald describes a third multi-directional appropriation in Figure 1 which is a hybrid product of architectural theory on either an already hybridized theory or an ‘impure’ source theory. Ostwald defines this as ‘multi’ directional because the cycle of hybridizing hybrid theory can continue as described by the arrow connecting the hybrid and multi-directional in Figure 1. There are several motivations for researchers to appropriate theory from other disciplines. These cover the negative; a need to legitimize the research or confuse the observer in order to create ‘mystique’ (Ostwald, 1999). As well as the positive; helping to explain and transmit knowledge. Our research aims to extend these positive motivations in both directions to construct an interdisciplinary bridge to support the transmittance of knowledge in architecture through a biological lens and vice versa. However, uni-directional appropriation is common in architectural theory. This is a limitation of current thinking, as it brings about a solutions rather than systems integration focus (McGinley, Fotia, and Abroe, 2015). We need to focus on system models more than biomimicry of the mechanisms and features of the final phenotype. We need system models from other disciplines that we can apply in architecture (Azizkhani, 2015) (Zavoleas, 2015).

Figure 1: Ostwald’s three classifications for theory appropriation in architecture (diagram by authors)
The challenge is therefore to construct a hybrid theory that contains concepts appropriated from other disciplines that can support architectural science and embrace the nuances of architecture without losing the connection with the core conceptual components of its scientific source theory. To address this challenge, an alternative to Ostwald’s definitions for architectural theory appropriation is described in Figure 2 as a ‘multi-dimensional’ appropriation. The aim is that the translated theory would be useful in both the source and appropriating discipline. Whilst some loss of meaning in interpretation is unavoidable, the multi-dimensional approach aims to minimise it. This is achieved by breaking the theory down into components that can be fed back into the source discipline and ‘refreshed’ to reduce the loss of meaning and potential feedback and replication of interpretation errors in architectural discourse. To achieve this, the first step is to be explicit about what concepts we are appropriating.

5. Phenotype and Genotype

The phenotype and genotype have been previously discussed in architecture through the lens of genetic algorithms (Maher and Poon, 1994) (Damsky and Gero, 1997). This paper seeks to revisit these terms in their source discipline. In biology a phenotype describes an organism’s observable traits that can be measured. These observable traits are the result of genotypic expression. In this way the traits that we can observe in an animal or plant can be thought of as the result of the expression of genes. Before biologists could sequence (read) an organism’s genotype directly they had to infer the expression of genes by making comparisons of similar phenotypes. Developmental biology knowledge has itself grown from being able to make phenotypic observations through comparative biology combined with an understanding of the role of genes in the development of the organism. In comparison to architecture, the challenge is that we are still in the process of identifying and comparing (pheno)types and have not yet progressed to a genotypic analysis. Traditionally in biology the relationship between these concepts is expressed as:

\[ \text{genotype} + \text{environment} \rightarrow \text{phenotype} \]

Therefore, if we know the phenotype (presuming that we take this to be an architectural typology) and we imagine that we could encode the influence of the environment, the bit left over must be the genotype. So the equation above could be rearranged as:

\[ \text{Architectural (pheno)type} - \text{environment} \rightarrow \text{(Architectural) genotype} \]

So what is a multi-dimensional theory appropriation methodology for architecture and design? We introduce one here called Morphogenetic Prototyping (McGinley, Hoshi, and Iacopetta, 2015). We first seek to present an agreed definition of architectural typology, which when hybridized with the biological concept of phenotype results in the definition of an architectural phenotype. With a fixed (pheno)type and environment established, it should then be possible to ‘reverse engineer’ the architectural genotype.
3. Morphogenetic Prototyping

Architectural science requires that architecture is possible to analyze from a variety of perspectives. Much contemporary architectural modelling effort requires the explicit definition of each unique element in the building. As such, contemporary architecture is largely drawn component by component i.e. wall by wall rather than space by space for instance. At the same time, despite our large combined collective experience as architects, we find ourselves ‘starting from scratch’ with each project. In developmental biology the distinction between the phenotype and the genotype is well suited to the scientific method as it enables scientists to ‘knock out’ or ‘knock in’ specific genes and observe their effect on the development of the organism. An alternative approach for architecture would be to start with a rough typological sketch. Which in a way is what experienced designers have as tacit knowledge in their heads.

In the unidirectional theory of Morphogenetic Engineering (ME) (Rene Doursat et al., 2012), engineered objects are conceptualized as if they had developed like organisms. Morphogenetic Prototyping (McGinley, Hoshi, et al., 2015), extends the uni-directional ME theory with architecture to form a hybrid theory. In this paper we propose to further extend Morphogenetic Prototyping into a multi-dimensional theory that supports transferable explicit and transferable concepts to provide shared understanding (Saad and Maher, 1996). These will include the hierarchies and levels of detail (LOD) of contemporary architecture through building information modelling (BIM) as analogous to the concept of stages of developmental biology (McGinley, 2015). This supports the appropriation of the phenotype and genotype concepts with architectural typologies into a multi-dimensional architectural theory. This paper aims to achieve a reconceptualization of architectural typology through the scientific concepts of phenotype and genotype to illustrate an alternative approach to theory appropriation in architecture. This invokes the conundrum that typology could be useful to support decision making and modelling in the design process if only, we knew: (1) the ideal or normal for that typology; (2) the other potential solutions; (3) the success of previous solutions and (4) how to present this to the designer in a non-confusing way.

4. Architectural typology

So what is ‘type’ in reference to architecture? Even within the architectural community no consensus has been reached in answer to this question. Robinson (1994, p. 178) notes that in architecture ‘type is often used as if there were only one way to categorize buildings’. According to Newton (1991), Bannister Fletcher saw architecture as ‘an almost Naturalistic phenomenon’ (1991, p. 49) influenced by late nineteenth century science, with three classes of type arising: building types resulting from social activities; formal types resulting from plan; and constructional types resulting from constructional method. Australian architectural historian Phillip Goad defines type as a ‘universally accepted building form drawn from history and merged into a timeless canon, supported by the fiction of a morphological perfection attributed to each ‘species’ of building’ (1988, p. 56). However Argan, (1996, p. 244) states that type is tied to both a building’s configuration and its functions. Architects make use of known types in their designs because they are tried and tested. Crowe (1984) notes that cultural traditions are transmitted through forms which are strong enough to take precedence over an individual architect’s self-expression. That said, if architectural types are not changed in any way they risk becoming redundant and typological thinking can become a barrier to problem solving rather than a stimulus to it (Symes, 1994, p. 189).

The architect’s role is seen as one of performing operations on existing typologies according to Francescato (1994, p. 260). These operations may accept the type, diverge from it or generate a new type. If buildings are culture and place specific then, when the culture changes, the buildings should change as
well, either by demolition, adaptation or the changing of the dominant meaning the culture attaches to that particular physical form. The challenge with the architectural typology concept is that it is stored in the material architecture. Whilst this provides a good way to maintain architectural typologies and support the vernacular, it makes our challenge to identify an appropriate response to the contemporary conditions more challenging. A solution would be a rigorous global typological taxonomy for architectural ‘species’. These species could be thought of as composed of basic genotypes that could respond to environmental conditions. These would provide conceptual ‘building blocks’ for architecture. The following section seeks to identify complex and nuanced typological models to support the scientific study of architecture and provide opportunities to develop a clearer understanding of architectural typology.

6. Architectural phenotype

We have seen in the previous section that in biology the phenotype is the measurable result of genotypic expression within a specific environment. Maher and Poon (1994) describe the phenotype as both a living organism and biological system but also suggest in their investigation of the use of genetic algorithms in architecture that it could be thought of as a ‘design solution for a design system’. We previously rearranged the equation to reflect that in architecture we know the environment and the phenotype at least for single instances, therefore we are searching for the genotype. Whilst this initially does not seem to be very helpful, we know that this is similar to early genetic research in biology. Therefore, robust phenotypic and environmental models could help us identify architectural genotypes. The previous section on architectural typology demonstrated that there are many ways to measure and define types: building, formal and constructional types. It seems from these that building type categorized by social activity is the most relevant to our research here. It is also important therefore to remove ourselves from the idea of an ideal type, as a real architectural phenotype is not complete without its environment. In that sense the architectural phenotype must be more than a specific instance, it must be a container that could potentially house the appropriate social activities required of it in a specific environment.

Architects must acknowledge the changing nature of society and its demands. Therefore, architectural (pheno)types are only useful as long as they evolve with society. Architectural type may present problems however, including that of being contextually neutral. Type can ignore cultural, geographical, climatic and individual’s needs by becoming standardised (Franck, 1994, p. 352), for example, a design for a house may be repeated irrespective of place, culture, climate or inhabitant’s needs. This is not to say that the standardized (pheno)type does not have genes. It is that the phenotype does not have the plasticity to adapt to context. Maybe the plasticity in this sense is the skill of the designer. In biology, phenotypic classification is made from empirical observations by comparing organisms’ physical appearance to each other using phylogenetic trees. PhyloXML (Zmasek, 2016) provides a common schema for describing species and their relationships to each other, it would be possible to adapt or extend it for use in architecture. The following text describes a South Australia Type A3 (Johnson, 1983) in the PhyloXML format. It demonstrates that it should be possible for the architectural implementation of PhyloXML to be extended as required to support the representation of architectural phenotypes.
Implementation of this schema in architecture would require that we identify the phylogenetic clade (branch) of architecture that the architectural phenotype belongs to. Having constructed this *phylogenetic tree* it would then be theoretically possible to identify the ‘design genes’ (Gero and Kazakov, 1998) as architectural genotypes. From an evolutionary perspective successful developmental processes are referred to as ‘conserved’ processes. It would then be possible to identify where a particular conserved process originated from. From an Adelaide house perspective that moves the attention from the walls and floors to the social activities. Focusing on the *why* not the *what*.

From a BIM perspective the architectural model can be viewed as a hierarchy. This hierarchy branches out from the elemental building node, to different floor definitions, spaces and material elements within the building. Much contemporary modelling effort requires the explicit definition of each unique element in the design process. Whereas visual programming tools for architects such as Grasshopper and Dynamo point to more dynamic approaches to control architecture; they do not provide a metaphor to help us to interpret, manipulate and control the design of architecture. We therefore require a metaphor to support the standardised abstract system of systems representation of architecture. This would allow us to make use of historical typologically relevant post occupancy evaluation data in new or adaptive reuse projects for instance. In biology this happens by mutation of genes and creating multiple copies of genes, to adopt differing functions and have redundancy inbuilt to the system.

As an example, Figure 3 describes a phenotypic comparison of the fruitfly (Drosophila Melanogaster) and the typical Adelaide house. The translation of the drosophila body plan to the Adelaide house involves an expansion of the thorax and head (sensing) organs and a reduction of the abdomen. The design genes that could be extracted from this include those which influence both the morphological and behavioural characteristics of the phenotype, or in architectural parlance - form and function, or, spatial and social. The purpose of such phenotypic mappings is to enable the inference of genes for architecture typologies from comparable biological systems.

*Figure 3: Drosohila Melanogaster mapped to a typical Adelaide cottage (McGinley, Fotia, et al., 2015)*
7. Environment

In Australia, using AURIN (Australian Urban Research Infrastructure Network) map (NCRIS, 2016), it is possible to see recorded sightings for many biological species. When these geo-referenced sightings are referenced to the seasons and the available resources and environment, it is possible to understand why they are where they are and how to conserve them in the future. The taxonomic organisation of nature supports this type of conservation and analysis. This is typically described in Phylogenetic trees. Phylogenetic trees describe a gene, species or trait. Traditionally, they were developed based on the morphological (phenotypic) characteristics of species, much like architecture is classified today. We previously posited that it may be possible to identify the genotypes of architecture by establishing an architectural phenotype and then subtracting the environment from it. The form of the phenotype was discussed in the previous section however it is unclear what the environment would be in this case and how it would best be represented and responded to by the phenotype. An architectural (pheno)type database like the bimimetic ontology proposed by Vincent (2014) might be the appropriate. This could make use of environmental data sets that might be relevant to architecture. Most approaches to applying biological knowledge in architecture do not focus on addressing a phenotypic and genotypic classification system. A potential exception is Foreign Office Architects book Phylogenesis (Foreign Office Architects, 2003) which charts FOA’s projects as a phylogenetic tree. However we have not seen this approach taken for an architectural (pheno)type. This is therefore an area for future investigation.

8. Architectural genotype

‘The [architectural] types that are physically created support and promote the values, social relationships, and patterns of activities that are dominant in that society at that time’ (Franck, 1994, p. 345). Hence it is only when the dominant values of a society change that the types of buildings can change. It therefore matters where the genotype is stored. Is it cultural, inside the user, the environment, the designer or encapsulated in our common understanding of the architectural typology as a conveyer of cultural values? Hillier (2007) presents the idea of architectural genotypes as an underlying spatial logic of architecture. In this sense the phenotype is the material architecture. In biology the phenotype is the result of the genotype and epigenetic and non-inherited environmental factors. The biological phenotype’s evolutionary response is imprinted in the organism’s DNA genotype. In addition, the organism’s ‘phenotypic plasticity’ - or ability to adapt to its environment during its development – would need to be accommodated in a genotypical description of architectural typologies. From an architectural perspective, Gero and Kazakov (1998) presented the idea of ‘design genes’ which they proposed could be used to inform spatial organisation. Architectural genotypes could provide a wholly new way of looking at architecture. Causing the questioning of what we consider to be the base unit of architecture. In contemporary digital modelling it is typically the wall, floor or some other material container of space. BIM can extend this to the level of rooms, to provide a hierarchical model of the phenotype, which is equally exceptionally well supported in space syntax. However, is there an alternative fundamental unit of architecture that we could use to retain control of architecture as the environment it sits in become increasingly complex?
9. Discussion

The idea that an architectural phenotype would contain the ‘ghosts’ of every instance of an architectural typology, requires that we develop less rigid models of that typology. These new quantum ‘ghost’ typologies require a different way of considering the base units of architecture. One way to resolve this is to think of an architectural site as being filled with equally spaced virtual agents that have not yet decided if they are outside or inside. These agents will contain the appropriate number of genes to define the architectural typology, but some of these will turned on and some will be off. So how would this resolve itself in architecture? The floating agents would start to absorb the environmental information and express their architectural genotypes in response to those environmental stimuli. The blurred boundaries between different typologies in this concept are described as a pseudo phenotypic plasticity, which as a preprogrammed part of the genotypic description defines the constraints to the expression of particular elements of the phenotype. These agents would, through a series of ‘building development stages’, rationalize into a recognizable building. Figure 4 shows a representation of what this might look like in the early stages as applied to a type A3 South Australian House. Through the construction of a representation that inscribes the different building development stages of the vernacular historical architectural (pheno)types, Morphogenetic Prototyping allows us to speculate on the future development of the typology based on computational evolutionary processes. When the exploration of appropriate representations is complete and we have identified the genotype for our existing architectural typologies, we can explore the potentials and limitations in relation to climate change for instance and suggest future architectural phenotypes that better represent the future we want for ourselves and our children: one that reflects social, cultural and environmental sustainability. We will investigate this potential in future work by analyzing the existing archives of south Australian house plans to identify both the evolution and development of architectural phenotypes and the genotypes that control them.

10. Conclusion

The concepts of phenotypes and genotypes in architecture have been uni-directionally appropriated into architecture previously. This paper states that uni-directional theory appropriation limits the transdisciplinary utilization of concepts by breaking the link to the source discipline. In response to this concern, this paper offers an approach to establish a bi-directional multi-dimensional relationship of genotype and phenotype in architecture. relationships to each other. We suggest to revisit those terms in the context of the MP framework to explore the use of the Hybrid Concepts (as presented in Table 1) in current design and practice and how they can refer back to the source theory.
### Table 1: Overview of the concepts in the multi-dimensional theory appropriation framework

<table>
<thead>
<tr>
<th>Biological concepts</th>
<th>Hybrid Concepts</th>
<th>Architectural Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenotypic Plasticity</td>
<td>Architectural Phenotypic Plasticity</td>
<td>Limits of adaptation to environmental conditions</td>
</tr>
<tr>
<td>Phenotype</td>
<td>Architectural Phenotype</td>
<td>Architectural Typology</td>
</tr>
<tr>
<td>Genotype</td>
<td>Architectural Genotype</td>
<td>Architectural Typology</td>
</tr>
<tr>
<td>Biological Development stages</td>
<td>Building Development Stages (McGinley, 2015)</td>
<td>Hierarchy (BIM Level of Detail) (McGinley, 2015)</td>
</tr>
<tr>
<td>Evolution / Phylogenetic trees</td>
<td>Extended architectural phenotype</td>
<td>Architectural history</td>
</tr>
</tbody>
</table>

Table 1 provides an overview of the concepts introduced in this paper and their multidimensional. To this end, this paper proposes several novel perspectives:

- firstly that of viewing evolutionary development as a kind of architectural typological history
- and secondly of tracing this development using architectural (pheno)types to provide a new way to describe architectural typological vernacular development as a phenotypic product of architectural genotypes.

We propose a strategic investigation into the evolution (history) of vernacular typologies to extract knowledge about the reaction to local conditions. This can also help us to understand the development of these typologies and their phenotypic plasticity in response to the changes we face such as architecture’s adaptation to climate change. Future work in this area offers many benefits to the field of architectural science including:

- Clarifying the important role of the vernacular and our environment in the future of architecture;
- Offering an alternative base unit of architecture to aid in analysis and design;
- Interrogation of architectural typologies at a genotypic level;
- Establishment of new research pathways in architecture with external disciplines.

The presented research represents a step towards understanding the genetic dynamics of architectural design and opens up possibilities to transcend knowledge about biological systems inside the architectural discourse through the direct link with biological theory through a multi-dimensional approach. In future work, starting with the A3 house, we propose the development of a searchable typological database for architecture that researchers and designers can use to understand the evolutionary development of architectural typologies and design their futures in adaptation and homeostasis to our changing climate and environment.

### References


Overheating risk in the Australian Nationwide House Energy Rating Scheme: A case study of Adelaide

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Abstract: Heatwaves are Australia’s most deadly natural hazard and the principle driver of peak electricity demand in South Australia. The disproportionately high peak demand increases electricity prices, causes occasional blackouts and exacerbates energy poverty, all of which limit the use of air-conditioning. Meanwhile, the desire for more energy efficient homes may decrease their heat stress resistance. This paper challenges whether the current Australian Nationwide Energy Rating Scheme encourages heat stress resistance.

Cooling consumption, peak demand and the risk of indoor overheating were assessed for a typical single-storey home in Adelaide. Design scenarios between 6 and 8 stars, plus two additional, traditional building structures were simulated with the AccuRate building thermal simulation program. A new overheating analysis is proposed based on the combination of the Excess Heat Factor and the Adaptive Comfort Model. Although the uninsulated, double brick scenario required significantly more heating, that configuration also outperformed many scenarios with higher star ratings during summer. A higher star rating did not necessarily coincide with a decrease in cooling consumption, demand and overheating. Consequently, the integration of heat stress resistance in the Nationwide Energy Rating Scheme would be advantageous to avoid building new homes with potentially lower coping capacity and increased dependence on air-conditioning.

Keywords: Housing; energy rating scheme; indoor overheating; heat stress

1. Introduction to heat stress resistant buildings

Heatwaves are not just the most dangerous natural hazard to health in Australia (Coates et al., 2014) but they are also responsible for the annual peak electricity demand in cooling-focused regions (Santamouris et al., 2015). Peak electricity demand increases the risk of power outages, depriving the population of air-conditioning (AC) (Maller and Strengers, 2011). Higher and more frequent peaks drive increases in
electricity prices (Saman et al., 2013) and that aggravates energy poverty. Energy poverty refers to the ‘situation of low-income households paying more than 10 per cent of their disposable income to meet energy costs’ (Chester and Morris, 2011, p.443). Meanwhile, more than one third of deaths between 1956 and 2010 in Australia recorded as heat-related occurred indoors. This proportion has been rising since the 1850s (Coates et al., 2014), showing the importance of the indoor environment.

Consequently, more attention has recently been paid to heat stress resistant buildings to minimise indoor overheating and heat-related health problems (Dengel and Swainson, 2012). This is particularly so, since climate change will decrease heating and increase cooling consumption and the risk of indoor overheating (Karimpour et al., 2015; Mavrogianni et al., 2015). In general, energy efficient retrofitting can decrease the overheating risk (Alam et al., 2016) particularly in very inefficient homes. However, energy efficiency can also interfere with heat stress resistance (Zuo et al., 2014). For example, high levels of insulation and air-tightness can foster overheating in summer (Ren et al., 2014; Dengel and Swainson, 2012) without a comprehensive design leading to both energy efficiency and heat stress resistance. Heat stress resistant features include shading (Porritt et al., 2013), more reflective roof colour (Cotana et al., 2014), reflective foil in the roof cavity (Saman et al., 2013), slab-on-ground compared to elevated structures in warmer climates (Lapisa et al., 2013), ceramic floor covering (Karimpour et al., 2015), orientation (Porritt et al., 2013) and increased natural ventilation (Daniel et al., 2015).

The first energy efficiency measure, the Nationwide House Energy rating Scheme (NatHERS) was introduced in the Australian Building Codes, now called National Construction Codes (NCC), in 2003 (Australian Building Codes Board, 2016). The NatHERS classifies buildings with stars from 0 to 10, based on the predicted annual energy consumption. The minimum requirements for new buildings have been raised gradually to six stars by 2010. As research has shown that energy efficiency with inappropriate design can decrease heat stress resistance (Porritt et al., 2013; Dengel and Swainson, 2012), NatHERS can be potentially counterproductive to heat stress resistance. Further research should be undertaken to understand the impact of NatHERS on heat stress resistance in the Australian climate considering Australian building construction practices.

It has to be acknowledged that overheating is mostly under regulated worldwide (Mulville and Stravoravdis, 2016). Considering countries of the European Union, Sweden does not regulate overheating, while many countries have only recommendations, such as the UK and the Republic of Ireland (Kontonasiou et al., 2015). Where overheating is regulated, indoor temperatures are limited (Brussel, Denmark and France), or maximum solar gain (Germany, Poland) or the maximum differences between indoor and outdoor temperatures in summer (Hungary) have to be meet (Kontonasiou et al., 2015). No example was found where a building is rated according to not just its energy efficiency but also its heat stress resistance.

Based on the research gap identified, this paper aims to (1) evaluate whether the NatHERS encourages heat stress resistance in new residential buildings (2) and compare their resilience with traditional construction methods in Adelaide. Adelaide, with a population of near 1.3 million (Australian Bureau of Statistics, 2015) is the capital city of South Australia (SA). Adelaide has had heatwaves with the highest intensities (Nairn and Fawcett, 2013) and the highest normalised heat-related mortality within Australia since the middle of the 19th century (Coates et al., 2014). The Adelaide metropolitan region was selected for the data analysis, as a city suffering from regular, severe heatwaves.
2. Analysis method of different design scenarios

A second generation NatHERS energy simulation software, called AccuRate, was used for performance compliance analysis. A limitation of AccuRate is that the typical meteorological year (TMY), which mostly excludes weather extremes such as heatwaves, is applied. An especially hot period of time was selected for analysis, nevertheless, which is included in the TMY file for Adelaide in the middle of February.

2.1. Design scenarios

A typical single-storey home with floor area of 211 m² has been modelled by AccuRate, in free-running mode, to assess the building performance during summer without AC. The building design chosen was adopted from an earlier report (Saman et al., 2013). Investigating the existing residential building stock in Adelaide, the most frequent wall structure material is brick veneer, followed by double brick (Australian Bureau of Statistics, 2008). This ratio of wall structure types is the result of a shift from double brick (also called cavity brick walls) to brick veneer walls in the late 1970s (Pullen, 2007), resulting in the loss of thermal mass. The loss of thermal mass in walls was, nevertheless, compensated to some extent by the longitudinally rising popularity of slab-on-ground structures used in brick-veneer homes. More than 90% of the residents own AC (Australian Bureau of Statistics, 2014). Double glazed windows are still rarely used and the average level of energy efficiency is low in the existing building stock.

As the long-term, aspiration is a gradual increase of energy efficiency in the NatHERS, a shift is expected in new residential buildings to 7 stars in the next decade. Within this study, 6 design scenarios between 6 and 8 stars were created, with extremely cooling and heating-dominant scenarios under each star rating. Two additional scenarios were included to reflect the traditional, uninsulated double brick and brick veneer construction types. These scenarios and the configuration of design features are listed in Table 1.

<table>
<thead>
<tr>
<th>Design features</th>
<th>2.6 stars (double brick)</th>
<th>2.6 stars (brick veneer)</th>
<th>6.2 stars cooling-dominant</th>
<th>6.2 stars heating-dominant</th>
<th>7.1 stars heating-dominant</th>
<th>7.2 stars cooling-dominant</th>
<th>8.0 stars cooling-dominant</th>
<th>8.0 stars heating-dominant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof colour, material (total solar absorptance)</td>
<td>light metal (0.30)</td>
<td>light metal (0.30)</td>
<td>dark, concrete tiles (0.75)</td>
<td>white, concrete tiles (0.25)</td>
<td>white, concrete tiles (0.25)</td>
<td>dark metal (0.75)</td>
<td>dark metal (0.75)</td>
<td>white, concrete tiles (0.25)</td>
</tr>
<tr>
<td>Foil in roof</td>
<td>NIL</td>
<td>NIL</td>
<td>NIL</td>
<td>yes</td>
<td>yes</td>
<td>NIL</td>
<td>NIL</td>
<td>yes</td>
</tr>
<tr>
<td>Roof insulation</td>
<td>NIL</td>
<td>NIL</td>
<td>NIL</td>
<td>NIL</td>
<td>NIL</td>
<td>NIL</td>
<td>R2</td>
<td>R2</td>
</tr>
<tr>
<td>Ceiling insulation</td>
<td>NIL</td>
<td>NIL</td>
<td>R4.0</td>
<td>R4.0</td>
<td>R4.0</td>
<td>R4.0</td>
<td>R4.0</td>
<td>R4.0</td>
</tr>
<tr>
<td>External wall</td>
<td>double brick with cavity</td>
<td>brick veneer</td>
<td>brick veneer, R2.5</td>
<td>brick veneer, R2.5</td>
<td>brick veneer, R2.5</td>
<td>brick veneer, R2.5</td>
<td>brick veneer, R3.5</td>
<td>reverse brick veneer, R3.5</td>
</tr>
<tr>
<td>Foil in wall</td>
<td>NIL</td>
<td>NIL</td>
<td>NIL</td>
<td>NIL</td>
<td>NIL</td>
<td>NIL</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>
2.2. Heat stress resistance analysis of the scenarios

To evaluate overheating risk three approaches were applied. Firstly, the annual cooling energy consumption of each scenario was calculated and graphed against the energy star rating. Secondly, the procedure was repeated for the peak cooling demand. AccuRate calculates the hourly peak load demand, however, predicated on the assumption that the capacity of the cooling system is infinite. Consequently, the peak demand was calculated from the three-hourly running mean, which is more representative of the capacity of a real cooling system (Saman et al., 2013). Thirdly, the numbers of hours with discomfort were assessed. To evaluate the overheating risk, a north-facing bedroom was selected since beyond its poor orientation, overheating risk in a bedroom can be particularly dangerous, because of both the lower temperatures required for sleeping and the deprivation from sleep due to thermal discomfort.

Note that several static and adaptive overheating thresholds exist and are used in different jurisdictions at the time of writing. All thresholds have been developed based on perceived comfort instead of the corresponding health implications (Dengel and Swainson, 2012). Two approaches exist to determine overheating, namely the static and the adaptive thresholds. The traditional static thermostat set point stipulates one threshold for cooling and heating each. Although the static threshold is simpler to use, they have been widely criticised in case of free-running and mixed-mode ventilated buildings, for neglecting adaptation and acclimatisation (Nicol et al., 2012). In contrast to the static thresholds, an adaptive set point changes with the outdoor temperatures, based on the adaptive comfort model (ACM). ACM has been validated globally and implemented in the standard of the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE), (ASHRAE, 2010). The ACM was, furthermore, validated for residential mixed-mode ventilated buildings in Australia (Saman et al., 2013). This paper adopted both static and adaptive overheating thresholds. The AccuRate AC set point of 25°C, defined for Adelaide, was adopted as the static threshold. To increase the accuracy of the adaptive comfort model, a version of the model based on the exponentially weighted running mean of the recent 7 days was adopted (Morgan and de Dear, 2003). The indoor thermal conditions, furthermore, were assumed to be perceived...
as acceptable by 80% of the occupants, in line with the ASHRAE standard. With these assumptions the ACM applied here allowed for indoor temperatures between 30-31 °C during the designated heatwave, which is notably higher than the 28.9 °C calculated for February based on the ACM from ASHRAE.

To connect indoor overheating risk with its health implications, a novel combination of standard thermostat set point temperatures and a heatwave intensity factor was used. The excess heat factor (EHF) was devised by Nairn and Fawcett (2013) to assess the heatwave intensity and predict the excess number of mortality and morbidity cases during heatwaves. The EHF is calculated as the deviation of the daily mean temperatures over the most recent three days compared to the recent thirty days and the 95th percentile of the recent thirty years, considering long-term acclimatisation. The unit of the EHF is °C². A more elaborate description of the calculation is provided in an earlier study (Hatvani-Kovacs et al., 2015). The EHF was validated as a superior predictor of excess mortality (Langlois et al., 2013) and morbidity (Hatvani-Kovacs et al., 2015) in Adelaide. The EHF can also better differentiate days with excess morbidity compared to normal summer days than earlier weather metrics used (Hatvani-Kovacs et al., 2015). Consequently, the EHF was used to identify days with higher than average health risk due to the elevated indoor (and outdoor) overheating. To assess the intensity of the heatwave included in the TMY, the 95th percentile of the recent 30 years was adopted from an earlier study (Hatvani-Kovacs et al., 2015). The strength of the heatwave analysed from the TMY between 12th and 17th February, identified as days with positive EHF, was in the average range, considering the range of heatwaves since 1970s in Adelaide (Nairn and Fawcett, 2013). Note that heatwave days, calculated as days with positive EHFs are usually lagged by 2-3 days behind compared with the peak in daily maximum temperatures.

3. Results and discussion

Firstly, the ratios of cooling and annual energy consumption were compared across scenarios (Fig.1). Since the star rating is based on annual energy consumption, a home with 6 stars could have nearly the same cooling energy consumption as an energy inefficient double brick home with 2.6 stars. A scenario with 7.2 stars, meanwhile, used more energy for cooling than a scenario with only 6.2 stars. Similarly, one scenario with 8.0 stars used almost twice as much energy for cooling as a scenario with only 7.1 stars. To summarise, star rating did not indicate the cooling energy consumption of a building.

Figure 1: Total annual and cooling energy consumption and cooling demand of different scenarios
Secondly, the peak cooling demand was compared in Fig. 1 across the scenarios. Although the double brick home had a higher peak cooling demand than any new construction with 6 or more star ratings, a home with 8 stars had a higher peak demand than a home with 7.1 stars. An increase in the star rating did thus not necessarily result in a decrease in peak demand.

Thirdly, the numbers of hours with discomfort were evaluated in the selected north-facing bedroom, considering the whole year. Figure 2 shows that overheating in most of the buildings with 6 stars or above was higher than in a traditional home with only 2.6 stars. Three homes with 6, 7 and 8 stars even reached indoor temperatures above 35 °C. The indoor temperatures in the north-facing bedroom were investigated further during the heatwave period. Heatwave days were identified from the TMY as days with positive EHF. The highest EHF occurred on 15th and 16th February, indicating the highest level of heat-related hospitalisation, when indoor overheating can potentially be the most dangerous. Figure 3 demonstrates that indoor temperatures in the bedroom would be higher in many scenarios with 6 stars or more than in a traditional double-brick home with only 2.6 stars. If AC was not available, overheating would, nevertheless, occur across all scenarios, on each day of the heatwave according to the static threshold of 25 °C (Figure 3). The highest levels of indoor overheating occurred on the first and second days, simultaneously with the outdoor temperature peaks. On the most dangerous third and fourth days, scenarios with the 8 stars and the double brick home only exceeded the static but not the adaptive thresholds. Meanwhile all other scenarios also exceeded the higher adaptive threshold. Indoor temperatures, nevertheless, remained the most above the static overheating threshold in the double brick homes and the least in the brick veneer home, at night during the most dangerous days. This result can be explained by the thermal inertia of the building mass and the missing insulation, showing that thermal mass can be counterproductive at night, during long heatwaves.

![Figure 2: Overheating analysis of a north-facing bedroom for the whole year](image)
These results demonstrate that the negative impact of thermal mass on overheating is the most tangible at night, during prolonged heatwaves and coincides with the peak in negative health problems. Note that these aspects would have not been investigated, if the designated heatwave was defined based on the temperature peaks. Consequently, the use of light-weight structures would be more recommended in bedrooms, while heavy-weight structures would be preferred in rooms with daytime functions, potentially without compromising the annual energy consumption. Such a hybrid construction would require substantial changes from the building industry. Cool retreats (Saman et al., 2014), when only one room is used for different functions during heatwaves, is an alternative form of the same concept. Furthermore, there is a lack of knowledge about the importance of the combination of the length and strength of overheating on health. Future research should explore whether the higher overheating occurring during the first half of a medium heatwave, or the relatively lower overheating during days with the highest number of health implications have a stronger impact on human physiology.

Figure 3: Overheating analysis of a north-facing bedroom during a medium heatwave period

4. Conclusion and policy implications

The paper demonstrated that the NatHERS increasing energy efficiency does not encourage heat stress resistance in new homes, and traditional double brick homes can even outperform some new constructions with 6 stars during heatwaves. Note that the two aspects of building design, namely energy efficiency and heat stress resistance do not inevitably interfere. A comprehensive design approach considering both aspects simultaneously is, nevertheless, an imperative, particularly considering future
increases in population vulnerability and climate change. Current building construction methods rely greatly on AC, increasing the population dependence on it. This trend overlooks the problem of blackouts, energy poverty and the many negative consequences of AC. Although AC is acknowledged as an efficient, preventative measure during heatwaves (Hajat et al., 2010) it also has several negative impacts. AC creates a feedback loop with the waste heat generated increasing local ambient temperatures (Salamanca et al., 2014), contributes to energy poverty (Santamouris and Kolokotsa, 2014), might cause addiction (Cândido et al., 2010) and potentially decreases other means of adaptation (Bélanger et al., 2015; Hatvani-Kovacs et al., 2016). The implementation of heat stress resistant measures in the NatHERS would be warranted to decrease the population’s dependence on AC.

The combination of the EHF and thermostat set points is the first of its kind to assess overheating risk beyond comfort preferences in relation to health risks. A limitation of the study is that buildings were tested only during a medium heatwave. Increased thermal mass, however, can be potentially more detrimental to the indoor thermal comfort during extremely long heatwaves. Future research should focus on the energy model simulation of different scenarios during long and extreme heatwaves and evaluate the combined influence of the length and strength of overheating on human physiology.

Acknowledgements

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References


Future proofing the accuracy of building simulations by addressing climate change projections in modified weather files

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Abstract: Complex building simulation is increasingly common in the design process of buildings in Australia. Traditionally, building simulation has been conducted using weather files constructed from typical historical weather data, but in a period of climate change the use of historical data to assess performance has been criticised as inappropriate. Modern buildings need to be efficient and comfortable today, but also into the future. This new design challenge requires adaptability and resilience to be included in building designs from the outset, and necessitates that data used for simulation is as accurate and reflective as possible of the environmental conditions in which buildings are likely to operate. This research utilises the improved imposed offset method proposed by Guan to construct a future hourly weather data file for various Australian locations that can be used in building simulation software. This approach will produce weather time series that incorporates the RCP8.5 climate change scenario while maintaining the local and realistic characteristics of the original weather file. This future weather data can then be used by designers and building engineers to assess off-axis scenarios in the simulation and address the risks of overheating during the lifetime of the building.

Keywords: Building simulation; climate change; future weather data; morphing technique.

1. Introduction

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (2014) concluded that since the 1950s many observed parameters including atmosphere and ocean temperature, snow and ice cover, and sea levels have undergone adverse and unprecedented changes. By the end of the 21st century the global mean surface temperature is projected to increase in the range of 0.3-1.7°C to 2.6-4.8°C relative to 1986-2005 baseline climate, heat waves will occur more frequently and last longer, and extreme precipitation events will become more intense and recurrent (IPCC 2014).

Buildings designed to operate in a period of climate change need to be efficient and comfortable today, but also into the future. This new design challenge requires adaptability and resilience to be incorporated into building designs from the outset, and also necessitate that data used for decision-making is as accurate and reflective as possible of the environmental conditions in which buildings are likely to operate during their lifetime. Over the last decades detailed building simulation has increasingly become part of the design process to demonstrate compliance with regulations, optimise design and
building services’ performance, and inform developers, building’s owners and occupants of the expected efficiency of their buildings (Augenbroe 2002). Traditionally, building simulation has been conducted using weather files constructed from typical historical weather data (usually for a period of 20 to 30 years) for a particular location. However, when considering that buildings have an operational life of 50 to 100 years, the use of historical weather data to assess their performance in a changing climate has been criticised as inappropriate (Watkins et al. 2011; Gupta, & Gregg 2012; Ren et al. 2011).

Previous research has investigated a number of methods to develop weather files representative of the possible future climate that can be used in building simulation (Chow & Levermore 2007; Rimante et al. 2015; Robert & Kummert 2012; Wilby & Wigley 1997; van Paassen & Luo 2002). The objective of this paper is to use the framework proposed by Guan (2009) to construct future hourly weather data files for Sydney, Brisbane, Perth, Darwin, Melbourne, Canberra, and Adelaide to use in building simulation software. Guan’s approach allows to simultaneously employ different methods, thus providing a more holistic and representative method to obtain future weather data that can be used by designers and building engineers to assess the performance of their proposed design and the risks of overheating during the lifetime of the building.

2. Climate change projections and scenarios

The Intergovernmental Panel on Climate Change (IPCC) (2014) has predicted that by the end of the 21st century the global mean surface temperature will likely increase in the range of 0.3-1.7°C to 2.6-4.8°C relative to 1986-2005 baseline climate. This prediction is the result of multiple global emissions scenarios developed by the IPCC and based on varying assumptions for future possible economic growth, resource consumption, technology implementation, social equity and global population development. The scenarios used to predict the future climate exclude targeted strategies for the mitigation of climate change, however they represent possible development pathways of human activities (Jentsch et al. 2013).

The emissions scenarios used by the IPCC to conduct the fifth Couple Model Intercomparison Project (CMIP5) are referred to as Representative Concentration Pathways (RCPs). Four RCPs have been defined based on the radiative forcing (W/m²) associated with a particular pathway by 2100 and include: RCP8.5 (high emission scenario), RCP4.5 and 6.0 (intermediate emission scenarios), and RCP2.6 (low emission scenario). The assumptions underpinning each of these scenarios range from a future assuming very rapid economic growth with a population peak around mid-century, rapid introduction of new and more efficient technologies, substantial reduction in regional differences in per capita income, and little curbing of emissions, to a future assuming a peak in emissions around 2020 followed by their rapid decline due to very ambitious and sustained emissions reduction targets (Climate Change in Australia 2015). At this time there is no particular probability attached to any one of the proposed scenarios (Belcher et al. 2005; Holmes & Hacker 2007), however, for the purpose of this study and in order to represent a worst case scenario, RCP8.5 has been used.

3. Generation of future weather data

3.1. Methodology

The imposed offset method, also called morphing, imposes data from complex climate models on top of observed historical weather data (Belcher et al. 2005). This method involves three general operations: 1) shifting; 2) stretching; and 3) a combination of shifting and stretching. These operations are applied to the data available within historical weather files using the climate change forecast included in global
Future proofing the accuracy of building simulations by addressing climate change projections in modified weather files
circulation models (GCMs), thus producing a future weather file that preserves physically realistic weather sequences of the baseline data (Chan 2011). Due to its ability to retain the nature of the observed data and the relatively low amount of computational power required for calculation, morphing has become the most used approach for constructing future weather files for building performance simulation and is also used by the Chartered Institution of Building Services Engineers (CIBSE) in the development of their climate change weather data files (Jentsch et al. 2013).

Based on a review of the literature of the various methods available to generate future weather data, it was established that no single procedure can be considered fully robust. This paper therefore proposes to utilise a hybrid approach, whereby procedures from various methods are integrated into one. Following the process proposed by Wang et al. (2010), climate change projections in Australia have been simulated using the Climate Future Tool developed by the CSIRO. For the purpose of this study, and in order to account for the strengths and weaknesses of individual GCMs, data from a total of 26 models has been used (see Table 1). These models have been selected based on their confidence levels to predict climatic variables in Australia.

### Table 1: Atmospheric-ocean general circulation models used in this research

<table>
<thead>
<tr>
<th>ACCESS1-0</th>
<th>CESM1-CAM5</th>
<th>FGOALS-s2</th>
<th>IPSL-CM5B-LR</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCESS1-3</td>
<td>CMCC-CESM</td>
<td>FIO-ESM</td>
<td>MRI-CGCM3</td>
</tr>
<tr>
<td>bcc-csm1-1-m</td>
<td>CMCC-CM</td>
<td>GFDL-CM3</td>
<td>MIROC5</td>
</tr>
<tr>
<td>bcc-csm1-1</td>
<td>CMCC-CMS</td>
<td>GFDL-ESM2M</td>
<td>MRI-ESM1</td>
</tr>
<tr>
<td>CanESM2</td>
<td>CCSM4</td>
<td>HadGEM2-CC</td>
<td>MPI-ESM-LR</td>
</tr>
<tr>
<td>CNRM-CM5</td>
<td>EC-EARTH</td>
<td>HadGEM2-ES</td>
<td>MPI-ESM-MR</td>
</tr>
<tr>
<td>CESM1-BGC</td>
<td></td>
<td>HadGEM2-AO</td>
<td></td>
</tr>
</tbody>
</table>

The climate change projections obtained from the GCMs have then been downscaled using the framework proposed by Guan (2009) in order to develop weather files for the studied locations. Guan (2009) elaborates on the imposed offset method proposing to retain current conditions when a reliable prediction for a particular climatic parameter is not available or when there is little confidence in its accuracy, while adopting either the morphing approach or the diurnal modelling method depending on the details of projection available.

### 3.2. Dry bulb temperature projections

The GCMs used for this study provide predicted changes in monthly mean temperature, monthly maximum temperature, and monthly minimum temperature. Using the current IWEC data, the monthly mean daily maximum and minimum temperature are determined. The scaling factor for the stretch algorithm is then determined by Eq. (1):

$$\alpha_{dtm} = \frac{\Delta T_{MAX_m} - \Delta T_{MIN_m}}{(dbt_{max,m}) - (dbt_{min,m})}$$  \hspace{1cm} (1)
Where the subscript symbol "m" stands for "monthly", $\alpha dbt_m$ is the scaling factor, $\Delta TMAX_m$ is the predicted change in monthly maximum temperature, $\Delta TMIN_m$ is the predicted change in monthly minimum temperature, $(dbt_{omax})_m$ is the current monthly mean daily maximum temperature and $(dbt_{omin})_m$ is the current monthly mean daily minimum temperature.

The hourly future dry bulb temperature is then given by Eq. (2):

$$dbt = dbt_o + \Delta TEMP + \alpha dbt_m \times (dbt_o - (dbt_o)_m) \tag{2}$$

Where $dbt$ is the hourly future dry bulb temperature, $dbt_o$ is the existing dry bulb temperature, $\Delta TEMP$ is the predicted monthly mean temperature rise, and $(dbt_o)_m$ is the existing monthly mean daily temperature.

### 3.4. Solar radiation on horizontal projections

Although the overall solar energy is not predicted to change, an increase in the surface temperature is likely to alter the Earth’s cloud cover and albedo, which in turn could impact on daylight and solar gains at ground level (Jentsch et al. 2013). To calculate the projected increase in global solar radiation, a scaling factor was obtained by Eq. (3):

$$\alpha gsr_m = 1 + \left(\frac{\Delta DSWF_m}{gsr_0}\right) \tag{3}$$

Where $\alpha gsr_m$ is the scaling factor, $\Delta DSWF_m$ is the absolute monthly change in solar radiation as projected by the GCMs, and $gsr_0$ is the existing monthly mean solar radiation.

The projected solar radiation is then obtained by multiplying the scaling factor by the existing hourly solar radiation using Eq. (4):

$$gsr = \alpha gsr_m \times gsr_0 \tag{4}$$

### 3.5. Diffuse solar radiation on horizontal

Predictions for the diffuse solar radiation are not given by the GCMs used within this study and therefore, as suggested by Belcher et al. (2005) this data has been assumed to change proportionally to the global solar radiation. The equation used to calculate the projected diffuse solar radiation is given below (Eq. 5):

$$dsr = \alpha gsr_m \times dsr_0 \tag{5}$$

Where $\alpha gsr_m$ is given by Eq. (5) and $dsr_0$ is the existing diffuse solar radiation.

### 3.6. Air humidity projections

The humidity projection data provided by the used GCMs is given as changes in percentage, and thus the future relative humidity is given by Eq. (6):

$$RH = \left(1 + \frac{RH_m}{100}\right) \times RH_0 \tag{6}$$

Where $RH$ is the future relative humidity, $RH_m$ is the projected change in relative humidity, and $RH_0$ is the current relative humidity.
3.7. Wind patterns projections

Changes in wind direction are not provided by the utilised GMCs, therefore for the purpose of this research the future wind direction has been assumed to remain unchanged, while the future wind speed has been calculated using the morphing approach as outlined by Eq. (7):

$$ws = \left(1 + \frac{\text{WIND}_m}{100}\right) \times ws_0$$

(7)

Where $ws$ is the future wind speed, $\text{WIND}_m$ is the projected change in wind speed, and $ws_0$ is the current wind speed.

4. Cross correlation verification

A method of demonstrating that the morphing approach is valid and ensuring that the future weather data file has maintained the characteristics of the historic file is to evaluate whether similar relationships occur between the variables in the historic data and those in the future data.

Weather data has been found non-normally distributed, and therefore the Spearman’s correlation coefficient has been used to conduct this test. This nonparametric measure of statistical dependence allows to assess how well the relationship between two variables can be described using a monotonic function, with values of +1 or -1 occurring when each of the variables is a perfect monotone function of the other. Table 2 presents the test results from the statistical analysis with correlation significance at the 0.01 level (2-tailed). These results demonstrates that the correlations within the historic data and the future data files are very similar, thus offering confidence on the utilised approach.

<table>
<thead>
<tr>
<th></th>
<th>Dry Bulb Temperature and Diffuse Radiation</th>
<th>Dry Bulb Temperature and Global Radiation</th>
<th>Dry Bulb Temperature and Relative Humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Historic</td>
<td>Future</td>
<td>Historic</td>
</tr>
<tr>
<td>Adelaide</td>
<td>.413</td>
<td>.409</td>
<td>.463</td>
</tr>
<tr>
<td>Brisbane</td>
<td>.546</td>
<td>.555</td>
<td>.565</td>
</tr>
<tr>
<td>Canberra</td>
<td>.419</td>
<td>.415</td>
<td>.470</td>
</tr>
<tr>
<td>Darwin</td>
<td>.638</td>
<td>.637</td>
<td>.682</td>
</tr>
<tr>
<td>Melbourne</td>
<td>.462</td>
<td>.453</td>
<td>.508</td>
</tr>
<tr>
<td>Perth</td>
<td>.434</td>
<td>.432</td>
<td>.511</td>
</tr>
<tr>
<td>Sydney</td>
<td>.391</td>
<td>.393</td>
<td>.421</td>
</tr>
</tbody>
</table>

5. Results and discussion

5.1. Global Circulation Models characteristics

The variations in climate change projections for the seven studied locations are presented in Figure 1 and are relatively large due the different climate zones in which each city is located, ranging from Darwin’s humid and warm climate to Canberra’s cool temperate climate.
The mean surface temperature projections obtained from the models range from 3.19°C to 4.67°C, with higher temperatures occurring during the warmer months (October to March) for Melbourne, Perth, Canberra, Adelaide, and Brisbane (see Figure 1). In Darwin, higher temperatures are projected to occur during the winter months and in Sydney, the approximate 4°C increase is projected to remain almost constant throughout the year. Solar radiation is projected to follow the opposite pattern to surface temperature, with solar radiation increasing by up to 8% during winter in Canberra, decreasing by up to 1.37% during summer in Perth, and remaining almost unchanged throughout the year in Darwin. This may be due to changes in cloud cover which will be affected by air temperature. Warmer air usually results in more evaporation, which consequentially means more water vapour and more clouds. The increase in cloud cover during summer means a reduction in solar radiation reaching the Earth’s surface, but also a warming effect caused by the clouds trapping some of the heat emitted from the Earth’s surface and reemitting it back towards the Earth. Humidity is projected to decrease in a similar way in all studied cities, with Canberra projected to experience a decrease of up to 11% during spring. Rainfall is likely to follow a similar pattern, with projections showing a decrease in precipitation in all cities during most of the year and only slight increases between December and April (expect for Melbourne which is projected to have no increase in rainfall). Lastly, wind speed is projected to variate between -10% and +10% with the variation pattern relatively irregular and different for all cities.
5.2. Changes to dry bulb temperature, and heating and cooling degree days

The results from the morphing process for dry bulb temperature are illustrated in Figure 2, which show the historical and projected annual variations for the studied locations. It can be seen how the projected dry bulb temperature maintains the characteristic of the historic data thus providing further confidence in the morphing approach. Moreover, these changes in dry bulb temperature are likely to have significant impacts on the performance of buildings and occupants' comfort. With the expected rise in temperature and more frequent and severe heat waves, buildings will be subject to increased cooling loads to maintain the indoor environment at thermal comfort levels. Various research has concluded that this variation in air temperature will likely increase the risk of overheating and have serious negative impacts on heating and cooling systems energy requirements (Dodoo et al. 2014; Wang et al. 2010; Williams et al. 2012).

Degree days are a simplified representation of outside air-temperature data, and provide a simplified measure of the heating and cooling required to maintain thermal comfort in the indoor environment and the consequential expected energy consumption. In this study, the changes in heating and cooling degree days in response to climate change are calculated in order to estimate the impacts that a warming climate could have on thermal comfort and energy consumption by the end of the century. Here, the heating and cooling degree days are calculated by counting the number of hours that dry bulb temperature is below 18° C (for heating) and above 25° C (for cooling).

Table 3 presents the heating and cooling degree days obtained from the historic weather data and the future (2090s) weather file. From these results it is possible to establish that the number of cooling degree days increases by between 22 and 95 degree days per annum, while the number of heating degree days decreases by between 2 and 102 degree days per annum. The effects that this variation will have on energy consumption may not be extreme, as increases in cooling energy demand will be partially absorbed by decreases in heating energy demand in most cities. However, this data further demonstrates the higher vulnerability to overheating that buildings in all studied locations are likely to face.

Table 3: Comparison of the heating and cooling degree days between the historic and future weather data

<table>
<thead>
<tr>
<th>City</th>
<th>Cooling Degree Days (above 25° C)</th>
<th>Heating Degree Days (below 18° C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Historic</td>
<td>Future</td>
</tr>
<tr>
<td>Adelaide</td>
<td>36</td>
<td>64</td>
</tr>
<tr>
<td>Brisbane</td>
<td>69</td>
<td>164</td>
</tr>
<tr>
<td>Canberra</td>
<td>16</td>
<td>47</td>
</tr>
<tr>
<td>Darwin</td>
<td>287</td>
<td>356</td>
</tr>
<tr>
<td>Melbourne</td>
<td>19</td>
<td>41</td>
</tr>
<tr>
<td>Perth</td>
<td>50</td>
<td>101</td>
</tr>
<tr>
<td>Sydney</td>
<td>29</td>
<td>93</td>
</tr>
</tbody>
</table>
Figure 2: Mean annual historic and projected dry bulb temperature (degree C)
6. Conclusion

This research has developed predicted climate change weather data files incorporating the RCP8.5 scenario for the major Australian capital cities including Sydney, Brisbane, Perth, Darwin, Melbourne, Canberra and Adelaide, representing a diverse range of climates. The improved offset method proposed by Guan (2009) has been used for this study, and has resulted in climate change weather files that maintain the local characteristics of the historic weather data. As a way to demonstrate the accuracy of the future weather data, a cross correlation study has been conducted and demonstrated that similar relationships exist both in the historic weather file and in the future weather file.

This research shows that heating degree days are projected to decrease by 25-100% and cooling degree days projected to increase by 24-221%, depending on location. While the actual energy intensity of building may not vary by much as a result of these changes, the risk of overheating posed by higher temperatures and extended heat waves is significant. When considering that these changes are projected to occur within the lifetime of most buildings constructed today, the design and construction industry faces the new challenge of developing a built environment able to be efficient today and into the future. To achieve this task, it is important that design teams are provided with tools that empowered them to future proof their designs. In this sense, building performance simulation can be a powerful tool to evaluate the effectiveness of design solutions. Critical to the long term success of the design solutions is the ability to address climate change scenarios in the building simulation process.

This research is part A in a two part study. Part B is concerned with the testing of the future weather files generated in this study in building simulation in order to establish actual impacts on a range of buildings and evaluate mitigation strategies that can be included in the design of new buildings.

References


Method for determining the efficiency of shading devices

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Abstract: The effective control of solar energy can significantly impact a building’s energy efficiency. Understanding the shadowing behaviour of a shading device is a key step to establishing its consequences for the building’s thermal performance and user’s thermal comfort. This study presents a method to determine the efficiency of external shading devices throughout the year with regard to the variations of direct solar radiation intensity and the incidence period, in order to facilitate the evaluation and comparison of different shapes of shading devices, constituting a practical tool that assists its design. Simulations were made with Energy Plus software considering the latitude of the analysed location in order to determine the incident beam solar radiation on a vertical surface without shading and the reduction of incident solar energy with seven typical models of shading devices applied. Eight solar orientations and twelve "reference days" throughout the year with clear sky were considered. Analysing the shading devices efficiency for São Paulo, Brazil as an example of the method application, among the conclusions drawn it is emphasized that to the east and west orientations, the horizontal shading device is more effective than the vertical, especially from September to March.

Keywords: Shading devices; efficiency; solar radiation intensity.

1. Introduction

Windows without shading can let significant amounts of solar radiation into buildings, causing visual problems such as glare, and thermal problems with consequences affecting the user’s comfort. The effective control of incident solar energy in buildings contributes both to the improvement of its thermal performance, and for the use of natural light, factors associated with the energy efficiency of buildings, which is fundamental in the sustainability of the built environment. This is highlighted in several works that present the influence of shading devices in energy consumption for air-conditioning systems and thermal comfort of users (Tzempelikos and Athienitis, 2007; Datta, 2001; Palmero-Marrero and Oliveira, 2010; Gupta and Ralegaonkar, 2010). However, these analyses do not consider separately the effect of shading devices’ efficiency.

Florides et al. (2002) studied the effect of overhang length on energy demand and found that a longer horizontal overhang reduces the cooling demand but increases the heating demand. The study shows that the thermal loads of each building and the different climatic conditions throughout the year
for each place demand appropriate shading efficiencies. A higher proportion of shading (higher device efficiency) does not necessarily mean a more comfortable environment. Depending on the situation, it is appropriate to admit or to prevent the solar heat gain through the opening in the environment. Thus, a pattern to establish the monthly shading efficiency is an essential factor for choosing a suitable shading device.

Cho, Yoo and Kim (2014) present a shading efficiency analysis of shading devices. A reference window was defined and models of shading devices (vertical and horizontal), each with dimensional variations, were applied to the reference window for three solar orientations (south, east and west). The incidence of beam solar radiation is simulated only from May to September, when the cooling load occurrence is expected, without assessing the influence of shading devices in the other months of the year. The solar radiation data used for the simulations is from a typical meteorological year with cloud variation. The clouds cause the higher attenuation of radiation, but they are unpredictable and its location, size and thickness cannot be determined, thus it can mask the effect of shading devices. The total incident beam solar radiation throughout the month is used as the result, which covers the incidence pattern during the day and does not show the time that the shading device is effective.

Bellia et al. (2014) present a critical analysis of studies that investigate shading devices’ effects on building thermal and lighting performances and it points out that there is no standardized procedure to establish the efficiency of shading devices. The analysed papers consider different conditions regarding climate, shading typology, solar orientation, methodology used, characteristics of building, and especially different parameters considered to evaluate the performance of the shading system. Therefore the lack of uniformity between the studies, since there is no established protocol to perform these analyses, leads to results that cannot be compared with one another.

Understanding the shadowing behaviour of shading devices regarding the variations of beam solar radiation intensity and the incidence period throughout the year is a key step for the designer to determine its final consequences on energy consumption, thermal comfort and daylight efficiency of the building. The aim of this study is to present a method to determine the shadowing behaviour of typical external shading devices throughout the year, in order to facilitate the evaluation and direct comparison of shading devices’ efficiency for every need of performance, constituting a practical tool that assists its design.

2. Description of the method

To determine the efficiency of shading regarding the reduction of incident solar energy on a surface it is necessary to consider the variations in solar radiation intensity and in insolation period over time. Therefore a method was developed, based on simulations with Energy Plus software, to determine the incident solar radiation on a vertical surface unit area without shading and with seven models of typical shading devices applied.

The seven shading device models considered in the method include the basic shapes of shading devices typically used in buildings. The behaviour of the shading provided by these models demonstrates the influence of each shape on hourly and monthly shading, leading to the understanding of the devices efficiency throughout a day and a year.

Eight solar orientations were considered for the vertical reference surface (N, S, E, W, NE, NW, SW, SE) in order to spread the behaviour of insolation to the various implementation possibilities of a building, and twelve "reference days" with clear sky. The 21st day of each month was selected for the
simulations, in order to consider the monthly changes of solar geometry and also the solstices and equinoxes (extreme and representative solar geometries).

The efficiency of the shading devices was determined according to their capacity to reduce the incident solar energy on the analysed vertical surface in comparison with the condition without shading.

2.1. Software - Energy Plus

The Energy Plus software enables to simulate the incidence of solar radiation based on the solar path, and the geometric relationship with the analysed surface, allowing the determination of the incidence period and the intensity of beam solar radiation on a surface at a specified time interval. In addition, it allows the calculation of the percentage of shaded area of a vertical surface with the effect of external shading devices for the time interval.

2.2. Solar Radiation Data

For the evaluation method of shading devices’ efficiency, clear sky was the condition considered, in other words, in the situation where the period and the intensity of beam solar radiation are the highest for the amount of aerosols in the atmosphere, even though this can be an atypical situation for the analysed place. This is because the aim of the method is to demonstrate the shading efficiency for a critical situation of solar radiation, and the unpredictability of clouds and its mitigation of irradiation can mask the effect of shading devices and hinder the understanding of the shading device’s efficiency.

The clear sky model introduced by the American Society for Heating, Refrigerating and Air-conditioning (ASHRAE) was used in the simulations to obtain the direct solar radiation data, revised based on specific optical depths for each location for direct and diffuse radiation. The optical depth values of clear sky for direct radiation ($taub$) and diffuse ($taud$) are location-specific and vary during the year. These values are tabulated by month in the climatological data from ASHRAE and they embody the dependence of clear sky solar radiation upon local conditions, such as elevation, precipitable water content, and aerosols.

2.3. Shading Devices

The reference surface set for the simulation is vertical, and it represents a window or an opening. It is one meter wide by one meter high, but its dimensions do not intervene in the analysis, because the comparison of the results is made per unit area. It works as a reference geometry for sizing the shading devices, and what must be considered are the shading limit angles: alpha ($\alpha$), beta ($\beta$).

Using the developed method in this study to compare the efficiency of shading devices (Figure 1) with the same shading limit angles alpha ($\alpha$) and gamma ($\gamma$) and divided into different numbers of fins, the identical efficiency of the devices can be noted. If the device has the same shading limit angle but leans over the window, it demonstrates the same pattern of shading but is more efficient. Thus examples of shading devices typically used in buildings were analysed (Figure 1) and its basic shapes summarized in seven models of shading devices for evaluation, the single shapes: Horizontal, Right, Left; and the composite shapes: Vertical, Horizontal + Right, Horizontal + Left, Horizontal + Vertical. The analysed shading devices (Figure 2) are all the same size with 60° shading limit angle to the reference surface. Independent of their size, the typical models demonstrate the shading pattern of its shape throughout the day and the year.
Figure 1: Efficiency of shading devices with the same limit angles, divided into different numbers of fins, and leaning over the window.

Figure 2: Examples of shading devices and the equivalent typical shapes.

3. Example of method application

As an example of the method application the results for the city of São Paulo, with the latitude 23°50', are presented. São Paulo is one of the largest cities in Latin America, with a significant amount of buildings generally designed without shading devices. For the simulation the optical depth values of clear sky for direct radiation \((\tau_{ab})\) and diffuse \((\tau_{ad})\) described by ASHRAE for the city in question (Figure 3) were inserted into the program Energy Plus for their "Reference Day" in the solar model ASHRAE Revised Clear Sky.
Method for determining the efficiency of shading devices

3.1. Evaluation of solar orientation

First, the incident beam solar radiation for the eight solar orientations had to be determined without shading devices for the whole year. The evaluation of the amount of incident solar energy on the facades can determine which orientation needs sun shading and in which period, depending on the performance needs of each building. The daily totals of incident beam solar radiation per hour (Wh/m²) in the reference surface for the 21st day of each month of the year are presented on a monthly chart to demonstrate the variation of energy incidence throughout the year. And the hourly values of beam solar radiation (Wh/m²) are shown in graphs of the three "reference days" with the extreme solar geometries (solstice - 21/December, equinox - 21/ March, solstice - 21/June) to present the time variation of incidence throughout the day (Figure 4).

<table>
<thead>
<tr>
<th>Clear Sky Solar Irradiance</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>taub</td>
<td>0.391</td>
<td>0.383</td>
<td>0.365</td>
<td>0.325</td>
<td>0.392</td>
<td>0.395</td>
<td>0.397</td>
<td>0.366</td>
<td>0.436</td>
<td>0.441</td>
<td>0.289</td>
<td>0.286</td>
</tr>
<tr>
<td>taud</td>
<td>2.593</td>
<td>2.589</td>
<td>2.602</td>
<td>2.689</td>
<td>2.576</td>
<td>2.533</td>
<td>2.406</td>
<td>2.206</td>
<td>2.168</td>
<td>2.363</td>
<td>2.534</td>
<td>2.589</td>
</tr>
</tbody>
</table>

Figure 3: the optical depth values of clear sky for direct radiation (taub) and diffuse (taud) by month for São Paulo. (ASHRAE, 2009)

Figure 4: Incident beam solar radiation for eight orientations in São Paulo.
In the monthly chart it can be noted that, for the latitude of São Paulo, from September to March the solar orientations with higher incident solar radiation are: east and west, northeast and northwest, southeast and southwest. From March to September the solar orientation with the higher incident solar radiation are: north, northeast and northwest, east and west.

The solar orientations south, southeast and southwest have low amounts of incident solar radiation from March to September, and depending on the building’s performance demand it may not need shading during this period. The same goes for the north and south directions from September to March.

The solar orientations east and west, northeast and northwest, southeast and southwest, have the same amount of incident solar radiation during the year and so its curves overlap on the monthly chart. The difference is up to the hourly period of incidence during the day.

In the hourly charts of the three most representative "days of reference" it may be noted that for the south orientation, during the solstice 21/December, the incidence of solar radiation period is just early in the morning and late in the afternoon with low intensity. The north orientation has a long incidence period with high intensity of solar radiation during the solstice 21/June. For east and west orientations the daily incidence period is short, but with high peak intensity, especially during the solstice 21/December reaching 700 Wh/m². For northeast and northwest orientations the daily incidence period is long and with high intensity, especially during the solstice 21/June reaching 700 Wh/m². Southeast and southwest are the solar orientations in second place with higher peak intensity of solar radiation in the solstice 21/December reaching 605 Wh/m².

The evaluation of the need for shading in each orientation depends on the performance demands of each building throughout the year. The designer can observe the peak intensity of incident beam solar radiation, as well as the orientations with high amounts of the incident solar energy due to long periods of incidence. The chart already shows, for an initial evaluation, the critical solar orientations and the ones with low amounts of incident solar energy.

3.2. Evaluation of shading devices by solar orientation

After establishing the amount of incident solar energy by solar orientation without shading, the efficiency of each shading device must be defined throughout the year by solar orientation. The shading devices’ efficiency was determined according to their reduction capacity of incident solar energy on the analyzed vertical surface. The curve of incident beam solar radiation without shading device by orientation is the maximum radiation that the facade can receive for the defined period and latitude, and thus serves as the baseline for evaluation. The incident solar energy reduction by applying shading devices may be seen by hour during the representative "reference days" and throughout the year with the total daily incident beam solar radiation. To illustrate this method, the study evaluated the effect of shading devices only for the four most critical solar orientations with the larger amounts of incident solar energy for the city of São Paulo (N, NE, SW, W).

3.2.1. North orientation

To the north solar orientation (Figure 5), with the highest amount of incident solar radiation from March to September, it can be seen that the "Horizontal" shading device has the highest efficiency of the single shading devices for shading the daily peak intensity of solar radiation (12:00 pm). Yet the "Right" and "Left" shading devices are inefficient because they do not shade the daily intensity peak of solar radiation and shade only during the morning and afternoon, respectively. Consequently, for the
composite shading devices, those with “Horizontal” overhang will be more efficient, and it will reduce solar radiation in the morning with the presence of the "Right" fin and in the afternoon with the presence of the "Left" fin. The "Horizontal" single shading device is more efficient than the composite "Vertical".

3.2.2. Northeast orientation

To the northeast solar orientation (Figure 6), with incident solar radiation during the whole year and the highest amount from March to September, it can be seen that the "Horizontal" shading device has the highest efficiency of the single shading devices throughout the year. The "Right" fin shades from September to March and shadows little quantity from March to September. Yet the "Left" fin just shades from March to September and does not shade from September to March. Consequently, for the composite shading devices, those with “Horizontal” overhang will be more efficient, and it will reduce the solar radiation from September to March with the presence of the "Right" fin and from March to September with the presence of the "Left" fin. The "Horizontal" single shading device is more efficient than the composite "Vertical".

3.2.6. Southwest orientation

To the southwest solar orientation (Figure 7), with the highest amount of incident solar radiation from September to March, it can be seen that the "Horizontal" shading device has the highest efficiency of the single shading devices throughout the year. The "Right" fin is less efficient but also shades from March to September. Yet the "Left" fin is not efficient to this solar orientation and does not shade throughout the whole year. Consequently, for the composite shading devices, those with “horizontal” overhang will be more efficient, and it will reduce the solar radiation throughout the year with the presence of the "Right" fin. The "Left" fin does not contribute to shading in any composite shading device.

3.2.7. West orientation

To the west solar orientation (Figure 8), with incident solar radiation during the whole year and the highest amount from March to September, it can be seen that the "Horizontal" shading device has the highest efficiency of the single shading devices throughout the year. The "Left" fin shades little quantity from September to March and does not shade from March to September. Yet the "Right" fin just shades from March to September and does not shade from September to March. Consequently, for the composite shading devices, those with “horizontal” overhang will be more efficient, and it will reduce the solar radiation from September to March with the presence of the "Left" fin and from March to September with the presence of the "Right" fin. The "Horizontal" single shading device is more efficient than the composite "Vertical".
Figure 5: Shading devices’ efficiency to the north orientation in São Paulo.

Figure 6: Shading devices’ efficiency to the northeast orientation in São Paulo.
Method for determining the efficiency of shading devices

Figure 7: Shading devices’ efficiency to the southwest orientation in São Paulo.

Figure 8: Shading devices’ efficiency to the west orientation in São Paulo.
4. Conclusions

In the evaluation of shading devices for the city of São Paulo, as an example of the method application, it can be observed that among the single shading devices, from September to March during summer in the analyzed city, the "Horizontal" is more efficient than vertical fins for all the analyzed solar orientations. Even for the west orientation, contrary to what is normally stated, "Horizontal" shading devices are more effective than the vertical fins during this period. Among the conclusions of this evaluation, it also stands out that for the west solar orientation, with the software's accuracy in calculating the percentage of shaded area and intensity of incident solar radiation, the "Right" shading device is more effective than the "Left" from September to March, contrary to this device's inefficiency according to the usual method of the solar chart.

The presented method is a standardized procedure for determining the efficiency of shading devices throughout the day and the year for each facade’s solar orientation, considering the software’s accuracy to establish the percentage of shaded area and the shading period, and mainly due to the intensity of solar energy and the amount that the shading device prevents reaching the surface. This procedure is fundamental to demonstrate the shadowing behavior of shading devices regarding the variations in the period of incidence and intensity of direct solar radiation. The different building’s materials and characteristics, and thermal loads that could mask the efficiency of shading devices are not taken into account. For this procedure, only the isolated effect of the typical shapes of shading devices on reducing the solar energy reaching the window is considered. It also stands out among the obtained findings with the method that the shading devices with identical shading limit angles, although divided into more fins, demonstrate the same efficiency. Therefore, typical shapes of external shading devices were synthesized in seven models, which represent a number of other design possibilities that meet the same shading limit angles, to demonstrate the influence of each shape on the shading efficiency. At the same time, this standardized method can be used to evaluate the efficiency of different shading devices than those established in this study.

Therefore, the designer has a practical tool available which, combined with the specific demands of performance for each building throughout the year, assists in the evaluation and the design of shading devices, essential for thermal performance, user comfort, and energy efficiency of buildings.

References

Integrating Green Building Index consultancy with residential building design

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Abstract: Despite government incentives, developers are reluctant to invest in green building initiatives due to their perceived extra costs – in particular additional consultant and construction implementation costs. This paper examines the issues preventing the integration of Green Building Index (GBI) consultancy with residential building development in the Malaysian construction industry. Following a literature review of the challenges involving GBI consultancy at the early stage of green residential development, a semi-structured interview method was used to elicit opinion on perceived barriers to integrating the GBI process from 30 interviewees; mainly developers, GBI consultants, building consultants and regulators in the Malaysian construction industry with involvement in green building. The study found that a lack of communication between design team members and GBI consultants was a major barrier. This reduced the opportunity for a more collaborative effort to minimise costs and wastage during the design stages. Lack of insight into the impact of integrating the GBI consultancy into design process within the project time frames was evident. Effective coordination is necessary if the involvement of GBI consultants, particularly at early design stage, is to be successfully managed. It is recommended that work coordination among design team members and GBI consultants needs periodic review.

Keywords: Green Building Index Consultancy, Early Design Stage, Residential Development, Malaysia

1. Introduction

The Malaysian Construction Industry Master Plan (2005–2015) pinpointed sustainability as being indispensable in the Construction Industry Development Board (CIDB, 2007). Green Building Index is an extensive rating system and environmental assessment tool used for appraising the environmental design and the performance of buildings (Samari et al., 2013; ACEM, 2012). The rating system had strong support from the government through income tax deductions equivalent to the additional capital expenditure incurred by building owners in obtaining GBI certification from 24 October 2009 to 31 December 2014, and stamp duty exemption for the first owner of a green building (Atsusaka, 2003;
Samari et al. (2013). Construction stakeholders are beginning to implement the concept into their designs and projects.

The government has identified residential building development as an essential human requirement and an all-important ingredient in the nation’s economy and it is used as part of the government’s political strategy to achieve both its social and economic goals (Aziz, 2007). It is noted that the building industry alone contributed about 3-5% of Gross Domestic Product (GDP) and provided employment for close to 10% of the total labour force (Ministry of Finance (MOF), 2009). In the 10th Malaysian Plan (EPU, 2010), it is projected that, urban areas in Malaysia alone will need to accommodate six million more residents between 2012-2020 (Abidin et al., 2012). Despite increased demand for residential buildings (RHEDA, 2013), green building practice is not yet a commonplace in residential building development. It is apparent that developers rarely engage the services provided by GBI consultants in their projects (Esa et al., 2011). Therefore, it is important to get an appropriate understanding of the current scenarios and barriers to GBI implementation at early design stage in residential building development. The development of general strategies to improve acceptance of GBI consultancy in the construction industry whilst utilizing the expertise of professionals and regulators from both public (local building authorities and construction agencies) and private sectors (architects and planners) is imperative and it is the aim of this paper.

2. Literature review

A brief description of GBI Consultancy, the rating tool and its categorization, and an overview of the link between residential needs and green practices are reviewed in the following section.

2.1. Green Building Index consultancy

Green Building Index consultancy is a process of getting buildings rated as “green”. It is an advisory service to clients in the building industry. This consultancy is focused on enabling architects, engineers, urban designers, developers, public authorities, contractors and other construction professionals to identify the benefits of considering sustainability within a construction project benefits such as reduced operational cost, improved resource use, waste minimisation, energy efficiency, the use of renewable energy and other innovative practices which aim to minimise the impact on our environment (USGBC, 2012). However, green building consultants in this context are construction professionals who are involved in green building practices.

The first suitability rating tool, the Building Research Establishment Environmental Assessment Method (BREEAM) was developed in the United Kingdom in 1990 and was brought to Canada in 1996. In 1998, the United States Green Building Council (USGBC) launched its own Leadership in Energy and Environmental Design (LEED) tool while in 2004 the Green Building Initiative (GBI) adapted the Canadian version of BREEAM to create Green Globes and began distributing it in the U.S. market in 2005 (Smith et al., 2006). Australia’s Green Star was developed in 2003, whereas, Singapore’s Green Mark was launched in 2005. Japan’s Comprehensive Assessment System for Built Environment Efficiency, (CASBEE) was developed in 2004, New Zealand’s version, Green star was launched in 2007 (Prins, 2016) while Malaysia’s Green Building Index (GBI) was established by Malaysian Green Building Confederation (MGBC) in 2009 (Green Building Index, 2013).

In GBI rating categorisation, a Platinum rating is awarded to buildings scoring between 86 and 100 points. Buildings are also rated Gold when they score between 74 and 84, and Silver if between 66 and 75. Finally, buildings are rated Certified if between 50 and 65. Available data from Green Building Index
show that 93 out of a total of 135 green rated residential new construction (RNC) are rated “Certified”, 26 buildings are rated “Gold”, 10 buildings are rated “Silver” and 4 are rated “Platinum” (see Table 1). For a building to be rated green, it is required to undergo a three-stage certification process. At stage one, Application and Registration, the clients or developers complete the GBI application form, after which a GBI registration number is issued and the terms and conditions are signed between the developer and the Malaysian Green Building Council (MGBC) in which a GBI Certifier is then assigned for the project.

The second stage, Design Assessment (DA) is the process of ensuring that the specified points are met in the design. This will usually involve a presentation by the applicant and their project design team or a Green Building consultant. Upon completion, the GBI Certifier tables the assessment report to the GBI Accreditation Panel (GBIAP). If the assessment is successful, the design is certified as meeting the criteria (GBI, 2013). At stage three, Completion and Verification Assessment (CVA), upon project completion, the client is required to prove that all the points are met by submitting a CVA usually within 12 months of the completion of the building or when the building becomes 50 percent occupied. The final GBI award is issued by the GBI Accreditation Panel (GBIAP). Points might be lost at this stage. An assessment of the building needs to be done annually in order to maintain their rating (Green Building Index, 2013).

2.2. Green Building Index and residential needs

In the seventh Malaysia Plan, the government envisioned 800,000 housing units would be provided for its population (EPU, 1996). 70% of this target had been realized by the end of 1999. Of the 110,644 units approved by the Ministry of Housing and Local Government (MHLG) for construction in the first six months of 2000, 25.4% of the approved units were for low cost unit housing, 38.7% medium cost housing and 35.5% higher end housing. A total of 57,925 units of residential property were launched in housing schemes in the first half of 2000. Out of these, 39.4% were condominium/apartment units and primarily concentrated in Selangor and Kuala Lumpur. This huge supply of higher end condominiums depressed the rental market (Ministry of Finance, Malaysia, 2000).

In the eighth Malaysia Plan in (2001-2005), the country continues efforts to developing affordable and sustainable low and medium cost housing (EPU, 2001). However, the country was faced with the challenging task of providing between 600,000 and 800,000 houses during a period when the residential construction industry faced various project-related factors that hindered the prompt completion of projects. At the end of 2013, there were 4,718,534 existing residential buildings as against 4,640,269 residential units in 2012 (RHEDA, 2014).

Meanwhile, statistics from MGBC show that, as of October 15 2015, (see Table 1) there were 361 Non-Residential New Construction (NRNC), 271 Residential New Construction (RNC), 20 Industrial New Construction (INC), 21 Non Residential Existing Building (NREB), 4 Industrial Existing Building (IEB) and 16 Township (T) applications amounting to a total of 693 applications while only 650 were registered representing 333 NRNC, 259 RNC, 19 INC, 20 NREB, 3 IEB and 16 T green building (GBI, 2013). Only 327 buildings received Green Building Index certification (164 NRNC representing 50% and 135 RNC (41%), 9 INC, 10 NREB, 2 IEB and 7 T representing 10%, 2% and 2% respectively). 118 RNC and 139 NRNC received provisional certification after design assessment while 17 RNC and 24 NRNC received final certification after CVA. It is apparent that green building is not commonly practised in residential buildings while most certified buildings are still at design stage. It can therefore be seen that while there are continuous increases in conventional buildings, this is not echoed in the green building industry. The next section
reviews the literature on the barriers toward implementing the green practices at an early design stage of residential buildings.

### Table 1: GBI Certified Projects by Category (Modified from GBI, 2016)

<table>
<thead>
<tr>
<th>Update on Green Building Index</th>
<th>TOTAL as of 15 OCTOBER 2015</th>
<th>NRNC Non Residential New Construction</th>
<th>RNC Residential New Construction</th>
<th>INC Industrial New Construction</th>
<th>NREB Non Residential Existing Building</th>
<th>IEB Industrial Existing Building</th>
<th>T Township</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied</td>
<td>693</td>
<td>361</td>
<td>271</td>
<td>20</td>
<td>21</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Registered</td>
<td>650</td>
<td>333</td>
<td>259</td>
<td>19</td>
<td>20</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>Total Certified</td>
<td>327 (100%)</td>
<td>164 (50%)</td>
<td>135 (41%)</td>
<td>9 (3%)</td>
<td>10 (3%)</td>
<td>2 (1%)</td>
<td>7 (2%)</td>
</tr>
<tr>
<td>Provisional Certification after DA</td>
<td>276</td>
<td>139</td>
<td>118</td>
<td>5</td>
<td>7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Final Certification after CVA</td>
<td>50</td>
<td>24</td>
<td>17</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Renewal Certification after RVA</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

### 2.3. Barriers toward implementing GBI Consultancy

GBI practitioners require more knowledge and experience of green principles to effectively cope with GBI requirements. As a result of intricacy of the design process, there could be insufficient or inappropriate effort put in place for planning and control (Tilley, 2005). In a study on managing the cost of green buildings, Tyagi (2005) highlighted that lack of experience with green building technology, components, and energy and water modeling programs can significantly impact the cost overruns. These have become critical issues for the industry.

The demand for green construction as well as the increased cost perception of green buildings means GBI Consultants have to manage green projects with tighter budget and tighter profit margins (Isa et al., 2014). Effectively managing the risks which could lead to cost overrun is essential in green building consultancy. Cost overruns according to Carter & Keeler (2008) are common problems in residential development. In their study reviewing the green building demand factors in Malaysia, Aliagha et al. (2013) found that the higher costs perceived to be associated with green building may have been based on outdated information and practices.

Communication and coordination among design team members and GBI consultants could contribute to enhancing the success of project delivery at the early design stage; they are also required to reduce complications and challenges inherent within the design process of green buildings (Elforgani and Rahmat, 2012). There is rarely enough time for coordination meetings, and to research all the interesting new green materials. Green building consultants only observe the requirements specified in the sustainability guideline without assisting the clients to identify and develop other crucial objectives and requirements for the overall project (Akintoye et. al., 2003). It is therefore useful to work out a
process for discovery and decision-making ahead of time (Telegen, 2005). The aim of this paper is to understand the barriers toward implementing Green Building index Consultancy and strategies to further improve green practices in residential building development. The strategy of inquiry into achieving this aim and the results of findings are discussed in the following section.

3. Research methodology

To achieve the aim of this paper a semi-structured interview of stakeholder group namely, consultants, developers/owners, builders/property owners and policy maker/regulators in the building construction industry from both private and public sectors was conducted. In terms of selection criteria, interviewees with the knowledge of, and experience in, green building were targeted. A semi-structured interview is one of the most appropriate ways of gathering data on phenomena which are not directly observable (Minichiello et al., 1990; Patton, 1989; McCracken 1988) and was deemed to be the preferable approach here to generate the essential data for analysis. Walker (1985) suggests that an interview of this nature requires between 20 and 40 respondents to generate the needed information for analysis. Of the 60 stakeholders sent an invitation 37 agreed to be interviewed. In the event, 11 consultants, 4 developer/building owners, 6 builders/property managers from the private sector and 9 Policy makers/regulators from the public sector were interviewed, 30 in all. The data from the interviews were then analysed using discourse analysis. Discourse analysis is the study of social life, understood through analysis of language in its widest sense (including face-to-face talk, non-verbal interaction, images, symbols and documents (Potter & Wetherell, 1987). It offers ways of investigating meaning, whether in conversation or in culture (Traynor, 2006). Table 2 summarises the profiles of the interviewees.

4. Analyses of the interviews

This section discusses the analyses of the interviews conducted. The findings were analyzed using discourse analysis and categorised into five themes namely: the stakeholders’ understanding of GBI consultancy, meeting the sustainability goal, services provided by GBI consultants, cost related issues, and general strategies to improve GBI consultancy; and concludes by presenting a summary of all the points raised.

4.1. The stakeholders’ understanding of GBI consultancy

Interviewees were asked to define GBI consultancy, the aim being to ascertain individual perceptions of the practice. Interviewees were of the view that it is a new field in the construction industry that looks at a wide range of services across the board including architecture, engineering and planning, together with some knowledge of materials. Interviewees C4; C6; B3; P1 and P4 were consistent with their definition that it is a specialist service providing sustainable designs solutions and requires knowledge of every aspect business. Interviewee C3 lamented that there were a handful of firms that purely do green building consultancy while the ones that include analysis work, such as ventilation studies and energy studies are more successful.

Two property contractors, interviewees B1 and B3 opined that providing consultancy services in green building requires an organization or person with the right knowledge and right experience to be appointed to render advisory services on how to go green. The issue of right and adequate knowledge of green principle and practice cropped up during the interviews. This is consistent with the views of Samari et al. (2013) on engaging well-qualified personnel with the right knowledge at the initial stage. Only one interviewee (C9) claimed to have a superficial understanding of GBI consultancy, having gone
through the GBI rating system. He pointed out that it only focuses people’s attention towards green. It can however be generalised that all the interviewees have a good understanding of GBI consultancy.

Table 2: Summary of Interviewees

<table>
<thead>
<tr>
<th>POSITION OF INTERVIEWEE</th>
<th>TYPE OF ORGANIZATION OR COMPANY</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSULTANTS:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Architect &amp; Member of PAM</td>
<td>- Architectural consultant</td>
<td>C1</td>
</tr>
<tr>
<td>- Engineer &amp; Member of MGBC</td>
<td>- Engineering consultant</td>
<td>C2</td>
</tr>
<tr>
<td>- Architect &amp; Member of GBIAP</td>
<td>- Architectural consultant</td>
<td>C3</td>
</tr>
<tr>
<td>- Engineer &amp; Member of GBIAP</td>
<td>- Architectural consultant</td>
<td>C4</td>
</tr>
<tr>
<td>- Architect &amp; Member of PAM</td>
<td>- Architectural consultant</td>
<td>C5</td>
</tr>
<tr>
<td>- Architect, GBI Facilitator &amp; Member of PAM</td>
<td>- Architectural consultant</td>
<td>C6</td>
</tr>
<tr>
<td>- Architect &amp; GBI consultant</td>
<td>- Architectural consultant</td>
<td>C7</td>
</tr>
<tr>
<td>- Architect</td>
<td>- Architectural consultant</td>
<td>C8</td>
</tr>
<tr>
<td>- Mechanical Engineer &amp; GBI consultant</td>
<td>- Architectural consultant</td>
<td>C9</td>
</tr>
<tr>
<td>- Mechanical Engineer &amp; GBI consultant</td>
<td>- Engineering consultant</td>
<td>C10</td>
</tr>
<tr>
<td>DEVELOPERS / BUILDING OWNERS:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Executive Director &amp; Head of Corporate</td>
<td>- Real estate developer and investor</td>
<td>D1</td>
</tr>
<tr>
<td>- Senior General Manager</td>
<td>- Real estate contractor and developer</td>
<td>D2</td>
</tr>
<tr>
<td>- Director of Operations</td>
<td>- Real estate developer and investor</td>
<td>D3</td>
</tr>
<tr>
<td>- Managing Director</td>
<td>- Real estate developer</td>
<td>D4</td>
</tr>
<tr>
<td>BUILDERS/PROPERTY MANAGERS:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Executive Director</td>
<td>- Property contractor</td>
<td>B1</td>
</tr>
<tr>
<td>- Manager</td>
<td>- Facility Manager</td>
<td>B2</td>
</tr>
<tr>
<td>- Managing Director</td>
<td>- Property contractor</td>
<td>B3</td>
</tr>
<tr>
<td>- Director</td>
<td>- Project Management</td>
<td>B4</td>
</tr>
<tr>
<td>- Director</td>
<td>- Property contractor</td>
<td>B5</td>
</tr>
<tr>
<td>- General Manager</td>
<td>- Project management</td>
<td>B6</td>
</tr>
<tr>
<td>POLICY MAKERS/REGULATORS:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Assistant Director</td>
<td>- Construction Industry Development Board</td>
<td>P1</td>
</tr>
<tr>
<td>- Director</td>
<td>- Construction Industry Development Board</td>
<td>P2</td>
</tr>
<tr>
<td>- Senior Architect</td>
<td>- Local Authority under Ministry of Federal Territories</td>
<td>P3</td>
</tr>
<tr>
<td>- Director</td>
<td>- Local Authority under Ministry of Federal Territories</td>
<td>P4</td>
</tr>
<tr>
<td>- Manager</td>
<td>- Local Authority under Ministry of Federal Territories</td>
<td>P5</td>
</tr>
<tr>
<td>- Manager</td>
<td>- Statutory Body under Ministry of Works</td>
<td>P6</td>
</tr>
<tr>
<td>- Senior Manager</td>
<td>- Statutory Body under Ministry of Works</td>
<td>P7</td>
</tr>
<tr>
<td>- Senior Technical Advisor</td>
<td>- Statutory Body under Ministry of Energy, Water and Communications</td>
<td>P8</td>
</tr>
<tr>
<td>- Senior Technical Advisor</td>
<td>- Statutory Body under Ministry of Energy, Water and Communications</td>
<td>P9</td>
</tr>
</tbody>
</table>

MGBC = Malaysian Green Building Confederation  
GBIAP = GBI Accreditation Panel  
PAM = Persatuan Arkitek Malaysia / Malaysian Institute of Architects  
ACEM = Association of Consulting Engineers Malaysia  
C = Consultant; D = Developer/Building Owners; B = Builders/Property Managers; P = Policy Maker/Regulator
4.2. Meeting the sustainability goal

The opinions of interviewees were sought on how GBI consultation had assisted in meeting sustainability goals. C3 was particularly enthusiastic of the fact that GBI had exceeded its goal in some of the rated buildings. It was further stressed that some certified buildings have exceeded what they predicted in terms of energy saving and water savings. D2 opined that the minimum certification had already given a 20% saving; for anything higher than that, the GBI consultant must know the target in terms cost saving, energy saving and water conservation and not just ticking off points. This interviewee further stressed the missing link is that developers know it is a rating tool but do not understand the target is to achieve 20% reductions. Interviewee C5, on the other hand believes that a lot of time is needed to confirm targets are being met. He perceived the practice is focused on points gathering for financial benefits and not for sustainability. It was argued that if buildings are certified, developers can claim tax and have a lower running cost but the true green is not met as the focus is on money and image (C5). To support the point raised by C5, D1 in his response described the GBI industry as a market place for trading points. This is consistent with some of Prins’ (2015) findings in his research into the application of New Zealand Green star sustainability rating tool.

4.3. Services provided by GBI consultants

Interviewees were asked to comment on the current services provided by GBI consultants. Some interviewees agreed consultants are very genuine in their practice; they hold on to the spirit of what the green building is really about. Most of the policy makers and regulators, P1, P3, P5, P7, P8, and P9 were impressed by the services provided so far. They agreed GBI consultants are successfully providing the services to the clients. They have made quite a good impact in the industry because of their services (P7). C3, a member of GBI AP, believes that there is need for more GBI consultants as there may not be enough in the industry now because the take up rate in GBI now is very high. It was emphasized that in the early days there was a bit of confusion because some of the fees charged were very high but over three and a half years the price has stabilized and became affordable. This statement is consistent with Darus et al. (2009). It was further stressed that at the inception of GBI in 2009, it was argued that it was a waste of time but now it is seen as worthwhile. However, the real issue is the level of greenness their services have achieved. On the other hand, P2 complained that some GBI consultants are very poor in rendering the services while some are stronger. Those who have done a few projects and possess an in depth knowledge of mechanical and electrical engineering provide a better service than those who do not have that experience (P2).

Interviewee C4 a member of GBIAP expressed that they have received a lot of complaints about GBI consultants in the industry who are not doing well due to the way they practise but that developers are actually committed to green building practice. Interview C1, shared that the initial projects were difficult because green building materials were available, there was no information to show they were actually green. MGBC has now published green pages (The Green Building Products & Services Directory) and most green building materials suppliers have to demonstrate their green content. Also, with the recent Construction Industry Development Board’s guideline on green building construction, this whole gap has been closed. Designing with the green rating tool has assisted in closing the design gap, while the procurement gap was closed using green material through the MGBC’s green pages (C1).

The three–day GBI consultant training program does not cover the wider field of sustainability. Though seminars, workshops and conferences are organized to train GBI consultants and widen their knowledge of the concept, those without a prior knowledge of green building are disadvantaged. The
process of certification is still weak due to some of the GBI consultants not knowing what documentation is required and how to present it to the client. There are no yardsticks to measure the performance of the consultants’ services as there are for conventional buildings and developers do not see any need to engage GBIF in their projects (P3). D4 concluded that GBIC must be experienced practitioners, not someone who only completed the three-day training program.

4.4. Cost related issues

This section explores some of the cost issues in the mind of industry stakeholders that are seen as major challenges to the adoption of GBI consultancy. C7 was of the opinion that reducing green building cost at the early stage could be accomplished by enacting by-laws to address green building in Malaysia. According to him, there are regulations in Europe that glass must be double or triple glazing and the walls all need insulation while Malaysia has only fire rating to prevent fire spread. The new building by-laws coming up have all these things and it is partly driven by Green Building Index rating tools. Once the laws are in place the cost will come up and the base building cost will be negligible. “So when you say green building is expensive it’s not true.

C1 and B6 argued that green building is not as expensive as perceived. They claimed it should not cost a lot because in the United Kingdom, the cost is about the same as conventional buildings. Green building materials are still being imported to Malaysia and not locally sourced, with the potential for delays in construction and extensions of completion periods (P9). In addressing cost related issues, Green building consultants’ approach to cost effectiveness must be strong enough to critically examine how financially viable the design is. B7 lamented that in order to do that, if GBI consultant is fully aware of the rating system it is better to go for a criteria that is low cost or no cost at the first before you actually do one that will take a lot of cost. Then one can have a green building with a very low cost. C5 opined that while the GBI proposes photovoltaic (PV), there is no reason for using solar PV cell unless looking at different energy systems. Everything is about optimisation and how to build sustainability. He argued that to make GBI cost effective is a long process and would require adopting a passive design approach. He further argued that the cost of installing PV cannot be recouped within the PV lifecycle. This is consistent with Applasamy’s (2011) finding that, the cost to generate per kilowatt hour of electricity by applying life cycle costing (LCC) analysis for a typical household of four using stand-alone PV technology is more than five times the current cost of electricity for residential household.

4.5. General strategies to improve GBI consultancy

Interviewees were given the opportunity to share their opinions on actions to improve GBI consultancy in order to promote green practices in the Malaysian construction industry. They suggested the government need to further encourage and support the implementation of green building practices by providing financial incentives to developers who may require assistance to cope with the increased up-front costs of resource-efficient technologies in their projects. Suggestions were made that building capacity within the public sector will help to raise the level of understanding in government circles and the political class, thereby bringing the changes in policy and legislation necessary for the implementation of green building practices.

As a way to further improve green building consultancy in the industry, the general public which constitutes an integral part of the client base, require a number of public awareness campaigns and outreach programmes in schools and the media. Educating the public at large about the principles and concept of green building and how it relates to their lives and businesses and the benefits of demanding
more sustainable options needs to be a priority. Not only that, incorporating green building practices in the built environment courses taught at tertiary institutions and monitored by the Malaysian Green Building Council and the Malaysian Board of Architects was suggested. In order for a building project to become green it is very important that the GBI consultants be involved at the onset of the project and get a proper direction of the project from the client then see what they think about sustainability and develop its scope. Once this is done, the whole team can actually sit around the table and workshop ideas and apply it to the actual project (D2.2). On the other hand, interviewee C1.9 was of the strong opinion that the services provided by GBI Consultants would eventually be phased out when all architects and engineers are fully experienced in green building technology. Finally there was clarion call to MGBC to give an annual award to outstanding GBI consultant.

5. Discussion, Conclusion and Recommendation

The interviews revealed that the lack of involvement of the GBI consultants at the initial stage of the green building design process was a major barrier. The incompetence and lack of experience of some GBI Consultants in sustainable design affects design process duration and project resources. The stakeholders stressed poor coordination and ineffective communication among design team members and GBI consultants was a major concern. A more collaborative effort to reducing cost and wastage during design stages was vital. Design team members are required to have integrity and be cooperative, responsive, responsible, courteous, friendly and proactive in dealing with consultants. While better knowledge of the requirements of the client is also required, communication is needed with clients and consultants at all times. Setting up a third party to check the performance of the consultants will help identify the better performers and get rid of poor consultants in the industry. Training the architect to work with the climate and all those concerned is important and the GBI consultants should be part of the setup within the architectural firm rather than an external party. A lot of construction wastage, expensive errors and technical fallout may be averted when competent and appropriate GBI Consultants are engaged. However, ensuring a proper level of service and effective co-ordination with team members are pointers to managing GBI consultancy at the design stage; the introduction of green pages by MGBC has now made it very easy to get green materials and has helped to close the procurement gap in green material supply in the industry. CIDB’s new release of guidelines on green building construction has helped to close the green construction gap.

A lack of performance evaluation of GBI consultants engaged in the design stage has hindered their development in Malaysia. It is recommended that engagement of GBI consultants be based on demonstrable skills, knowledge, and professionalism. In addition, they should be particularly responsive to the clients’ requirements and feedback. The current green building guidelines should be reviewed from time to time and supported by proper research and decision making at the local level. Better collaboration amongst government agencies is also vital for effective implementation of these consultancies. Finally, a process for independent third party evaluation of the performance of GBI consultants is needed to ensure confidence in their skills.

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Using LCA to assist the selection of wall systems in the early stage of building design

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Abstract: Choice of materials for a buildings’ façade significantly affects its life cycle environmental performance (LCEP). However, accurate assessment of the environment impact of different wall materials from a life cycle assessment (LCA) viewpoint is too complex for designers to determine in the early design stages of design. Assessing the life cycle environmental impacts (LCEI) caused by manufacturing, maintenance and disposal require knowledge of variables that are often unknown at the early stage of design. This paper evaluates the potential for developing principles that may assist designers to estimate the impact of material selection on the building LCEP at the early stage of design. The paper examines a small number of variables (material weight, service life, and recyclability/reusability) to both highlight the level of LCA complexity and uncertainty at different phases of material life cycle and to show that it may be possible to determine more elementary heuristic principles that may help designers make LCEI decisions at the early stage of design.

Keywords: LCA; façade material selection; early stage design; embodied energy and CO₂ emissions.

1. Introduction

Buildings are responsible for significant environmental impacts through all their life cycle including construction, operation, and end of life. The importance of considering the life cycle environmental impacts (LCEI) of a building has been elaborated by several studies (Fay et al., 2000; Thormark, 2002; Dixit et al., 2010; Monahan and Powell, 2011). They have shown that the environmental impact of initial construction can be just as significant as those affected by their operations.

A multitude of interrelated variables affect a building’s Life Cycle Assessment (LCA), making it too complex for designers to base decisions on, particularly at the early design stage. Any attempt to find common criteria or principles for design decision making from the results of previous studies is problematic because different studies determine LCA results using different parameters (such as site-specification, applied databases, analysis method for example).

Building envelope design is a common area identified for energy-saving opportunities. The significant impact of building envelope design has been identified by several studies, (Cheung et al., 2005; Ramesh et al., 2011; Zabalza Bribián et al., 2011). Choice of materials for a building’s external walls significantly
affects a building’s energy performance during use and life cycle environmental performance (LCEP). While the energy performance during the use phase is reasonably well understood and commonly applied to façade design, there is a lack of designer-friendly information on the overall environmental impacts of manufacturing, maintenance and disposal which has limited the ability to reduce the building LCEI.

This study highlights the level of complexity of calculating LCEI, and therefore the difficulty of developing elementary heuristic principles to assist designers, by considering three façade material variables: material weight; service life; and disposal/recycling/reuse. For this research, the environmental performance of alternative façade assemblies is assessed using the energy consumption and CO₂ emissions throughout their life cycle. A simulation-based optimization methodology was developed for comparing the environmental impacts of different façade materials to elaborate the difficulty of employing LCA at the early design stage. It uses a multi-residential building in Sydney Australia as the project and site, as knowing the building scale and study location allows reasonable assumptions to be made for material production and transport, material useful life, dismantling and disposal technologies, and heating and cooling demands over the assumed 50-year building lifetime. A comparative LCA method was selected as a sustainability-measuring tool to compare the environmental impacts of producing different facades.

2. Background: Complexity of Life Cycle Assessment

There is a growing body of literature on LCA around building production. Most studies typically analyse the role of different construction materials and quantify them in terms of the embodied energy and the environmental impacts.

The most critical decisions regarding building efficiency in terms of the minimization of LCEIs and energy consumption are often made at the beginning of the design process. Early decisions thus significantly influence the life cycle energy performance of the building (Figure 1).

The availability of data in the initial stages of design is a major problem for designers. A huge amount of data and a certain degree of expertise in the field are required for LCA. Furthermore, building plans, including details of external walls, partitions, slabs, roof, and the selected cladding system, need to be well defined to accurately perform LCA. Because architects and engineers have limited expertise in LCA and the building form and fabric is fluid at the early design stage, most design decisions at this stage are based subjectively upon the designer’s experience rather than quantitative indicators.

Figure 1: Influence of design decisions on life cycle impacts and costs (UNEP, 2003)
Inventory assessment of building materials and the process of construction and demolition are the main aspects of the environmental impact assessment. However, a major difficulty with this kind of analysis is that the material production processes are not always standardised due to the unique character of each building. The availability of assessable information about the environmental impacts of the production and manufacturing of construction materials, the actual process of construction and demolition are limited (Ramesh et al., 2012).

The majority of tools used to assess the impact associated with building products are often limited in their ability to provide comprehensive, reliable and comparable environmental information across their whole life cycle. There are few consistent environmental impact results of building LCA outcomes to be found within the literature because of the application of different parameters, factors, datasets, system boundaries, interpretation methods, erroneous or overly-specific assumptions. In addition, values of embodied energy and equivalent emissions of carbon vary by country due to the energy mix, transformation processes, efficiency of the industrial and economic system of the country, and the variability of these factors over time, making calculation even more difficult (Sartori and Hestnes, 2007).

The other important criteria for decisions made from a life cycle perspective involve ensuring that a solution to reduce energy consumption for one life cycle stage does not increase overall life cycle energy demands. Results from previous studies of life cycle energy requirements demonstrate that a particular material or assembly may perform differently when applied in a different situation. For instance, materials with low initial embodied energy do not necessarily have low life cycle energy (Utama and Gheewala, 2009; Crawford et al., 2011). We analysed nine selected LCA studies of building materials and products (Asif et al., 2007; Kofoworola and Gheewala, 2008; Monahan and Powell, 2011; Zabalza Bribián et al., 2011; Monteiro and Freire, 2012; Crawford, 2013; Thiel et al., 2013; Dodoo et al., 2014; Lee et al., 2015) and found that these studies used different assumptions, materials, databases and analysis method. It is therefore difficult to draw comparisons among the studies and find generalisable design principles that could be employed by designers at the early design stage.

3. Methodology

A quantitative and qualitative analysis was undertaken for a limited number of façade materials on a multi-storey residential building to assess the impact of material weight, durability, and recyclability/reusability on their life cycle energy demand.

3.1. Definition of a reference building as a case study

A four-storey residential building in Sydney (33°52.071′ S, 151°12.4392′ E) with an assumed 50-year life is taken as a reference building for this study. The building shape is rectangular (long axis east-west) with total floor areas of 3135 m². At the ground floor, one unit is substituted by an office. Overall the building includes 31 residential units, 1 office, corridors and vertical distribution zones.

For the purposes of this paper a hypothetical external wall system consisting of the following 4 main materials was considered: Cement-bonded particleboard, Expanded Polystyrene (EPS), Cross Laminated Timber (CLT) and plasterboard (Table 1). The embodied energy and the equivalent CO₂ emissions of the façade materials were analysed using three different scenarios:

- **Scenario 1**: The embodied energy and the equivalent CO₂ emissions of the external wall panels analysed with two different weights (Table 1)
• **Scenario 2**: The impact of materials service life on the building’s life cycle energy demand analysed based on three different assumptions: (i) total embodied energy calculated considering service life of each layer; (ii) the whole external wall panel replaced in the middle of the building’s life; (iii) no material substitution occurring during the building life.

• **Scenario 3**: Different waste scenarios to determine the impact of end of life phase on building LCA.

Table 1: Description of External wall’s assemblies

<table>
<thead>
<tr>
<th>Materials</th>
<th>Base Case Thickness</th>
<th>Base Case Density kg/m³</th>
<th>Heavy Case Thickness</th>
<th>Heavy Case Density kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement-bonded Particleboard</td>
<td>10 mm</td>
<td>1200</td>
<td>16 mm</td>
<td>1200</td>
</tr>
<tr>
<td>EPS</td>
<td>60 mm</td>
<td>28</td>
<td>90 mm</td>
<td>28</td>
</tr>
<tr>
<td>CLT</td>
<td>94 mm</td>
<td>500</td>
<td>108 mm</td>
<td>500</td>
</tr>
<tr>
<td>Gypsum Plaster Board</td>
<td>12 mm</td>
<td>900</td>
<td>12 mm</td>
<td>2800</td>
</tr>
</tbody>
</table>

### 3.2. Life Cycle Assessment

Building life cycle energy demand and emissions are affected by various parameters directly or indirectly. Construction, operation, renovation and demolition are direct, while production of materials used in construction and technical installations are indirect effects (Sartori and Hestnes, 2007). The life cycle energy of a building’s external facade was analysed in this study. It included initial embodied energy (associated with manufacture of products and materials), recurrent embodied energy (required for maintenance of components and materials), and the disposal energy (for demolition and disposal of materials or possible reuse or recycling after the building’s useful life). Life cycle energy finally includes operational energy, used for operating Heating, Ventilating and Air Conditioning (HVAC) systems in order to maintain indoor comfort conditions.

### 3.3. Material Manufacturing & Construction Phase

**3.3.1. Initial Embodied Energy (IEE)**

The total energy used to transform raw materials into ready to use building products is initial embodied energy. Quantifying the embodied energy of a product or process is complex due to the variation of its design and location of manufacture and use. Technology, fuel supply infrastructure, region, product specification and analysis method affect the embodied energy assessment (Ngo Tuan et al., 2009).

SimaPro 8.2.0 (Australian database-AusLCI unit processes) was applied in this study to quantify the embodied energy and CO₂ emissions. The software databases include a variety of parameters such as construction materials, transportation, installation and waste treatment. The cumulative energy demand (version 2.02) method used to quantify the embodied energy and, the equivalent CO₂ per Kg was analysed by ACLAs best practice LCIA Recommendation (version 2.0).

The constant parameters were defined for each material and all input from the techno sphere (materials and fuels) were described based on AusLCI unit process records. Energy consumption of transportation of materials from plant to construction site was added based on assumed truck weight and distance. As an overseas manufactured material, CLT required consideration of all legs of its
transportation from Austria. All other installation processes (e.g. the crane at the construction site) were considered as constants in this analysis not affecting comparative results for the sake of this study.

### 3.3.2. Recurrent Embodied Energy (REE)

The recurrent embodied energy is calculated based on the number of times each individual material is assumed to be replaced during the useful life of the building. This can significantly increase the total embodied energy. The material service life and the building useful life (which ends with demolition) are the effective parameters for analysing REE. These parameters are uncertain due to their dependency on uncontrollable factors such as users’ behaviour, climate, and maintenance. The materials’ service life was drawn from the literature (Table 2). The life cycle embodied energy of the building’s external walls, including initial and recurrent embodied energy, was calculated using Eq.1 (Crawford R.H., 2009).

$$LCEE_a = \sum \left( \frac{UL_b}{UL_m} \times EE_m \right)$$  \hspace{1cm} (1)

Where $LCEE_a$ = Life cycle embodied energy of the building assembly, $a$; $UL_b$ = Useful life of the building; $UL_m$= Useful life or replacement period of material, $m$; $EE_m$ = Embodied energy of material, $m$, includes initial embodied energy and disposal energy.

### 3.4. Operation Phase

Building envelope design affects heating and cooling demand as it is the main area where thermal losses and gains occur (Koo et al., 2014). Thermal properties of the reference building were modelled in DesignBuilder. The initial model was selected from a Department of Energy (DOE) reference building of mid-rise residential apartments in the USA. Configurations of the model were changed for Sydney’s climatic location. All settings for construction, lighting and HVAC configurations were inherited from the DOE and heating and cooling are based on gas and electricity respectively. Configurations were set to be compliant with the building code of Australia (ABCB, 2014), in particular deemed-to-satisfy provisions. All internal load schedules were changed accordingly based on (NatHERS, 2012). The optimized window system was a double glazed unit with timber frame and window to wall ratio of 40% for all external walls without any internal or external shading. The final model is fully described in (Bashirzadeh Tabrizi and Fiorito, 2016).

### 3.5. Demolition and Disposal Phase

Few reliable studies exist for the LCEI associated with the demolition of buildings and disposal of materials. Crowther showed that the amount of energy required for the disposal phase is extremely low in comparison with the energy demand of a building during its whole life cycle — less than 1% of total
embodied energy (Crowther, 1999). However, considering end-of-life choices for building materials—including reuse, recycling, reprocessing, energy recovery, and landfill—could vary the result significantly.

Qualitative analysis was applied to analysing the LCEI of different waste scenarios for the building, as variables affecting end of life analysis are uncertain. Early assumptions about energy for dismantling facilities, emissions from dismantling and handling, transport to dismantling facilities and final disposal of waste materials might totally change at the end of the 50-year building life.

4. Results and Discussion

This section presents the results and discussion of the significance of different variables for life cycle environment assessment of the hypothetical façade system.

4.1. Scenario 1

Results: The comparison between the life cycle EE demands of each of the 4 different materials in the hypothetical façade system was first examined in terms of their weight. The impact of changing panel weights is illustrated in Figure 2a-2b. The heavier panel had an increased embodied energy of 60% for cement-bonded particleboard, 49% for EPS, 11% for CLT and 211% for plasterboard. A similar result was observed for the equivalent CO2 emissions. Increased emissions for cement-bonded particleboard were 60%, EPS 50%, CLT 14% and plasterboard 211%. The impact of changing wall material density or thickness on the reference building’s operational energy (heating and cooling) is elaborated in Figure 3.

![Figure 2a-2b: Embodied energy and CO2 emissions comparison of panel layers with different weights](image1)

![Figure 3: Operational energy comparison of two CLT panels with different weights](image2)
Discussion: From the results it is evident that changing material weights does not affect operational energy in a significant way (differences less than 0.7% were recorded for heating energy demand). However, the choice of facade panel layers with various weights has a significant effect on EE. A building with the façade constituted by lighter materials consumed 48% less energy and produced 57% less CO₂ emissions (Figure 4a-4b).

Figure 4a-4b: Embodied energy and CO₂ comparison of two facade panels with different weights

4.2. Scenario 2

Results: Figure 5 shows the influence of differing service lives of wall materials. It shows that energy demand of replacing materials through the building life significantly affects the total EE. However, the effective variables are both uncertain and interrelated in this phase, making it difficult to determine exact results even for a very tightly constrained case study such as this. Consequently, this study analysed the impact of REE on total embodied energy in terms of three common assumptions: (i) total EE of the panel considering each material’s service life (793.84 MJ/m²). (ii) total EE of the whole facade panel substitution at the middle of building life (1166.2 MJ/m²), (iii) total EE of facade not being replaced during building’s life (583.1 MJ/m²).

Figure 5: Embodied energy comparison of panel layers with considering REE
Discussion: Overall it can be noticed that total embodied energy significantly changes by considering the REE (Figure 6). This study shows the 50% increase for total EE demand of the multi-storey building’s external facade.

4.3 Scenario 3:

Building materials as Construction and Demolition (C&D) waste encounter various waste treatments: disposal to landfill; indirect or direct recycling; reusing the material or product. The difficulty of investigating each treatment is highlighted by selecting timber as an example in this section (as timber is used in both particleboard and CLT in this case study) (Taylor and Warnken, 2008).

![Figure 6: Embodied energy comparison of panel layers with considering REE](image)

Wood recovery and recycling (2008) advises that reuse (keeping original form and function) is the best recovery opportunity for waste timber; next is direct recycling into other timber products such as particleboard; then indirect recycling non-timber products (such as landscape mulch); then energy generation (process heat and/or electricity). Increasing demand for reusing building materials is derived from sources such as architects, home renovators, and hobbyists/craftspeople. However, factors such as transport costs, and the space available for receiving, sorting and display of the timber materials make this business complex. Recycling processes are influenced by many uncertain factors and a lack of information about the recycling process energy demands and possible environmental impacts of ‘contaminants’ and preservative treatments on the direct or indirect recycled products. Using timber waste for energy generation raises issues such as air pollution. Methane, a potent greenhouse gas, is produced during the anaerobic decomposition of timber waste in landfills. Recovering timber prevents the release of greenhouse gases. It is evident that the environmental impact of products or materials at the end of life is more complicated than can be quantified by LCA tools.

5. Conclusion

This study examined the LCEI of a hypothetical façade system constituted by 4 materials, for 3 scenarios: varying material weight; varying service life, and varying end of life options (landfill/reuse/recycle).

From scenario 1, varying material weight, it can be seen that considering a materials’ mass at the early design stage is important due to: (i) its influence on the end of life scenario. Lowering construction waste mass decreases, the environmental impact of this phase and helps landfill shortage problems (ii) Material weights affect all interrelated transportation phases. This seems more important when a material is imported (like CLT panel in this study) compared to local materials, as transportation was mainly responsible for the amount of CLT embodied energy and CO2 emissions. Transportation energy
demands were calculated based on Kg*Km, therefore the weight of the materials significantly increases their LCEI for long distances. (iii) Increasing 30mm thickness of insulation of external walls generated 18849.47 KgCO₂ more and consumed 234929.24 MJ more energy for the case study building without any energy saving in the use phase.

Scenario 2 demonstrated that material service life was significant in terms of LCEI and that it has the potential to be the basis of heuristic advice for designers (e.g. ‘long service life and low maintenance is likely to reduce LCEI’), but that the interrelatedness and uncertainty of variables make simple advice problematic.

Scenario 3, varying end of life treatments, confirms the complexity of attempting to apply a comprehensive LCA in the early design stages. Considering various alternative waste scenarios — disposal to landfill, recycle or reuse — can significantly change the LCEI results of building materials. For instance, because it is hard to assume the impact of certain parameters on recycling or reusing materials process at the end of a building’s service life (particularly as technologies may change significantly during that time), it may be impossible to quantify their LCEI at the early design stages.

Overall, this research indicates that designers should be made aware that the level of complexity and certainty/uncertainty is different in each LCA phase. This small study illustrated the changing degree of certainty with three scenarios and the need to rely on both quantitative and qualitative analysis methods or different phases. The first scenario demonstrated the impact of material weight on the building energy demands and the equivalent CO₂ emissions as a result of certain parameters and consequently gave reliable and replicable results. REE calculation in the second scenario was based on uncertain variables (most of them dependent on user behaviour). However, considering the same assumptions would have led to the same results. Qualitative analysis was needed for investigating the LCEI in scenario 3 due to the lack of reliable end of life information and the high level of uncertainty of effective parameters.

References


Improving thermal performance design outcomes through NatHERS and BIM integration

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Abstract: The Nationwide House Energy Rating Scheme (NatHERS) has played a significant role in demonstrating the thermal performance compliance of residential buildings in Australia. However, NatHERS tools are rarely used during conceptual analysis to help iteratively improve and optimise the performance of buildings throughout the design process. A significant contributor to the lack of adoption in the design process is the user interface of these tools, which rely on manual data input, making them incompatible with typical Building Information Modelling (BIM) workflows. This paper describes a working software prototype called SketchuRATE that has the potential to convert BIM data directly into the AccuRate Sustainability file format, minimising the need for manual data entry or duplication. Once fully functional, a tool like SketchuRATE could shift the focus of house energy ratings away from achieving only minimum compliance, towards more economical, optimised and improved thermal performance outcomes.

Keywords: NatHERS, building compliance, thermal analysis, BIM.

1. Introduction

Since 2003, the Nationwide House Energy Rating Scheme (NatHERS) and associated software has played an increasing role in demonstrating the thermal performance compliance of residential buildings in Australia. According to the NatHERS Administrator, it is estimated around 70 percent of new dwellings in Australia are assessed using a NatHERS tool to demonstrate energy efficiency compliance under the National Construction Code (NatHERS, 2015). In the 2014-2015 financial year, this represented over 150,000 dwellings per year (derived from Kalisch, 2016).

However, because of the emphasis on compliance, NatHERS tools are rarely used as part of the design process to iteratively improve the thermal performance of the final design (even though that is invariably the only thermal analysis undertaken of the design). This situation is exacerbated by the user
interface of these tools, which all rely on some form of manual data entry of building information from architectural drawings and specifications, in order to complete a house energy rating.

A perhaps unintended consequence of this process is that the role of the thermal performance assessor has become more about data entry rather than the provision of thermal performance advice. What started as a cottage industry of individuals passionate about building sustainability has slowly deviated into a high volume, low cost operation where a handful of larger companies churn out tens of thousands of assessments each year. In turn, the focus appears to have shifted towards achieving the first minimum compliance outcome, as opposed exploring all options to genuinely improve and optimise a dwelling’s thermal performance.

Concurrently, there has been increasing uptake of Building Information Modelling (BIM) workflows within the building and construction industry. According to a 2010 study commissioned by the Built Environment Innovation and Industry Council, the “accelerated widespread adoption of BIM technology” is likely to have a “significant expansionary effect on the Australian economy” - an increase in GDP of between $4.8-7.6 billion over the 2011-2025 period (Allen Consulting Group, 2010).

Given the rich database of information available in a typical Building Information Model, there is significant potential to develop a workflow or methodology that could facilitate the use of this building information for the purposes of evaluating a building’s energy efficiency compliance. If successful, it is envisaged this would eliminate the unnecessary, manual duplication of data from architectural drawings and specifications into NatHERS tools. In turn, this could shift the focus of house energy ratings towards optimised or improved performance outcomes, not just minimum compliance. Streamlining the delivery of compliant energy efficiency outcomes also has the potential to reduce lead times and/or construction costs for clients in the procurement of new residential buildings.

The integration of energy and thermal performance analysis into a BIM-based workflow is not a new idea. Numerous papers have previously highlighted the benefits of this approach, such as allowing dynamic energy simulation and continuous verification of performance over a building’s entire life cycle (Laine & Karola, 2007). Other publications have also identified the challenges involved, such as a need for validation of the analysis model and additional information apart from building geometry (Moon et al, 2011).

This paper provides an overview of a proof-of-concept tool we have been developing, known as SketchuRATE, and the progress made to date in addressing some of these challenges in the Australian context.

2. What can be improved with the current approach to NatHERS?

It is important to note that this paper is not about the “accuracy” of the CHENATH engine upon which all current NatHERS tools are based. While there have been papers previously published questioning the effectiveness of NatHERS (Williamson, 2001), there have also been papers that validate its methodology (Delsante, 2004; Dewsbury, 2015; O’Leary et al, 2016). This paper assumes that NatHERS is a valid approach for estimating heating and cooling household energy consumption. Consequently, it focuses on improving the workflow integration of house energy ratings with the design and documentation of residential buildings using BIM.

Figure 1 illustrates the typical workflow required to complete a house energy rating on a single dwelling. Based on this workflow diagram, we have identified three opportunities for improvement in relation to the accuracy and/or time required to conduct house energy ratings:
• Significantly reduce duplication of key building information;
• Minimise or eliminate data entry inconsistencies; and
• Allow more time to improve building design and thermal performance outcomes.

2.1. Avoidable Duplication of Building Information

In order to conduct a house energy rating, dimensional data must be inputted into the rating software. This typically includes wall lengths and heights (external and internal), floor, ceiling and roof areas, door and window opening areas, and volumes of functional zones within the building. Building and construction materials also need to be specified in the rating software.

Figure 1: Typical workflow for conventional approach to House Energy Rating.

With all three software tools currently available for conducting a NatHERS assessment, all of this data and information needs to be manually entered into the rating software. While some tools such as FirstRate and BERS have limited capabilities to import PDF documents that can be traced over digitally, currently there is no direct connection between NatHERS tools and existing CAD/BIM software applications. If the design changes in any substantive way, much of this information has to manually edited or entered again to reflect those changes.

However, all of this dimensional, area and volumetric data already exists in a typical BIM or gbXML model; these models can also contain information regarding proposed construction materials and their associated properties. Given the ready availability of this building information, extracting and manually entering this information into the rating software seems a time-consuming and laborious exercise that is prone to error.

2.2. Inconsistency of Data Entry

Accuracy of data entry appears to be the area of greatest unreliability with house energy ratings completed using existing workflows. A 2014 benchmarking study conducted on behalf of the
Commonwealth Department of Industry found that in a statistically significant sample of assessors, 64% of assessors had an error greater than 0.25 of a star (Floyd, 2014). The study also found:

- errors increased significantly with the increasing complexity of [house] design and documentation;
- 25% of assessments reported incorrect window areas;
- the [calculated] area of different wall constructions and floor coverings ... showed error rates ranging from 10 to 70%; and
- [A variety of errors] indicated the lack of a systematic approach to the rating process by assessors.

These findings can be plausibly attributed to erroneous interpretation of the architectural drawings, construction specifications and/or mistakes when entering into the rating software. All of these are the direct responsibility of the assessor, which suggests changes to the NatHERS workflow that minimize or eliminate the possibility of data entry errors may help to improve the accuracy of house energy ratings.

2.3. Allow more time for optimising building design and thermal performance outcomes

The automatic generation of input aims to avoid unnecessary duplication of effort and substantially reduce data entry errors, allowing more time to review the thermal performance and compare options or explore design alternatives. By shifting the focus towards performance optimisation, and if minimum compliance ratings are achievable more quickly, this has the potential to encourage a transition towards improved energy ratings and yield potential construction cost savings as a greater range of design improvements can be explored as part of the optimisation process.

3. SketchuRATE: an alternative approach to house energy ratings

In response to the aforementioned opportunities for improvement, we have been developing and testing an alternative methodology for conducting house energy ratings. The ultimate goal is to create a seamless integration between NatHERS and a workflow based around BIM, so that house energy ratings can be conducted quickly, accurately and allow for the iterative improvement of thermal performance.

Known as SketchuRATE, the “proof of concept” workflow (Figure 2) is based around the creation of a standalone SketchUp model, from which key dimensional, area and volumetric data can be extracted. This initial starting point came about as a quality assurance process while conducting our own house energy ratings, as it allowed measurements to be checked both visually and quantitatively against a simple 3D model (modelled from the original architectural drawings). This in turn lead to the creation of an automated Ruby script that could extract this data directly from the model, which ultimately resulted in the development of a software service that could then convert this data into the .PRO file format used by AccuRate Sustainability.

While the current workflow is based around the use of SketchUp, it should be noted that this data and information could also be derived from BIM applications such as ArchiCAD or Revit, as is suggested in Figure 2. Recently, we have also developed a working prototype that can extract the required information from a Revit model.

Irrespective of the original model source, the data is then converted into a temporary XML file, which is uploaded to the SketchuRATE server, parsed, converted and downloaded as an AccuRate
Improving thermal performance design outcomes through NatHERS and BIM integration

Sustainability data file. At this time, a simplified XML schema has been used, though this can be readily adapted to suit another schema already adopted by industry, such as gbXML and/or ifcXML.

Figure 2: Proposed SketchuRATE workflow for House Energy Ratings.

The resultant data file can then be opened in AccuRate Sustainability, and is pre-populated with the following data and information:

- Project name and Design Option ID
- All Zones including volume, floor area, floor height and maximum ceiling height above floor
- All external walls including length, height and azimuth
- All external doors and windows, including name, height, head height, width and horizontal offset
- All internal walls including length, height and adjacent zones
- All floors and ceilings including areas, under the floor and above the ceiling adjacencies
- All roofs including areas, azimuth and pitch

At this time, the remaining data and information still needs to be entered manually in AccuRate Sustainability:

- Construction types and colours
- Zone types and ceiling penetrations
- Horizontal and vertical shading schemes
- Ventilation data

3.1. Results of preliminary trials

Even though the tool is still only at “proof of concept” stage, to date SketchuRATE has been trialled in over 50 certified building assessments by an accredited NatHERS assessor. The time taken to carry out an assessment was recorded and compared to times taken using previous assessment methods. The
results indicate that the time otherwise required for data-entry of the building geometry was reduced by around 50%. The overall time to complete an assessment remained similar, however more time was dedicated towards exploring multiple opportunities to optimise the final rating. Qualitative feedback from the assessor indicated that the number of data-entry errors were reduced and "de-bugging" of the model was faster due to the visual modelling environment.

These results indicate that the use of SketchuRATE can substantially reduce the time taken to enter the information required to conduct a house energy rating. Additionally, it improves the accuracy of data entry and the representation of zones and adjacencies within AccuRate Sustainability.

4. Critique and Analysis

We believe further development and deployment of a software tool like SketchuRATE has great potential to streamline the way in which house energy ratings are conducted in Australia. To help guide the development of a useful, robust software tool and associated workflow, the following is an attempt to objectively critique and validate the development approach that has been taken with SketchuRATE.

4.1. Why not keep using existing NatHERS software?

There are currently three software tools to choose from when performing NatHERS assessments, each with their own advantages and disadvantages. However, the disadvantage inherent in all of them is the need to manually translate dimensional data and information into the rating software. Since information already exists as part of a typical BIM workflow, it seems to makes sense to leverage this existing data, rather than duplicate unnecessarily.

4.2. Why not use other analysis software that already works with BIM?

There already exists a number of building energy analysis programs that are either already compatible or integrated with BIM workflows. For example, ArchiCAD includes the EcoDesigner plugin that can perform zone-based thermal analysis of a building envelope directly from the ArchiCAD model. There are also tools that can convert BIM data for use with comprehensive analysis programs such as EnergyPlus.

The challenge then lies in trying to produce correlated outputs with the CHENATH engine upon which NatHERS is based. According to NatHERS (2014), any new rating tool/engine must be capable of producing results within a 5 percent margin of those calculated by AccuRate Sustainability across a range of climate zones and sample floor plans.

To date, no thermal analysis program not based on the CHENATH engine has been able to achieve this requirement. Without detailed working knowledge of the CHENATH engine, this is a significant and discouraging hurdle for software developers wishing to explore alternative thermal analysis tools.

4.3. So why not develop a new analysis tool based on the CHENATH engine?

Floyd (2014) estimates that there are less than 2,000 active assessors across Australia; with the number of accredited assessors likely to have dropped further since this time due to the introduction of new qualification and accreditation requirements. Thus, the segment of this target market that would consider switching to a new, fourth rating tool is likely to be too small to justify the significant time and financial resources required to develop and support it. It would therefore seem a more viable approach
to integrate with an established software tool based on the CHENATH engine that is already accredited. Since AccuRate Sustainability is the tool that is used to benchmark all other NatHERS software, this would seem the ideal choice.

4.4. Why not demonstrate energy efficiency compliance using an alternative solution pathway?

While it is possible to demonstrate energy efficiency compliance for Class 1 buildings using an alternative solution approach such as the reference building methodology under the NCC, the outputs for compliance generated by this approach cannot be correlated to a NatHERS star rating. While there are critics (Williamson, 2001), it can be argued that “stars” are now embedded in the public and industry consciousness. This consequently makes verification by alternative solution a less attractive proposition for the purposes of NatHERS brand awareness in the housing market.

4.5. Why turn a compliance tool into a design tool?

While its primary function today is as a tool for demonstrating energy efficiency compliance, NatHERS and AccuRate Sustainability were originally conceived as tools that could help to inform (and improve) the design and thermal performance of residential buildings. However, in reality AccuRate Sustainability’s unintuitive and form-based user interface makes it difficult to use as a design tool. Consequently, house energy ratings have become the domain of assessors who focus on data entry rather than design optimization.

On the other hand, while more intuitive thermal analysis tools do exist that can give feedback on how a conceptual building design might perform, for the reasons stated above these tools do not satisfy the requirements for demonstrating compliance.

By creating a more streamlined workflow and connection between BIM applications and accredited rating tools such as AccuRate Sustainability, we believe this is the most effective way to optimise and improve a building’s thermal performance, while also ensuring analysis outputs can ultimately be used for compliance purposes.

4.5. Are there any competitors to SketchuRATE?

Recently, another software tool has been announced that claims to offer similar functionality to SketchuRATE. Known as FINE4Rate, the product website states it is “a customized BIM application for the NatHERS thermal comfort modelling environment. The software brings the power and speed of BIM to all Energy Assessors that using the AccuRateSustainability software [sic]” (4M, 2016).

FINE4Rate appears to be positioning itself as a standalone application, requiring the user to model or import the project in their proprietary software. It also requires a modified AccuRate.exe file to operate. While there appears to be similarities with SketchuRATE, we believe a non-proprietary, software agnostic methodology that integrates with established BIM tools has greater potential to be adopted by industry at large.

5. Where to from here?

While SketchuRATE still only exists as a proof of concept/working prototype, we have conceived a project roadmap for the further expansion of the tool’s capabilities, and ultimately commercialisation.
5.1. Automatic transfer of construction material properties

A key focus will be to find a robust way to transfer information about construction materials used in the BIM model into AccuRate Sustainability. While schema such as ifcXML and gbXML have a hierarchy capable of storing the thermal properties of construction materials that can be leveraged within SketchuRATE, it will be necessary to ensure these properties correspondence to those used within AccuRate Sustainability.

The prototype and implementation studies to date have focussed primarily on saving time in relation to the data-entry required to describe the building geometry; this was considered the more challenging and primary hurdle to overcome in the workflow. The need for mapping these geometric elements to construction materials in the Accurate Sustainability database was identified, however is outside of the scope of this study.

As such, it is anticipated this will be a process of mapping the AccuRate Sustainability material database into the required XML schema.

5.2. Automatic generation of shading schemes

Inputting the wing walls, vertical and horizontal shading schemes into an analysis model is perhaps one of the most tedious aspects of data entry when using AccuRate Sustainability. Shading elements such as eaves, overhangs, fences, perpendicular walls and neighbouring buildings must be entered for each individual external wall that is likely to be affected. The CHENATH engine does not possess the ability to resolve the shading impacts of adjacent structures geometrically, such as by using a shading mask calculation.

The advantage of BIM is the relative ease with which these elements can be modelled; elements such as eaves and perpendicular walls are already part of the model’s geometry, while neighbouring structures and fences are often modelled for the purposes of planning approval and/or to provide context. It would be extremely beneficial for all third party applications, not just SketchuRATE, if a way can be found to translate these shading geometries directly into the CHENATH engine.

Our experience with manipulating data to be compatible with Accurate Sustainability and the CHENATH engine has indicated that it is likely to be a significant challenge to develop an algorithm/routine for converting BIM geometry into shading inputs compatible with AccuRate Sustainability. However, adding this functionality to SketchuRATE (or other similar third-party developed applications) would be a significant enhancement, and will be a focus of future development.

5.3. Automated compliance checking

When demonstrating energy efficiency compliance under the National Construction Code, it is an expectation under the Scheme that assessments follow the NatHERS Principles for Ratings in Regulation Mode (NatHERS, 2014). Currently, this is largely dependent upon the assessor interpreting and following the principles as they conduct the house energy rating.

Because of the data and information that can be embedded within the XML file created by SketchuRATE, it should be feasible to develop an automated checking process that could parse an XML file prior to conversion, and confirm the validity of inputs against many of these modelling principles. This has the potential to improve house energy ratings and data entry consistency. It could even form
the basis of an industry wide quality assurance process, via a vendor-neutral export format, such as nathersXML or similar.

5.4. More informative design and performance feedback

There is strong brand recognition/awareness from both consumers and industry of the star rating system adopted by NatHERS. However, there are still individuals who would seek more meaningful data regarding a building’s thermal performance, for which a star rating alone would be insufficient.

Outputs from the CHENATH engine include hourly temperature profiles, along with heating and cooling loads by zone. While some of these outputs can be viewed within AccuRate Sustainability, the interface provided is not conducive to allowing the use of these outputs to inform and improve the building design.

While not directly related to SketchuRATE, finding better ways to display and visualise these outputs may also help to improve design outcomes. We are currently exploring these ideas in other research. We see these research opportunities as symbiotic - SketchuRATE makes it easier to complete a house energy while more intuitive visualisation tools help us to better understand how a building is performing. Together these tools are more likely to improve the design and thermal performance of buildings.

6. Conclusion

This paper discusses the opportunity that exists to integrate NatHERS energy efficiency compliance with a BIM workflow and methodology. While SketchuRATE is currently a proof of concept/working prototype with limited functionality, there is great potential to streamline the way house energy ratings is conducted. Eliminating the unnecessary duplication of building data helps to improve the accuracy of ratings when demonstrating energy efficiency compliance under the Building Code of Australia. This in turn may also help to reduce the construction costs for energy efficiency compliance.

However, additional investment of time and financial resources to further develop SketchuRATE’s capabilities is not without its risks. “Piggy backing” off existing software (and a scheme wholly dependent on the support of federal, state and territory governments) can be a risky proposition; this has previously been evidenced in the fallout from the well-intentioned (but failed) Green Loans scheme.

Despite these uncertainties, the modest “disruption” created by tools such as SketchuRATE will potentially result in a net improvement to the design, quality and cost of dwellings within Australia. When energy efficiency compliance requirements were first introduced into the Building Code of Australia, the intention was to reduce greenhouse gas emissions associated with the operation of buildings. While this net result appears to have been achieved (Ambrose, 2013), the work of house energy rating assessors has unintentionally become an obfuscated process not well understood by the construction industry as a whole, and dominated by laborious, menial data entry.

By more closely linking BIM with NatHERS tools already used for compliance, the focus will shift to iteratively improving a building throughout the design process, instead of just ensuring minimum compliance once a building design has been finalised. Concurrently, the role of a thermal performance assessor will transition from one largely based around data entry and duplication, to providing more comprehensive advice and feedback that can further enhance a building’s performance.
Combined with more meaningful and engaging ways to present analysis results, the optimised workflows enabled by a tool such as SketchuRATE will help to further reduce greenhouse gas emissions attributed to residential buildings in Australia, and assist in the transition towards a lower carbon economy.

References


Performance metrics in optimum conditioning for a library

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Abstract: The architects, construction and consulting companies promised to deliver an environmentally sound library renovation for a secondary school in Melbourne. Specifically, the open spaces were to be conditioned uniformly with minimal background noise. The installation of a newly designed packaged unit, consisting of variable speed drive fans, two differently sized compressors and a special pressurized balance control system aimed to deliver a uniform temperature distribution throughout the space. Construction measures of air leakage sealing, double glazed windows and additional insulation reduced the equipment load substantially. Yet, the evidence of measurement shows that this system could have been half the size. The measurements also show that the uniformity of the air temperature and its IEQ in a relatively new fit-out is achieved. This study serves as an example of post-measurement, the parameters that were assessed, a review of what was promised, and what might be learned in the renovation of other projects.

Keywords: Air conditioning assessment; air leakage performance; air balance; thermal comfort.

1. Introduction: early days in performance measurement

Questions about which protocols and what standards should be used to assess IEQ performance in a project frequently arise. While standards should provide guidance, they are often relate to formal laboratory situations and are otherwise over-prescriptive for field measurements, stating what and how to measure without accounting for what is involved in getting a valid result in-situ. This report describes several measurement processes thought to be useful to characterize the performance of an HVAC system in a refitted library space.

With regard to past efforts of composing standards for IEQ, building performance (CEN prEN15251 2005, ASTM Standards 2009A, 2009B), and Performance Measurement Protocols for Commercial Buildings, (ASHRAE 2010), the objective of this particular study is to achieve similar real in-situ space measurements. Critics should view the presented work here as a scoping study of what could comprise actual IEQ measurements. With respect to history, in order to establish processes and methods of measurement according to ‘standards’, realistically, in situ performance measurement is in its infancy. It would be more logical to allow, at the moment, ‘almost anything goes’ if it can be justified and accompanied by a rational explanation of its processes and can demonstrate effective, new and innovative methods, which yield a meaningful result. At present, we have parameters such as lighting,
temperature, air quality, etc. of measurement with either very exact or very relaxed (almost undefined) protocols of measurement.

For example, in the ASHRAE Performance Measurement Protocol (2010) there is no specification of where lighting levels should or need to be made. Kim and Haberl (2012), in testing this protocol, have a sensor (lux meter) mounted onto their cart. It could be questioned as to how this method of measurement complies with a lighting standard and whether a meaningful result is obtained. In another example, in the standard for thermal comfort, ASHRAE (2013A) specifies measurements to be taken at three distinctive vertical height levels (0.1, 0.6 and 1.1 meters). Does this mean that other devices, such as desktop IEQ meters (Parkinson and de Dear, 2015) that also calculate thermal comfort are invalid? Furthermore, new instrumentation has leap-frogged old methods of collecting data both in size and wireless communication, making ubiquitous and unobtrusive sensors feasible.

Protocols are established with little regard to trial outcomes. There seems to be a notion that our measurement processes and methods have been resolved and that a perfect system is in already place. Since the release of the ASHRAE Performance Measurement Protocols in 2010 there has been only one documented university trial of the intermediate and advanced protocol system (Kim & Haberl, 2012). Other authors have already performed a literature review on IEQ assessment models (Heinzerling et al., 2013), as if the term IEQ itself had existed for decades in the literature. The argument here, again, is that an experimental science takes time to grow and to develop, and to rush in to set boundaries and strict regulations in the early days of its development as to what constitutes legitimate measurement of real environments is ludicrous, if not limiting and damaging.

We discuss a project which involves the retrofitting and upgrading of a library space in a secondary school near Melbourne, Victoria (Figure 1). The space had some external alterations and extensions in the process. These included replacing the existing single glazed façade, primarily east and south facing, with a double insulated Low-E glazing system. Throughout the process, the interior detailing provided for an air barrier, sealing the external wall. This has been attended to meticulously by mounting with caulking rigid insulated sheets, sealing against air leakage between the exterior and interior envelope.

The following study centres on the performance assessment of a novel HVAC conditioning system which is claimed to provide better performance than other conventional air convection distribution systems on the market. It is claimed to use less energy, providing balanced comfort throughout the space it conditions. It also allows for the downsizing of the system (peak load) due to efficient distribution.

Furthermore, the design of the HVAC mechanical system is rather novel. It uses a common packaged unit technology which is known to be a rather energy consuming system. The innovation utilizes a package unit system and improves its design through the inclusion of variable speed drive fans, two compressor sizes (allowing for 3 variable load settings) and a specialized ‘Balance Control’ system that provides for a very non-conventional conditioning outcome.

The ‘Balance Control’ system turns the typical packaged unit into an energy efficient regulating device. It operates by providing supply air at a low velocity to the space by measuring air pressure in the ductwork, the space itself and outside the building envelope so that a constant positive interior pressure is maintained in the room. The difference in control from that of a typical system is that of a hybrid demand control system where the CO2 levels, humidity and air temperature are kept ‘balanced’ within the space according to their set-points. Fresh air is only supplied when required according to measurement and return air is also minimized, again according to set-points. If the outdoor conditions are acceptable, an economizer cycle becomes the operational mode. When the loads are minimal, only
Performance metrics in optimum conditioning for a library

one of the compressors is in operation, reducing the volume of activated refrigerant. The two different sizes of the compressors allow for variable loading. That is a 5kW and a 12kW compressor yields; 5, 12 or 17 kW to be used for control. These advances all contribute to a packaged unit saving between 50-70% of energy. The next step involves the testing methodology applied to verify its promised unique operational features.

2. Establishing the measurement

Measurement of the library and classroom spaces was conducted to obtain information on air quality and comfort. Testing is performed to justify the additional expense of advanced conditioning systems (i.e. energy recovery systems, air leakage sealing, double glazing retrofitting as well as the uniquely controlled HVAC system). An on-site weather station was positioned on one of the top outdoor floors of the building. It provides a reference for internal results of comfort, temperature and energy use. When and wherever useful, this data is integrated with measured and calculated interior results of performance. These are often applied in conjunction with internal results, to demonstrate differences, or to illustrate the circumstance under which comfort was (or was not) achieved.

Figure 1: Library Floor Plan with instrumentation locations
2.1 Thermal comfort & Air Temperature Stratification

The *Predicted Percentage* of occupants *Dissatisfied* (PPD) under the measured conditions, is calculated according to ISO 7730 (1994). The calculation integrates environmental conditions (air temperature, mean radiant temperature, humidity, air velocity, and an assumed parameter for the occupants’ clothing (CLO) and activity (MET). In the space, our method uses two comfort carts constructed according to the ASHRAE Standard-55 (ASHRAE, 2013A), which measuring air temperature, globe temperature, and air velocity at 0.1m, 0.6m, 1.1m and 1.7m heights. Air humidity is also measured at 0.6m. One cart is programmed to measure continuously at 15 minute averaged intervals while the second cart is set in a ‘survey’ mode to be located for 10 minute sampling times at designated locations (see floor plan in Figure 1).

It is generally considered that conditions less than 20% PPD are acceptable. Here, the calculation for PPD considers a range of CLO values where a summer value of 0.65 CLO, average value of 0.85 CLO and winter value of 1.05 CLO provide the ‘Comfort Band’. Recent studies from Queensland, New South Wales and Victoria indicate that a range of +/- 0.2 CLO among occupants in office buildings at various seasons of the year was encountered at any given time (Luther & Horan, 2015). This justifies the application of the ‘Comfort Band’ when making an evaluation since occupants dress according to their preferences. Even though secondary students have a set uniform, there are allowances and variations in clothing type permitted according to season.

The purpose of an on-going comfort measurement is to consider the behaviour of the space in accordance with the charting of comfort variation. Both the conditioned as well as the non-conditioned periods are observed. This type of charted measurement involves the calculation of the comfort bands discussed above. Also, the two different comfort cart measurements provide for potential cross-comparison differences throughout the space at various times. The comfort results observed would be one of several evaluation parameters to assess the effective operation of the new HVAC system.

Another outcome promised by the newly installed HVAC system and its control is that a thoroughly mixed space would occur. The measurement of air temperature stratification, air temperature measurements taken vertically in the space, allows this metric to be analysed. In this project there is only one vertical strand of thermocouples providing measurements starting from the floor to the ceiling at 1.0 meter intervals. The measurements are averaged over 15 minute intervals over several days. This metric is observed under both conditioned as well as non-conditioned periods.

2.2 Ventilation, air change rates and uniform distribution

A quantitative assessment of ventilation effectiveness in the Library using tracer gas measurements is another of the major performance metrics of the HVAC system. The ANSI/ASHRAE Standard 129 (ASHRAE 1997) is utilized here as a guide to measure air exchange rate as well as uniform air balance within the tested space. While this standard is more about the method of testing, the requirement of air-change effectiveness to design ventilation rates is detailed more in the ANSI/ASHRAE Standard 62.1-2013 (ASHRAE 2013B), Ventilation for Acceptable Indoor Air Quality.

There are two distinctive tests that emerge from the ASHRAE Standard 129 (1997) in the application of the tracer gas using Brüel & Kjær (now LumaSence Technologies) instrumentation. This equipment comprises of a doser and a sampler module. There are three sampler locations within the space identified in Figure 1.
The first test relates to the measured air change rate that is obtained from the constant concentration method as described in the ASHRAE 129 (1997) standard and B&K (LumaSence) catalogue. This method applies a pre-set concentration level of the tracer gas (in this case R134a), which is set to 3 ppm. The instrument program regulates the gas concentration level and calculates the air-change rate, which would have occurred over the interval (approximately every 10-15 minutes) given the dosage rate required to maintain the set-point (3.0 ppm concentration). Measurements are difficult to undertake in transient spaces and require longer periods of steady occupancy or absence. Yet, further in situ studies, using proper state-of-the-art (tracer gas) equipment are highly recommended.

The second test is in regards to what might be expected or required to do a proper tracer gas test in principle. This ‘test’ involves the observation of the three sampling points located throughout the space. It observes the fact whether the readings of ppm concentration are equal or uniform. This uniformity is representative of an equal and balanced air distribution ideally throughout the space, considering the variable location of the three sampling points.

The on-going concern for a building’s conditioning control is strongly related to its building envelope air leakage. Testing procedures to measure air permeability are derived from ATTMA (2010) based on BS 18329 (2001). The ASTM E779-10 U.S. Standard (ASTM 2004), also describes the method of air leakage testing through blower door fans. These methods were used to test this space before refitting, during its sealing and finally, after completion. The construction sealing process and its intermediate testing stages are a report on their own. An outstanding result has occurred here in relation to international benchmarks on building envelope permeability.

2.3 IEQ parameters & Energy Performance

The issue of indoor air quality is one of the most discussed parameters today. There is a diverse range of instrumentation and even standards that suggest which parameters are required to establish the ‘IEQ’ of a space or building. This project utilized the Grey Wolf IEQ kit, which includes formaldehyde, ozone, TVOCs, CO and CO₂ measurements. This was placed at two different locations over the total measurement period of the space, providing for an ongoing measurement during occupied and unoccupied periods. Considering that the space is relatively new, toxins from a possible off-gassing of the building materials is a possibility which would likely occur regardless of occupancy or not.

While the energy performance parameter is often viewed as the most important one in any project, it probably is the least analysed in this report. The metering period of the new operation in regards to the energy use before the retrofit isn’t yet sufficient enough to make a final judgment. Yet, there is a convincing argument in some measured parameters that indicate a successful HVAC installation from an energy standpoint. The old existing sizing of the equipment was reduced from a 90 kW unit to a 60 kW unit. Initially, a 45kW system was proposed for the new retrofit, but the larger system was installed.

3. Results of the various measurements

The following is a presentation of several measured results provided in a graphical format. These graphs are believed to best represent the data at present. It is in fact one of the most challenging aspects of performance measurement, to deliver a graphical result that best explains the behaviour of the metric. Note not all the charts can be presented in this paper.
3.1 Thermal comfort

The graph shown in Figure 2 is for the result of the comfort survey mode undertaken with the comfort carts in the various locations indicated throughout the library (see Figure 1). This chart indicates six particular periods of measurement across two days at five locations within the space. The graph charts individual Predicted Percentage Dissatisfied (PPD) results for each of the locations. A result of 10% PPD is considered an outstanding accomplishment. For the most part results shown are 13% PPD or below for the periods measured which is significantly below the generally accepted 20% PPD used in practice. These performance results are an indication of near optimal conditioning represented across a wide spatial area of the library.

![Figure 2: Survey Comfort Mode Results](image)

3.2 Ventilation, air change rates and uniform distribution

The idea here is to understand what is reasonable for an air change rate for the volume of the space considered. Perhaps this metric cannot be evaluated in isolation from several others that might explain a higher or lower ACH rate. In other words, if the air temperature, humidity or CO₂ levels within the space are unsatisfactory a greater ACH may be justified. Figure 3 shows the ACH of all three sampling points during an operational period of the HVAC as well as the concentration levels (ppm) of the tracer gas at all three sampling points.

The results of the air change rates indicate a similar sinusoidal result with extremes between 0.75 – 1.0 ACH. Note that the negative readings should be considered as an ‘absolute value’ reading under the constant concentration mode of operation. This is because the space oscillates with the dosage of tracer gas aiming to achieve uniformity during and after the leakage occurs. Two of the three points show a
similar reading while the third point (located quite separate from the other two) is indicating a slightly higher ACH rate.

The concentration level of the tracer gas was set for 3 ppm on the instrument. Readings range from 2.75 – 3.5 ppm on the scale shown and indicate from all three sampling points that the concentration level is practically the same at any given time in the space. This is quite remarkable given the separation of sampling points and indicates a balance or mixing uniformity of the air. This metric is perhaps one of the most significant in the justification of a uniform mixing of air, yet, other forthcoming results may also support this finding.

![Air Change Rate: Daytime HVAC - On](image)

**Figure 3: Air Change Rates per Hour and Concentration Levels (ppm)**

### 3.3 Air temperature stratification & IEQ parameters

The next metric to identify with the aspect of uniform and balanced air temperature mixing is that of a measurement in air temperature stratification, vertically, within the space. Figure 4 presents this result during operational and non-operation HVAC periods. It is clearly seen here that an operational period (between 6:30-16:30) reduces air temperature stratification to a minimum (within 0.5 °C) over a 5.0m high ceiling. The increase of stratification is clear during a non-conditioned period.

Figure 1 identifies the two locations where the IEQ instrumentation was located for continuous sampling in ongoing 5 minute intervals across several days of monitoring in the library. The bar charts in Figure 5 shows the various quantities of toxins measured. Given that this is a newly fitted-out space with new furnishings the results are quite remarkable. Levels of formaldehyde below 100 ppb are rather harmless and the TVOC readings are similar. Furthermore, one of the control inputs to the HVAC system is CO₂ levels, which are to be maintained under 650ppm. The average is maintained at 525 ppm which is a very acceptable figure considering background (ambient levels) are at 400 ppm at the moment. Together, all of these IEQ parameters indicate that a high quality controlled space has been achieved.
3.4 Air leakage & Energy

Probably the most important feat achieved in this project was attention to the detail of building envelope air leakage sealing. The meticulous work in sealing the building achieves near best international standards and is no doubt the reason for the outstanding performance (see Table 1). In conjunction with this is also the process by which double glazing has been retrofitted onto the existing single glass with attention to mullion detailing and sealing. This has indeed provided for a building free of unwanted infiltration/exfiltration allowing it to be effectively controlled from the HVAC system itself.

Table 1: Air Leakage Results of Before and After Renovation

<table>
<thead>
<tr>
<th>Test Period</th>
<th>Test Evaluation</th>
<th>Tested Value</th>
<th>Building Envelope - m$^2$</th>
<th>Building Volume - m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nicholson Library</td>
<td>Permeability@ 50Pa (m$^3$/hr/m$^2$)</td>
<td>18.22</td>
<td>2089 m$^2$</td>
<td>2946 m$^3$</td>
</tr>
<tr>
<td>Before Treatment</td>
<td>Flow @ 50Pa (m$^3$/hr)</td>
<td>27.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nicholson Library</td>
<td>Permeability@ 50Pa (m$^3$/hr/m$^2$)</td>
<td>6.49</td>
<td>Slightly more</td>
<td>Slightly more</td>
</tr>
<tr>
<td>After Construction</td>
<td>Flow @ 50Pa (m$^3$/hr)</td>
<td>5.03</td>
<td>than above</td>
<td>than above</td>
</tr>
</tbody>
</table>

Figure 4: Air Temperature Stratification for Operational and non-Operational Periods
Performance metrics in optimum conditioning for a library

The supplier of the advanced packaged unit system design provided their BMS (building management system) data for the period of September 2015 thru March 2016 on the activation (use) of the compressors provided in this system. The system comprises of two compressors at 35kW each with one being a variable (refrigerant volume) compressor. This accounts for a very economically operated unit where only the required volume of refrigerant is used at any given time. It was acknowledged that the second compressor was never used during the entire hot weather (Summer) period. The packaged unit total capacity is 70 kW, yet only 35kW were ever used. This implies that a 35kW compressor was actually accommodating the summer months of conditioning and is more than adequate for the load encountered.

4. Summary and conclusion

This paper and its associated project provides building performance measurement metrics and methods in order to evaluate and justify the performance of IEQ, Comfort and HVAC control of a building space. While a myriad of standards and protocols already exist, there is a confusion about what they actually provide in terms of ‘judging’ a space. Standards often set guidelines and limits. What is more important is an understanding of the mechanisms that lead to improved IEQ and performance and to understand the building more than ‘just the result of the air in the space’.

Further to this thinking, no one single measurement metric is capable representing conclusive successful or unsuccessful performance. In fact several metrics of measurement come together in the process of understanding the real performance explaining why fewer air changes are required, better thermal comfort distribution, or lower CO₂ concentration is achieved.
It was calculated and advised that a 45kW system would suffice for the thermal load operation of this building. The results indicate that over a 60% improvement from the originally installed (pre-retrofitting 90kW installation) was achieved for this project and that in principle the building is actually operating on a 35kW compressor. Furthermore, the system is very quiet, although no measurement was taken on this project, similar system installations have been measured on other projects. Generally the reduction is about 8-10dBA, indicating an apparent (‘feels like’) doubling in sound reduction.

Acknowledgements

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Comparing properties of interiors and perceptions of comfort: Results of an empirical study

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Abstract: Past research into environmental psychology has identified openness, enclosure, light, mystery and complexity as the key criteria shaping perceptions of psychological comfort. It has been suggested that these properties are responsible for evoking positive aesthetic responses to an environment and they have also been repeatedly linked to the works of renowned architects including Alvar Aalto, Glenn Murcutt and Peter Zumthor. However, the precise spatial and visual properties that allegedly evoke feelings of comfort have never been adequately identified, in part because previous research has involved multiple confounding factors or has lacked a controlled testing environment. The present paper responds to this situation by presenting the results of an empirical study involving 159 participants with diverse backgrounds who rated 24 carefully graduated images of virtual interiors for their feelings of comfort. The findings indicate a very high, positive correlation between an increasing degree of openness and perceptions of comfort. Furthermore, a comparison of perceptual responses with actual geometric room measures identifies several that correlate closely with feelings of comfort.

Keywords: Design assessment; environmental preference; interiors; prospect-refuge theory.

1. Introduction

Winston Churchill famously remarked that ‘we shape our buildings; thereafter they shape us’. This statement suggests that the properties of space influence the way we feel and behave. Furthermore, such responses to architecture are often both instant and intuitive, occurring without necessarily knowing what exactly triggered these feelings. It has been suggested that past experiences, cultural background and socioeconomic status all have an impact on preferences (Heerwagen 1998; Gosling et al. 2013), and while there are individual differences, people often respond in similar ways to certain environmental settings (Ellard 2009). For example, past research suggests that the effects of colour and texture are minimal, but style, shape, decoration and material are possibly more influential in shaping the way people respond to architecture (Askari and Dola 2009). In particular, the level of visual contrast and visual complexity allegedly shapes human preferences for architecture (Moughtin et al. 1999; Stamps 2003). Other important factors include the proportions of openings, their positioning and relationships with solid elements (Conway and Roenisch 1994). Collectively, all of these characteristics of space influence human
perceptions, but the factors that are most commonly cited as shaping feelings of psychological comfort in interiors are concerned with the relationship between enclosure and exposure.

Past research identifies a preference for spaciousness in interiors (Scott 1993; Franz et al. 2004) as well as for ceilings that are higher than standard (Baird et al. 1978; Stamps 2006), whereas in larger spaces (for example open-plan offices) partial enclosure and access to daylight are perceived as creating feelings of comfort (Scott 1993, Yildirim et al. 2007). Access to daylight and nature are not only preferred but are also potentially beneficial for wellbeing, stress relief and recovery (Farrenkopf and Roth 1980; Heerwagen and Orians 1993, Ulrich 1994), and visual connections satisfy the basic human need to derive information from the adjacent environment (Kaplan and Kaplan 1989).

A meta-analysis of theories of environmental perception reveals three main themes which are valuable in this context (Gosling et al. 2013). The first is Brunswik’s (1956) probabilistic functionalism which suggests that cues, including flooring, windows, colour and light quality, can lead to valid evaluations of a space. The second theory is Gibson’s (1979) ecological, perceptual approach of affordances that can be explained as detectable functions of an environment which allow actions. If a space is identified as functional, it will be preferred over others. The third idea is the most relevant to the present research. According to Berleyne (1971), collative properties (or the lack of such) — including novelty, incongruity (sensing that something is out of place), complexity and surprise — influence spatial perception. For example, an increase of pleasure occurs from observing an environment that has a certain degree of complexity; but if it is increased beyond a certain point, discomfort will be perceived (Berleyne 1951).

The architectural fascination with spatial psychology and environmental preference theory can also be traced to Jay Appleton’s The experience of landscape (1975). In this work, Appleton develops a theory — prospect-refuge theory — to explore and explain the properties of environments that influence innate feelings of security and stimulate perceptual preference. He asserts that it is the combination of certain characteristics of outlook and enclosure, coupled with the direction of light that generate this emotional response. Prospect is required to provide a sense of power or control, whereas refuge is needed to evoke feelings of safety and security. Prospect-refuge theory could be understood as describing a particular spatial setting or pattern, which is composed to elude feelings of safety and pleasure, when observing an environment (Dosen and Ostwald 2013a).

In the 1990s, Grant Hildebrand (1991, 1999) applied this theory to architecture and added complexity and order, and the opportunity for exploration, to the properties required of an environment to evoke feelings of comfort. Several of these are related to the Kaplans’ information model (Kaplan and Kaplan 1989). Complex and mysterious environments trigger a need to move around and explore space. Thus, Hildebrand expanded Appleton’s prospect-refuge theory to also emphasize the importance of several additional properties in architecture. In a revised edition, Appleton (1996) embraced Hildebrand’s exploration of the aesthetics of built environment and even encouraged future research and broader interdisciplinary outcomes. Nevertheless, despite prospect-refuge theory being repeatedly used in architectural design primers, and being linked to works of highly awarded architects, there is only limited empirical evidence for prospect-refuge theory. Ironically, most studies that are cited in an architectural context relate only to the experience of natural or urban environments (Dosen and Ostwald 2016). Furthermore, the computational-mathematical methods that are common in architectural analysis are only rarely linked to human perceptions.

This situation is the catalyst for the present paper which outlines results of an empirical study involving 159 participants with diverse backgrounds who rated 24 carefully graduated images of virtual interiors for
Comparing properties of interiors and perceptions of comfort: Results of an empirical study

feelings of comfort. The geometric and isovist properties of these 24 virtual interiors were also measured, providing a limited means of correlating feelings with geometry. The 24 test rooms varied in terms of fenestration (size and location) and roof form. In the following section, the methods are explained and participant demographic information is provided. Then the results of both survey data (perceptual responses) and room and isovist measures (geometric data) are presented and compared.

The limitations of the present research include that the virtual environment represents a relatively small and simple room which is viewed from a fixed position. The static viewpoint allows for the survey to be effectively run online, but it might limit the experience of the space. Also, even though participants are from various countries and backgrounds they do not evenly represent all groups, or at least some divisions result in very small groups that are not representative.

2. Method

This paper uses a combined survey method and mathematical analysis approach to examine varying dimensions of openings and their impact on feelings of comfort.

For the survey, participants were invited to assess, on a 7-point-Likert scale, 24 fixed-perspective, rendered colour-images of rooms that were generated from the virtual test environment. For each of the rooms, participants were invited to signal their level of agreement (from ‘strongly disagree’ to ‘strongly agree’) with the statement ‘I feel comfortable in this room’. The methods used in 30 past studies in this field have previously been compared and examined and the present method responds to the gaps identified in that study (Dosen and Ostwald 2013b). In particular, a virtual test environment was chosen which allows the production of stimuli with graduated variations under controlled conditions, while still maintaining a high degree of perceptual realism (Bülthoff and van Veen 2001; de Kort et al. 2003). An online questionnaire was chosen to allow participants flexibility for undertaking the survey to a convenient time, and while there could be some concerns about viewing conditions, for example, the time of the day or other physical conditions under which the images were viewed, there are arguments that most viewing conditions can be disregarded as they result in the same outcomes (Stamps 2006). It is more important to allow participants to progress through the survey at their own pace, as forcing a short viewing time can result in ill-considered decisions.

The 24 virtual rooms (5 x 5 meters) are of contemporary appearance and include some relatively neutrally coloured furniture and decoration to provide a sense of scale. No human figures are depicted. The distant view from the room is of trees and water, although its opacity is reduced to focus attention on the room and its features, and a general sense of outlook. The 24 rooms vary only in terms of window location and size, and roof pitch direction. All other features are the same.

The 24 specific variations are divided up as follows: Eight room variations each for three opening types were prepared. These three fenestration types include: (A) an enclosed window band, (B) a full height opening that is divided by columns, and (C) a full height opening without columns. Of the eight room variations, six variations (Room 2 to 7) have flat ceilings but increase in window opening width (Table 1). In addition, the first and last variations (Rooms 1 and 8 of each fenestration type) feature a low (downward sloping) and high (upward sloping) skillion roof that emphasises enclosure and exposure. Furthermore, half of these room variations (Rooms 3, 5, 7 and 8) have corner windows while the others offer only front views. Figure 1 presents three examples of the 24 stimuli.
Table 1: Room variations (Rooms 1 to 8 vary in opening width, location and roof/ceiling form, Types A to C vary in opening height).

<table>
<thead>
<tr>
<th>Room</th>
<th>Type A ‘Narrow height window band’</th>
<th>Type B ‘Full height window with columns’</th>
<th>Type C ‘Full height window, no columns’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room 1</td>
<td>Test room 1 A (See Figure 1)</td>
<td>Test room 1 B</td>
<td>Test room 1 C</td>
</tr>
<tr>
<td>Room 2</td>
<td>Test room 2 A</td>
<td>Test room 2 B</td>
<td>Test room 2 C</td>
</tr>
<tr>
<td>Room 3</td>
<td>Test room 3 A</td>
<td>Test room 3 B</td>
<td>Test room 3 C</td>
</tr>
<tr>
<td>Room 4</td>
<td>Test room 4 A</td>
<td>Test room 4 B</td>
<td>Test room 4 C</td>
</tr>
<tr>
<td>Room 5</td>
<td>Test room 5 A (See Figure 1)</td>
<td>Test room 5 B</td>
<td>Test room 5 C</td>
</tr>
<tr>
<td>Room 6</td>
<td>Test room 6 A</td>
<td>Test room 6 B</td>
<td>Test room 6 C</td>
</tr>
<tr>
<td>Room 7</td>
<td>Test room 7 A</td>
<td>Test room 7 B</td>
<td>Test room 7 C</td>
</tr>
<tr>
<td>Room 8</td>
<td>Test room 8 A (See Figure 1)</td>
<td>Test room 8 B</td>
<td>Test room 8 C</td>
</tr>
</tbody>
</table>

Figure 1: Example of three stimuli varying in ceiling and opening types: Room 1 of opening type A (window band), Room 5 of type B (full height columns), and Room 8 of type C (full height).

The geometric properties of the rooms used for the survey stimuli are represented by the following four metrics: (1) the area of all openings, (2) the perimeter of all openings, (3) the wall-to-window-area ratio (WWR) (a measure for the degree of enclosure), and (4) the window-opening-width of all openings.
3. Results

First, the mean ratings of perceptual responses to comfort are presented and the data is discussed by demographic groups. Then, a relationship between the survey data and geometric room properties is tested with a Pearson’s correlation test.

Of the 159 participants, 91 are males. The majority of participants are from Australia (59%), Asia (17%) and Europe (19%), while only a small number of participants from North-America and Africa (5%) (grouped as ‘other’ in the data). The ages of the participants ranged from 18 to 70 and they have been sorted in four groups: 18 - 25 (44%), 26 - 35 (23%), 36 - 45 (19%) and 46 or above (14%). Altogether 60% of the participants had at least one year training in architectural design (although only 20% of these had more than 5 years, and 12% between 3 to 5 years). While 22% of participants grew up in rural areas, only 13% lived there more recently. 43% grew up in suburban areas and 40% were living there predominantly during the past ten years. Most participants live now in urban areas (46%) although only 34% grew up in such a denser environment. Only 10% of the participants live in a one-room apartment.

3.1. Survey responses

The survey results for comfort in Figure 2 display the mean perceptual responses for each of the 24 room variations. The bars, which represent the three opening types (A, B or C) for all room variations (1 to 8) illustrate a general, but small upward trend.

![Figure 2: Mean ratings for perceived comfort (N = 159) for room 1 to 8, grouped by opening type (A – C).](image)

All opening types indicate a similar rise within a score range of 3 to 5 (on a 7-point-Likert scale) with the exception of room 8, the largest opening with a high skillion roof. Room 8 of opening type B (the full height window with columns), was rated highest for perceived comfort with a mean rating of 5.0440 while room 8 of opening types A (the window band) and C (the full height opening were both rated lower than room 7 of the same opening type. Thus, on average the widest and highest opening with the high skillion roof...
variation was perceived as most comfortable when there are columns, which allow some concealment. The window band (opening type A) was assessed on average lowest for perceived comfort by indicating a slightly increasing rating with an increase of the opening width (from room 1 to 8). The highest ratings were given for the full height opening type without columns (opening type C) with the exception of room 8 as described above. The lowest ratings with a mean of 3.3962 were given for room 2 of opening type A, the smallest opening with a flat ceiling, while room 1 with a low skillion was perceived on average slightly more comfortable with a mean of 3.6730.

The range of mean ratings is 6 in all but two of the 24 cases: room 2, of opening type B, includes only ratings from 1 to 6 and room 3 of opening type C from 2 to 7. In most cases at least one of the 159 participants always felt either very comfortable, or not at all comfortable, irrespective of the room geometry. The lowest standard deviation occurs for room C3 (1.2304, mean for C: 1.5007) and B2 (1.2556, mean for B: 1.4346). The standard deviation is highest for rooms C8 (1.8601) and C7 (1.7659), followed by the larger openings of opening types B and C. This indicates that there was least agreement on assessing the rooms with the widest views.

A Pearson’s correlation test between the ratings for perceived comfort by opening types shows a significant correlation (or similarity) between mean ratings for openings of type A (the window band) and B (the full height windows that are divided by columns) as well as between those for opening types A and C (the full height openings), but there is no significant similarity between perceptual responses for opening types B and C \((r_{AB}=0.780, r_{AC}=0.822\) and \(r_{BC}=0.697\); \(p_{AB}=0.023, p_{AC}=0.012\) and \(p_{BC}=0.055\)). This can result from the very high ratings for opening type C from room 3 onwards, while opening types A and B show a similar, but less marked increase in ratings. Interestingly, the ratings for opening types A and C follow the same ups and downs indicating higher ratings for perceived comfort for corner window variations than for pure front views with the same opening area (rooms 3 and 5 in comparison to room 4 and 6). Thus, the ratings for perceptions of comfort increase for all opening types with an increasing opening width.

### 3.2. Perceived ratings divided by demographic factors

Overall, a division by demographic factors confirms that there are relatively small differences in ratings for perceived comfort. The largest difference occurs between participants who are trained in architectural design and those that have no training with the former group providing slightly lower ratings in 75% of all cases. However, only 20% of the mean results show a significant difference in comfort ratings when assessing the larger full height openings with flat ceilings of opening types B and C, and a significance test indicates a high positive correlation in ratings for comfort by educational background (correlation coefficient \(r_A=0.829, r_B=0.895, r_C=0.817\) and \(p_A=0.011, p_B=0.003\) and \(p_C=0.013\)). A comparison by gender indicates with no significant differences in ratings that the perceptions of comfort are very similar, though females felt most comfortable in rooms with large openings with the columns interrupting them, while males perceived two thirds of the other openings as slightly more comfortable. A significance test indicates a highest, positive correlation for opening type C \((r_A=0.825, r_B=0.887, r_C=0.905\) and \(p_A=0.012, p_B=0.003\) and \(p_C=0.002\)). Thus, there was most agreement between male and female participants when assessing the full height openings.

A comparison by the participant’s background indicates on average slightly lower ratings for comfort from those who grew up or lived in an urban area while those from suburban areas have provided higher mean scores. The majority of those who live in a one-room apartment is from an urban area and has rated most room variations slightly lower for perceived comfort; and they have rated the largest, high skillion
opening variations of opening types B and C even significantly lower in comparison to those who have one or more bedrooms (mean difference for room 8 of type B: 1.1549 and for type C: 1.2380 at a 5% significance level). Interestingly, the latter group has always rated corner window variations higher for perceived comfort than same-sized openings that offer only front views, while those living in a one-room apartment confirmed this in only two thirds of these cases. A comparison between age groups shows relatively similar results though the youngest participants have rated on average the window band relatively high for perceived comfort while the older two age groups felt more comfortable in rooms with larger openings. A comparison by continent where participants reside indicates that European participants felt most comfortable in larger opening variations while Asian participants felt least comfortable in these room variations and Australians rated the window band openings higher than others for perceived comfort. However, significant differences occur only between the ratings for room variations 6, 7 and 8 of opening type B, the full height opening that is divided by columns.

3.3. Room measurements

In this section, metric properties of the 24 test rooms are compared with perceptions of comfort, to determine which properties most closely correlate.

A Pearson’s correlation test indicates a high to very high, negative correlation between the mean ratings of perceived comfort and the wall-to-window-area ratio, which is a measure for the actual degree of enclosure (Figure 3). A significance test shows a very high, negative correlation for opening type C with a probability against 1% that this is a chance finding ($r_C=-0.872; p_C=0.005$), while the correlation results for opening types A (the window band) and B (the full height opening that is divided by columns) are slightly lower and significant at a 5% level ($r_A=-0.749$ and $r_B=-0.818; p_A=0.032$ and $p_B=0.013$). Thus, the least enclosed openings (type C) achieved the highest ratings for perceptions of comfort with one exception: room 8, the largest opening with the high skillion, was rated lower than the variation of opening type B. Therefore, the difference between the lowest and highest score (or range) in mean ratings for perceived comfort is highest for opening type B while it is very similar between opening types A and C. Also, a comparison between opening width and ratings for comfort indicates a very high correlation with opening types A and B and a high correlation with C. However, there is no significant correlation between perceived comfort of opening type C and the room properties area and perimeter of openings, although the correlation factor $r$ is very high for opening types A and B for both room measures. This likely relates to the relatively high scores of perceived comfort for opening type C from room 3 while the ratings for the larger room variations are not much higher. For opening type A it is a similar trend with lower, but also increasing ratings for the smaller openings and a higher, but nearly horizontal trend for the larger openings.
4. Discussion and conclusions

Overall, the mean ratings for perceptions of comfort increase in line with increasing opening size, which does not support the classical argument repeated by architectural designers that settings which are balanced in outlook and refuge are most preferred (Appleton 1975; Hildebrand 1991, 1999). On the contrary, the survey results indicate that prospect-dominance is perceived as most comfortable. However, Appleton’s and Hildebrand’s arguments include several confounding factors which were not examined in this paper. For example, Appleton argues that symbolic properties associated with outlook may influence perception, while Hildebrand claims that spaces with internal prospect (visual connections between the rooms) are more significant. Thus, the simple test room in the present study cannot be used to examine every criteria identified in past research as possibly significant.

The variations of opening type B seem to be the closest to a setting of some balance of prospect and refuge, as the columns allow some concealment and increase in their number with an increasing number of openings. The highest rating for comfort was given for the largest opening of type B, and especially females perceived and rated the larger openings of type B even higher than those of the full height openings without columns. Nevertheless, the ratings for opening type C, are altogether on average higher than those for opening type B. A common argument in prospect-refuge theory is that a balance of prospect and refuge – the most preferred setting within an environment – occurs in a centre area of a room. However, as the present test environment excludes visual connections to adjacent rooms, this could explain the preference for prospect-dominance. Closer to the edge of outlook, near the façade, and with protective walls at the back, a sort of balance of prospect and refuge occurs which is broadly supportive for both, prospect-refuge theory as well as for prospect-dominance in the case that openings
are only on one side of the room. Interestingly, corner windows have been perceived in five of the six cases as more comfortable than those openings of equivalent opening size but which offer a front view only.

The survey data of perceived comfort indicates that there are very few, significant differences between the groups. The largest disparity, with only five significant results of the 24 cases, occurs for a comparison by professional background, which indicates that participants who had no training in architectural design provided on average higher ratings for perceived comfort than those who were trained in design. The older age groups of participants and those who live in homes with at least one separate bedroom have rated on average opening types B and C higher for comfort. Participants from urban areas provided on average lower ratings in opposite to those from suburban areas. Females as well as European participants rated the larger openings of type B and C higher, while Asian participants rated these on average lower.

All geometric room properties show for opening types A and B significant correlations with perceptions of comfort while this is not the case for opening type C when comparing area and perimeter with mean results. For opening type C, the most exposing fenestration type, only opening area and the wall-to-window-area ratio indicate a significant correlation with perceived comfort, of which the latter room measure is the most precise in capturing the geometric differences between the 24 room variations.

Despite some partially supportive results for prospect-refuge theory, more testing is required. A limitation of the present study is the simplicity of the rooms. Future studies are suggested that test also larger openings in one room and also openings on more than two façade sides, which might be judged differently, possibly leading to lower ratings for perceived comfort. Internal views have only been rarely examined, and also vertical connections (or three dimensions) should be considered. In addition, other room dimensions could vary, for example the width of walls, floor or ceilings, to learn when a space may be experienced as too complex or too exposed or enclosed and not so comfortable anymore.

In summary, the results of this paper indicate that people like large, wide openings and corner windows that allow one to derive even more information from the outside world. Windows that are divided by columns also elicit high feelings of comfort from some demographic groups. Such findings are relevant to designers and authorities responsible for decision-making about architectural form. Curtain wall façade systems that include flexible, exterior shading devices can be a solution for allowing the right levels of openness desired by the tenant and inviting daylight into habitable spaces in a controlled manner.

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References


A Comprehensive POE Process for Investigating Service Efficiency based on Universal Design Principles: A Case Study of Public Zones in Naresuan University Hospital

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Abstract: It is widely recognized that public hospitals are not only responsible for quality medical treatment, but that they should also be as inclusive as possible in providing access for all. Unfortunately, and for a variety of reasons, a quality service is not always provided. When measurement or evaluation of the service quality in healthcare organizations is carried out, it is mostly conducted in terms of medical service quality, whilst the physical layout, functionality and facilitating devices are not given as much scrutiny. Likewise, with Post Occupancy Evaluation, the majority of studies report on user perceived comfort, health and productivity and Universal Design is given little or no attention. The objective of this study is to investigate in a comprehensive way how the physical features, functionality and facilitating devices affect accessibility to medical services in the public zones of Naresuan University Hospital in Phitsanulok Thailand, and to propose changes that could improve service efficacy. The research is based on an empirical study using a new comprehensive combination of techniques based on qualitative methods and includes; identification of the general problem within NU Hospital public zones, an experimental access audit by participants with physical limitations, an evaluation of the physical features, functions accessible design using the seven principles of Universal Design (UD7), a comparative study between international standards for hospital design and the as-built hospital, and a comparison between recommended space per person(referring to best practice flow capacities) and actual usage. Problems that were identified include a lack of or poorly located specific devices that provide aid to disabled users, obstructions to and overcrowding in principal communication spaces reducing service efficacy, and poor people management practice exacerbating the above problems and contributing to less than satisfactory access for disabled users. By applying UD7 best practice to the existing layout and proposing small inexpensive design changes, it is estimated that service efficiency and universal access could be vastly improved.

Keywords: Universal Design, Accessibility.
1. Introduction

The globalization era has affected Thailand in many ways including changes in the economic system, population structure and a never ending demanding for natural resources. The modern way of life has increased environmental degradation, but more importantly, has seen changes in the social system, such as increased poverty and an increase in the number of disadvantaged including persons with physical limitations.

It is well recognized that to be sustainable, it is necessary to have social structures and infrastructure that facilitate equality. With this in mind it is also recognised that the role of a hospital is not only to provide quality medical treatment, but that it should also serve society in the matter of rights to health and security, (Preiser WFE, 2009, Setola N, et al. 2013, Longo E, 2012). This being the case and even though healthcare buildings often have complex facilities that may pose challenges for users (Murphy P, 2012), their design should be based on user activity and behaviour (Sahachaiseri N, 2012).

Universal Design (UD) is that paradigm that emphasizes social sustainability where different physical abilities are recognized as a regular human condition, and that promotes equal access to all service functions. The World Health Organization's definition of disability, ‘International Classification of Functioning, Disability and Health (ICF2001) refers to 7 measurement criteria (UD7) that address the accessibility level of service facilities; vis-a-vis; equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, size and space for approach and use. (Danford and Tauke, 2001 cited in Y. Afacan, 2008).

The design of the physical environment has been identified as having an influenced on well-being, healing, relief of pain and stress and reduced medical errors, infections and falls (Verderber S, and Fine D, 2000, Ulrich, et al, 2008). Despite this however, the majority of measurement or evaluation of the service quality in healthcare organizations is mostly conducted in terms of medical service quality, with the physical functioning of the building and facilitating devices being ignored. Built physical features that affect the quality of medical service provision including; artistic images, building character, lighting, air quality, circulation, and way-finding should be included. (Preiser WFE, et al., 2009).

Various evaluation or measurement methods have been employed to investigate the in-use quality of buildings of which, Post-Occupancy Evaluation (POE) is the most widely recognized. POEs focus on building occupants and their needs, and thus provide insight into the consequences of past design decisions and the resulting building performance. This knowledge forms a sound basis for creating better buildings in the future (Preiser WFE, et al., 1988). However, the vast majority of POEs report on user perceived comfort, health and productivity but Universal Design is given little or no attention.

Existing methods have also been used various times to identify problems associated with the functionality of buildings and facilities such as Behaviour Observation, Experimental Access Audits (Holmes-Siedle J, 1996), and Interdisciplinary Heuristic Evaluation (Afacan Y, Erbug C (2009). Measurement and comparative studies have also been undertaken using reliable best practice guides including; flow capacity and real-time head counting. Taken individually, each of the above methods has their own merit but they are deficient in comprehensively evaluating problems associated with Universal Design.

A preliminary survey of Naresuan University (NU) Hospital in Phitsanulok, Thailand indicated problems of overcrowding causing difficulty for access for disadvantaged users such as; pregnant women, elderly, frail patients, and those with physical impairments. It was unclear whether the hospital design, layout of facilities, too many people, poor wayfinding, or a combination of these factors caused
Conventional POE investigations do not provide a systematic approach to investigate such issues (Preiser WFE, 2008). This paper proposes a comprehensive and systematic process to evaluate the functionality, physical features and devices in terms of Universal Design.

2. Aim

The objective of this study is to investigate in a systematic and comprehensive way how the physical features, functionality and facilitating devices affect accessibility to medical services in the public zones of Naresuan University Hospital in Phitsanulok Thailand, and to propose changes that could improve service efficacy.

3. Method

To achieve the above aim an empirical study using comprehensive processes was employed as follows:

Underpinning this study are 3 levels of POE, including indicative, investigate and diagnostic investigations (Preiser WFE, et al., 1988, 54). In addition, this study applies POE methods to evaluate the service efficiency in term of UD whereby critical research issues such as human senses and spatial behavior are investigated, but perhaps more importantly, these are situated within a particular cultural context (Preiser WFE, et al., 2008).

In the indicative investigation, general problems were identified through observation by researchers and 5 universal design specialists from different design disciplines, focusing on UD7 criteria. Using experts at this stage allows identification of spatial problem in minimum time. Issues with physical features identified, included outpatient service flow, and the current accessibility problem at the main entrance area (triage point, reception), outpatient department (OPD), emergency room (ER), exam diagnostic room, service department (cashier counter, pharmacy), toilet, corridors, and elevator.

During the Investigative phase, physical obstructions that appeared to affect service space accessibility and the spatial behaviour and requirement of users were then further investigated using an experimental access audit. This was carried out by observing and recording the experience of participators, who simulated users with physical limitations including; deaf, blind, impaired mobility and elderly and comparing their experience to UD7 criteria. The experimental access audit is a useful method for examining usability, identifying problems relating to differing physical limitations and spatial behavior of specific users within the actual space and cultural context (Holmes-Siedle J, 1996). It is recognized that an appropriate range of participators is required to provide a reliable representation of other users with similar physical conditions.

The diagnostic stage is an in-depth investigation whereby existing physical features were measured and compared to both Thailand and International best practice hospital design guidelines and space standards. A photographic record and head count of users in the various spaces every 15 minutes during peak time, was compared to best-practice international standards of flow capacities and actual usage (Adler D, 1999, DoH, 2013, DoH, 2014).

4. Results

The result of the preliminary investigation using observation is as follows:

- Lack of separation between vehicles and pedestrian traffic.
- Physically disabled persons have difficulty gaining access to the hospital building by themselves.
• No car park for disabled persons and the location of general car park is far from main building entrance.
• The distance between each service function is too close necessitating overlapping space and causing overcrowding and congestion to block circulation routes and obstruct accessibility
• The space for some department appears to be inappropriate for the number of users, which appears to be the main cause of congestion causing problems for disabled, wheelchairs, trolleys and beds.
• The layout of zoning is not conducive to outpatient service flow.
• The way-finding system is confusing, such as layout of zoning is not concordant with outpatient service flow, unclear visual access, too many signs and inappropriate location.
• The furniture within public zone is insufficient or inappropriate for disabled such as higher counters and no seating for persons with physical limitations.
• No handrail for the ramp at the main entrance.
• No Braille sign system.
• Decentralized service point system contributing to confusion.
• The current circulation layout contributes to the problem in various locations such as location of seating area, counter etc.

The second investigation using participators (Access Audit) found that major physical obstacles affected service space accessibility as follows:

• Crowds and congestion occurring in various areas such as: queues too close to the main entrance, department entrances and across communication and circulation space.
• Furniture placed in communication spaces causing obstruction to general public, wheelchair users and patient trolleys, and people with disabilities.
• Way-finding deficiencies results in people being unable to identify their location, and destination.

The access audit divided the area into two parts consisting of outdoor and indoor physical features and functions. Table 1 shows a sample of evaluation results of some of the indoor physical features.

The comparative study between international standards for hospital design and the as-built hospital revealed that in some instances the observed space meets the international standard but overcrowding was observed causing congestion and blocking communication and circulation spaces. It also uncovered some spaces that do not meet the international standard but no problems were observed. Problem spaces frequently involved waiting areas encroaching on communication/circulation spaces within public zones including at: the registration point, reception, triage point, LAB, hallway intersection at outpatient cashier and the outpatient pharmacy. The definition of communication space is the space that provides access between departments including: hospital streets, corridors, internal lobbies, staircases etc. Circulation space is the space that provides for moving between rooms/ spaces within that department such as corridors, internal lobbies etc.

It is interesting to note that for the majority of identified congestion areas, the sizes measured on site compared favorably with published best practice space standards. It is also interesting to note that many areas that did not meet published best practice space standards that no overcrowding occurred, thus, there must be other issues that contribute to the accessibility problem.
Having identified the problem areas, a CCTV and photographic record of these areas was undertaken every 15 minutes during peak periods. This record was then analyzed to clearly identify what was causing the problem of congestion, particularly in the main entrance and laboratory areas where congestion appeared to be worst. The main entrance area includes the registration point, reception, triage counter, waiting areas and other areas incidental to communication spaces, with the (total space 205.34 m²).

The CCTV footage revealed that during the peak period at 7.00 am an average of 100 persons with 4 wheelchairs were in the space at any given time. When compared to best practice flow capacity for pedestrians walking at a good pace rough this area (45 pedestrians) the space is inadequate for the number of users. What seems to have contributed to the number of users is a waiting area located within the space with no clear separation between the waiting area and the communication space as illustrated in Figure 1. The waiting area was observed to have 40 seats with no areas designated for wheelchairs as per Figure 2. The number of seats provided is less than the standard for a waiting area, calculated as; 25 per cent for sitting (with 10 per cent for wheelchair) and 75 per cent for standing. Given this figure, the appropriate number of seats should be not less than 46 seats with 5 seats for wheelchairs. The laboratory area has a total space of 45.80 m². The CCTV revealed that 208 ambulant persons occupied this area during the peak period at 7.45 am along with 30 wheelchairs and 4 bed patient, 242 in total.
The suggested seating capacity for this space should be 223 persons, which matches the lower criteria for people moving at a shuffle. The 40 seats in this area is more than the requirement calculated at 25 per cent for sitting (with 10 per cent for wheelchair) and 75 per cent for standing. The appropriate number of seats in this area should not over than 20 seats with 2 seats for wheelchair. However, the total space of the laboratory communication area is smaller than suggested in the space standards and
additionally, most of the space is occupied by seats. It would appear in this case that the seating area is reducing the flow capacity causing congestion as shown in Figures 3 and 4.

![Images of congestion within the lab area. (source: Phaholthep C,2016)](image)

Within the cashier service area and outpatient pharmacy service area the number of users is less than that required by best practice, however, again there are obstacles within the communication space. The counters of both departments are located along the passageway, where the queues tend to run across the passageway. In the waiting area, the seating is not particularly appropriate for elderly or disabled thus causing stress, anxiety, irritation, which combined with the crowding, results in the waiting area being uncomfortable with little privacy as indicated in Figure 5.

![Images of where congestion occurred at cashier and pharmacy (source: Phaholthep C,2016)](image)

5. Discussion

There appears to be three main issues that contribute to the problem of congestion and poor accessibility within the main public areas of the hospital, namely; physical features, functionality and the facilities provided.

Physical features have an effect on service efficacy in relation to the number of users a space can reasonably physically accommodate relative to the activity that is taking place in that space. In some instances, insufficient space is provided for the number of users however in these areas there were no problems identified with congestion. In other instances, there is sufficient space provided according to best practice design, such as the main entrance and LAB areas, but congestion was observed in these areas. The congestion subsequently blocks access for other transient users, especially those with physical limitations. The location and layout of furniture also plays a significant role. Furniture located in
inappropriate places such as, the counters for some service points are located directly opening on to the main communication areas, resulting in queues that tend to run across passageways. Compounding the problem is the location of waiting areas far away from the service courters resulting in many users standing adjacent to service points thus creating further congestion. The fact that many spaces are being shared with other functions on the circulation zones also appears to cause congestion such as the triage point, registration counter, and waiting areas. Furthermore way-finding signage tends to be only located at intersections of main communication spaces resulting in too many signs and text that is too small so that people have to stop to find the sign they are looking for thus causing further congestion in the communication space.

Functionality has an effect on service efficacy in respect of circulation flows, static zones such as waiting areas and service areas where people queue. In the main entrance area where people arrive the study found that: access was not easy and people were unable to move at a good walking speed on main communication routes due to congestion. Additionally, because of congestion, people were unable to see beyond the entrance area to the reception, information and help desks. People were then hindered in moving around and in leaving because the entrance area was congested. The staff communication base, and the main registration point for patients could not be seen from the main entrance because of the lobby arrangement containing the triage point and the queue at the reception point crossing the main communication access to the rest of the hospital. Adding to the problem is that the reception desk location is inappropriate for wheelchair users. Firstly it is difficult to see amongst the congestion, and secondly there is no dedicated wheelchair point at the counter resulting in further congestion. Waiting areas appeared to be one of the main causes of congestion. Firstly the location within the communication and main circulation zones meant that if service was slow, and then the over spill of waiting patients ran out into the main communication zones. In addition, the seating provided is unsuitable for elderly, disabled and wheelchair users. Patients were frequently seen standing in the circulation zones adjacent to the waiting areas rather than sitting. The lack of provision for the visually impaired also contributed to congestion. Lack of braille on signage, lack of way finding devices for visual impaired and lack of audio way-finding also appeared to contribute to congestion. Overall it was evident that the elderly, disabled, blind and wheelchair users found it difficult to arrive at, enter, move around, access the required facilities and leave the building without significant anxiety and/or embarrassment.

The facilities provided within the various spaces of the hospital also have an influence on service efficacy. Parking for staff and outpatients is much too far from the main entrance and not provided at all for disabled user. The ramp to the building is too steep causing wheelchair users to use a lot of physical effort. There are no tactile pavement areas provided externally or internally causing difficulty for the visually impaired and blind. Most of the doors within the case study are of the swing type, are heavy, and open out into corridor spaces causing difficulty for the persons with physical limitations. Counter heights are too high compared to best practice guidance of 0.75m, causing communication problems for wheelchair users. No seating spaces are provided for disabled and no wheelchair waiting spaces are designated. Waiting spaces are too far from service points. The audible signal in the elevator is available only in English and no tactile pavement is provided for navigation. No LED text is provided at service points in the public zones for the deaf.

Proposed changes that could improve service efficacy relate primarily to reducing congestion. It is important that all users should be able to enter, move around and access services and then leave the hospital with relative ease.
Firstly, the triage point should be moved away from the main entrance lobby to allow users to enter and leave the hospital without hindrance.

Secondly, queues at service desks should be managed to prevent queues crossing main communication and circulation routes.

Thirdly, waiting areas, if located within communication spaces, should have sufficient seating and be enclosed to prevent waiting in the circulation areas. In addition some general seating and wheelchair/trolley seating should be provided with appropriate clearances and the PA / call system should be easily accessible within the waiting areas.

Fourthly, specific facility should be provided for persons with physical limitations to access services easily and equally including disabled car park spaces located close to the entrance, the visual impaired should be provided with warning blocks, braille blocks, and tactile surfaces, the hearing impaired should be provided with text signs, and the mobility Impaired should be provided with appropriately sized facilities.

6. Conclusion

A new comprehensive research method has been employed to identify issues relating to service efficiency at Nareasuan University Hospital. The method uses a combination of techniques and processes based on post occupancy study and adapt to appropriating the context of the case study with specific focus on universal design principle includes; identification of the general problem within NU Hospital public zones, an experimental access audit by participants with physical limitations, an evaluation of the physical features, functions accessible design using the seven principles of Universal Design (UD7), a comparative study between international standards for hospital design and the as-built hospital, and a comparison between recommended space per person (referring to best practice flow capacities) and actual usage. Problems that were identified include a lack of or poorly located specific devices that provide aid to disabled users, obstructions to and overcrowding in principal communication spaces reducing service efficacy, and poor people management practice exacerbating the above problems and contributing to less than satisfactory access for disabled users. By applying UD7 best practice to the existing layout and proposing small inexpensive design changes, it is estimated that service efficiency and universal access could be vastly improved. There are four main suggested improvements that require little or no expenditure. By moving the triage point to a new location, the main entrance area can be freed up and users can move into and out of the building easily. Simple queue management roping systems to prevent queues crossing main communication and circulation routes could manage queues at service desks. Waiting areas that are located within communication spaces should be enclosed to prevent waiting in the circulation areas thus removing significant congestion and consequently additional seating could be provided without causing further congestion. In addition wheelchair/trolley seating could be provided with appropriate clearances and a PA / call system could be provided within waiting areas. Last but not least, specific facilities should be provided for less able persons to access services easily and equally including disabled car park spaces located close to the entrance, warning blocks, braille blocks, and tactile surfaces for the visually impaired, the hearing impaired could be provided with text signs, and the mobility Impaired could be provided with appropriately sized facilities. All of this could be expedited with little or no disruption to existing
services, and for very little cost. The result would be a much better user experience for all building users, particularly those with physical limitations.

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Alternative housing options for older New Zealanders: the case for a life-cycle study

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Abstract: This paper makes a case for the resource assessment of housing alternatives for an ageing population that could make better use of existing housing in New Zealand. Limited housing choices for older people as well as personal factors have led to a demand for ageing in place. This requires finding effective design solutions for redeveloping the existing housing stock or designing new buildings to achieve a better quality of life, wellbeing and independence for those aged 65+. Research also suggests a considerable proportion of the ageing population live in large houses with two or more spare bedrooms, which implies large houses occupied by small households. Furthermore this age group, often on restricted incomes, does not necessarily maintain or heat these houses as much as needed. This is a potential health issue that can have implications for the national health budget. As a consequence, ways of altering such dwellings require more investigation to find those which have the lowest life-time resource use and are, at the same time, more energy efficient and affordable. This paper outlines a proposed research project to address these issues by undertaking life-cycle resource and cost assessments of design solutions for ageing in place in more suitable accommodation.

Keywords: Ageing population; housing alternatives; life cycle analysis; ageing in place.

1. Introduction

Housing plays a significant role in people’s lives by providing financial and psychological security as an investment and as shelter. Consequently, making appropriate housing choices is one of the most important decisions in the life of the 65+ age group, many of whom are no longer in full time employment, while having such choices can lead to greater life satisfaction and health (Office for Senior Citizens, 2013). According to Statistics New Zealand, the rate of home ownership for people aged 65+ is expected to decline (Office for Senior Citizens, 2013) while by 2050 numbers of older people with some form of disability are projected to increase by 60% (Statistics New Zealand, 2007). These two trends coupled with forecasts of more people in this age group living alone in the community (Statistics New
Zealand, 2015a; Office for Senior Citizens, 2013) lead to the growing need to address the issue of appropriate housing, one aspect of which is ageing in place rather than moving to a specially designed elderly residential facility, such as a retirement village. This paper explores this issue for New Zealand and suggests that renovation and redesign of houses that are too large for ageing households is worth investigating, and could lead to reduced resource and financial costs and better quality of life through retaining community ties.

2. An ageing population and the housing stock

2.1. Housing stock characteristics

In New Zealand 75% of dwellings have 3 or more bedrooms, with the number of one bedroom dwellings forming less than 6% in the last three censuses, and 1 and 2 bedroom dwellings less than 25% (Statistics New Zealand, 2001, 2006a, 2013a). Statistics New Zealand (2015a) suggest that in 2013, more than half of people aged 65+ in private dwellings (51.1%) were couple-only householders and just under one-third of this age group (28.8%) were one-person households, meaning that nearly 80% (79.9%) of people aged 65+ were in small households. Considering the growth in the number of one-person and couple-only households, mainly driven by the ageing population (Saville-Smith et al., 2008), the data demonstrate a mismatch between current and projected household characteristics and the existing housing supply (figure 1).

![Figure 1: Occupied private dwellings by number of bedrooms (Statistics New Zealand, 2001, 2006a, 2013a)](image)

The other problem is that new houses are added to the existing stock at a slow rate. Dwellings under construction comprised less than 1% of New Zealand housing stock in the census (Statistics New Zealand, 1998, 2006a, 2008, 2013b), so new affordable homes for older people are not an option, despite the fact the government is giving priority to the provision of affordable housing and making this available to those aged 65 and over (Office for Senior Citizens, 2013).

2.2. Ageing in place

The 65+ age group in New Zealand has nearly doubled since 1981 and a quarter of New Zealand’s population will be in this group by mid-century (Statistics New Zealand, 2015a). Taken with the
information in figure 1, this suggests a mismatch between small older person households and the existing housing stock, something also observed in Australia (Judd et al., 2014). Even if people wish to move from a house that is too large to something more suitable, the latter is generally not available (Davey et al., 2004).

Given this lack of new appropriate housing more older people are likely to remain in their family home in the future, leading to the need to ensure these houses are properly insulated and heated, have easy access and are safe, and are affordable (Davey, 2006). Living in the community in this way would be combined with the many assistive programmes in New Zealand that allow older people to remain in their current house safely and autonomously. These home support services enable ageing in place as long as possible by providing assistance with household tasks, shopping and other chores, and retaining or maintaining supportive social networks, providing certain eligibility criteria are met. The number of people aged 65+ who received financial assistance with equipment or housing modifications, between 1 July 2012 and 30 April 2013, was slightly less than 30,000 at a cost of $11.2 million (Office for Senior Citizens, 2013). Statistics New Zealand suggest that in 2006, 68% of people 65 and over made housing modifications, with those to improve access or moving within the home as a result of age related disabilities accounting for 37% of total housing modifications in 2006 (Statistics New Zealand, 2006b).

Numbers moving to residential care obviously increase with age and the higher levels of disability that come with this. However, living in the community is still appealing for some aged 85+, even with substantial disabilities (Davey, 2006). Around 75% of people aged 65 and over own or partly own the dwelling they usually live in (Statistics New Zealand, 2015a). Results from the 2013 Census show 92 % of those aged 65+ lived in private dwellings, suggesting older people are choosing to remain in the community as long as possible.

2.3. Housing and maintenance

Saville-Smith et al. (2008) believe that poor New Zealand housing conditions and maintenance and repair problems are the main barriers for ageing in place and hence maintaining community ties, and further suggest that along with the population, the housing stock is also ageing. BRANZ’S Housing Condition Survey (HCS) showed houses occupied by older people tended to be in better condition compared to those of the under 65s. However, the average condition of some components of older people’s houses (fasteners, steps/ramps, windows, carport, roof cladding, kitchen linings, kitchen joinery, stove, laundry linings, laundry fittings, and bedroom linings) were in a poorer condition (Clark et al., 2005; Saville-Smith et al., 2008).

Evidence from the New Zealand general social survey conducted in 2014/2015 suggests that in 2014/2015, 50.7% and 3.8% of New Zealanders over the age of 65 lived in dwellings which required minor/some and immediate/extensive repairs and maintenance respectively (Statistics New Zealand, 2015b). On the other hand, in 2008, 2010 and 2012, people aged 65 and over who had major problems with their house accounted for 32.3%, 19.8% and 17.5% of the population respectively (Statistics New Zealand, 2009, 2011, 2013c). It should be noted that the figures for 2008 include any major problem in either house or neighbourhood but for 2010 and 2012 only houses have been considered, which may explain the large drop.
2.4. Design characteristics of housing for older people

The Organisation for Economic Co-operation and Development (OECD) (2003) suggest an ageing population needs smaller houses to cope with later life, and these need to be in the community and specifically close to family members and relatives to reduce the need for residential care. Housing should also be designed considering “lifetime” standards to accommodate people of all ages and all levels of disabilities. Many countries are also seeking approaches that integrate housing and care in non-institutional accommodation. This supported accommodation reduces the need to move to residential care.

In New Zealand Davey (2006) has stated special attention should be given to heating and ventilation problems, which have a negative impact on the health and well-being of the elderly. Low-maintenance buildings are also important.

3. Existing research into resource efficient housing for an ageing population

3.1. Housing studies in New Zealand and overseas

Of the many New Zealand studies on the provision of housing for the elderly, most have dealt with affordable and suitable dwellings and improving the condition of existing houses in order to age in place rather than sustainable or more resource efficient housing (Davey et al., 2004; Davey, 2006; Boston and Davey, 2006; Saville-Smith et al., 2008; Saville-Smith et al., 2009; James et al., 2012; Saville-Smith and Fraser, 2014). A number of studies have also dealt with the energy performance and environmental impact of housing in New Zealand (Baird and Chan, 1983; Wright and Baines, 1988; Johnstone, 2001; Mithraratne et al., 2007). While in New Zealand a number of studies have evaluated the efficacy of energy efficient upgrades of existing residential buildings and the utility of sustainability features (Lloyd and Callau, 2006; Zhang, 2010), overseas several attempts have also been made using life-cycle analysis (LCA) to examine the resource implication of retrofitting existing buildings (Crawford et al., 2002; Vale and Vale, 2006; Itard and Klunder, 2007; Page, 2010). In order to further investigate cost-effectiveness, cross comparison has been carried out in a number of these studies (Vale and Vale, 2006; Zhang, 2010; Page, 2010). However, very little New Zealand research has examined the environmental impact of renovation involving substantial changes in the building layout. In a recently published study by Leah (2015), the embodied energy of transforming and upgrading two comparable residential complexes in New Zealand and the UK over time was examined. Despite disparities in terms of layout, style, building materials and methods of construction, shared components included occupant characteristics, planning and time of construction. Comparative study of an initial typical residential design with the proposed improved design in terms of reducing life cycle energy has been the focus of some research (Bagley and Crawford, 2015). In this case redesign emphasized reducing embodied energy in terms of using alternative construction materials and systems as well as sustainability features including passive thermal devices. Together these studies provide important insights into the resource implications of buildings using various scenarios and tools. However, far too little attention has been paid to the financial and environmental burden of possible housing alternatives for the ageing population who wish to age in place. Thus, this study aims to examine the environmental impact of housing alternatives for older people and their lifetime resource use. This means considering the preferences of older people for ageing in place and investigation of possible design solutions based on converting existing dwellings.
These solutions need to consider sustainability principles to help older people remain warm and comfortable as well as being able to afford the solutions.

3.2. Environmental impact assessment of retrofitting versus new build

Utilising energy efficient features such as double glazed windows and effective insulation generally feature in retrofitting dwellings to make them more comfortable. Page and Fung (2008) highlighted the significance of the environmental impact of the renovation and upgrading of existing houses in New Zealand. They argued that renovation and insulation upgrades in order to extend the life of an existing house are superior to demolition and replacement in terms of life cycle costs (Page, 2010).

As demonstrated by De Angelis et al. (2013), retrofit practices have not been sufficiently studied in terms of life cycle analysis. De Angelis et al. (2013) compared two scenarios for an Italian six-storey building (demolition and reconstruction and envelope refurbishment). External and internal thermal insulation, slab insulation, roof insulation and window substitution were considered for the second scenario. They found building refurbishment is more sustainable in terms of reducing energy consumption and life cycle costs. While this type of renovation has been identified as the cheapest and most environmentally friendly, the possibly better acoustical, structural and architectural performance of new constructions have not been considered in analyses (De Angelis et al., 2013). However, from the economic and environmental perspective, energy refurbishment activities are deemed to be the better strategies for existing buildings that are structurally and architecturally valuable. On the other hand, Bullen (2007, in Bullen and Love, 2011, p.34) compared the potential functional differences between new and adapted buildings, demonstrating that an adapted building does not necessarily have a better performance than a new one.

A similar investigation has been conducted in the Netherlands where four scenarios were examined for two typical residential buildings: “ordinary building maintenance, consolidation (insulation measures), transformation (change floor plan to accord with new needs), and rebuilding (demolition of the old building and reconstruction with new floor plan)” (Itard and Klunder, 2007, p.266). Environmental impact determinants measured included material, energy and water use, demolition waste, and total environmental impact using an LCA approach. In their study, it was argued that transformation of the existing housing stock is a much more environmentally efficient way to achieve the same results compared to demolition and redevelopment. However, transforming the design of existing buildings by changing the floor plan needed to be done in a way that would be sufficiently flexible to allow for any alterations to meet the new and changing needs of occupants. As yet no similar studies have been found for changing existing houses to make them suitable for use by an ageing population.

3.3. Using a life-cycle approach

Life cycle analysis (LCA) is “a quantitative assessment of resource uses (raw materials and energy) and waste discharges for every step of the life of products, services, activities and technologies, and thereby provides a way to evaluate and quantify the environmental impacts of a wide range of products and activities” (Mithraratne et al., 2007, p.23).

The utility of life cycle investigations in developing more sustainable building design practices has been acknowledged by many researchers (Ramesh et al., 2010; Stephan et al., 2012; De Angelis et al., 2013; Cabeza et al., 2014; Goh and Sun, 2016). As suggested by Mithraratne et al. (2007, p.32) “the
longer the useful service life of the building, the less will be the burden on the environment”. This statement has been advocated by many studies implying that increasing emphasis needs to be placed on the preservation and reuse of the existing building stock for meeting sustainability goals (Itard and Klunder, 2007; Kohler and Yang, 2007; Page and Fung, 2008).

LCA has generally been used for comparative life cycle energy studies in order to identify the critical factors influencing the lifetime energy and cost of residential buildings, thereby leading to improvement in building performance (Fay, 1999; Fay et al., 2000; Mithraratne & Vale, 2004; Mithraratne et al., 2007). Various approaches for comparing case studies have been used for this purpose including comparing alternative designs (Fay, 1999; Fay et al., 2000) and comparing various applications of different materials and construction components in a single standard house (Mithraratne & Vale, 2004; Mithraratne et al., 2007).

Since LCA studies are dependent on a considerable quantity of data, there is always an uncertainty about the credibility of them, with possible misleading results (Hendriks and De Hoog, 1998). Harsch et al. (1996) describe the limitations of LCA analysis as the influence of boundary conditions, system definitions and importantly, data quality. Nevertheless, as indicated by Mithraratne et al. (2007) the uncertainty of the results stemming from data quality can be assessed using statistical methods and presented as a range or standard deviation. Utilising LCA provides a good opportunity for assessing alternatives in the decision-making process, and it has “transparency and reproducibility”, but also areas that could be improved (Harsch et al., 1996).

Saville-Smith (2008, p.5) suggested the initial purpose of retrofitting the existing New Zealand housing stock is enhancing the energy performance of existing buildings. Many studies have focussed on enhancing energy efficiency (Figueres and Philips, 2007 in Shen, 2012). Crawford et al. (2002) evaluated the embodied energy of a small detached building which had undergone refurbishment aiming to make it more energy efficient and found that in terms of energy “the energy efficiency features generally paid back within the lifetime of the building” (Crawford et al., 2002, p.93). Research from the life cycle cost perspective suggests the cost of reusing and renovating existing buildings can be lower than demolition and rebuilding the same volume (Itard and Klunder, 2007, Page, 2010, Bullen and Love, 2011). Bullen and Love (2011) also highlighted the significance of adaptive reuse from the sustainability perspective. Bekker (1982) has suggested that renovation is an appropriate method of extending a building’s life in order to protect valuable resources and reduce the environmental impact.

4. Housing alternatives for an ageing population

Statistics New Zealand (2013d) suggest there is an increasing demand for communal dwellings driven by the ageing population. Communal residential buildings such as cohousing have the capacity of attracting older people as they can provide assistance and companionship. Although most existing co-housing acts as multi-generational communities, senior co-housing is seen as a new trend (Gottberg, 2016), an example in New Zealand being Abbeyfield House where 8-12 residents share a family-style home. Types of co-housing also include houses shared with family members or boarders, (Davey, 2006). The subdivision of existing sections (plots of land) in New Zealand is common in urban areas, especially to stop urban sprawl by housing more people on the same plot of land. Accessory Dwelling Units (ADU) have been developed in California in the form of proposed plans. An ADU is defined as “a completely independent living facility with separate cooking, eating, sanitation and sleeping facilities that is either in or added to an existing dwelling or in a separate accessory structure on the same lot as an existing dwelling” (Montgomery County Maryland, 2005 in Duff, 2012, p.33). This approach recognises the
problem of small households living in large houses and often on large plots, by suggesting ways to subdivide both. Duff (2012) studied the environmental impact of accessory dwelling units demonstrating that they contribute to reducing housing and land resources by accommodating a greater number of people through increasing density and avoiding infrastructure expansion.

5. Research justification: LCA in the context of gerontology

This research aims to address the collective impacts of an ageing population in terms of demographic changes and the preference of older people for ageing in place. The purpose of the proposed research is to investigate how to make existing housing more suitable for ageing generations and the environmental and economic implications of making such housing. This will need to be compared with the impact of building new appropriate housing. All designs will have to include features appropriate for housing the elderly.

One problem with ageing in place in small households of one or two people is that research suggests these “…are less efficient in terms of resource use per capita than larger households” (Liu et al., 2003 in Williams, 2007, p.331). Williams (2007) sees the growth in one-person households in England and Wales as leading to an increase in domestic resource consumption of energy, water, land and materials, something he considers the UK has in common with many developed countries. In order to tackle this problem, Williams (2007) investigated a number of design solutions including ecological homes (incorporating energy-efficiency measures and renewable energy technologies), communal homes (sharing resources between household members) and collaborative dwellings (sharing resources within a community such as in co-housing). He studied the resource implications of these solutions for England and Wales and found substantial resource savings for those living in both shared and co-housing arrangements (in terms of land, direct energy and household goods), mainly due to sharing resources in daily living. He estimated average resource savings of 44% and 57% in communal and collaborative housing respectively (Williams, 2005 in Williams, 2007). In addition to sharing resources it seems these types of housing encourage a wide range of environmental behaviours in terms of energy conservation and waste recycling.

This project will first look at typical house types found in New Zealand. Initially, four New Zealand house types will be investigated (early 20th century villa with central corridor, 1920-30s Californian bungalow, 1930-50s single storey state houses, and 1960-70s Keith Hay Homes). Examples will be selected based on floor areas and number of bedrooms. To make a comprehensive comparison, a new house designed for the older household will also be selected. All the houses will have 3 or 4 bedrooms as the 65+ age group currently tend to live in larger houses (Statistics New Zealand 2013a; 2015). Each selected example will be redesigned, with options ranging from separate units of 1 or 2 bedrooms, separate units with a shared guest room and entry, to private ensuite bedsits with shared living/dining area, kitchen and spare room(s) for visitors, hobbies, or a live-in carer. All designs will contain the features appropriate for dwellings for older people, including being warm, safe and affordable. This will draw an overseas works such as UK Lifetime Home Standards and universal design principles which ensure housing is accessible and appropriate for all life stages and disabilities. The aim in the alternative design strategies is to retain the same standards of comfort and wellbeing found in new housing for the elderly as well as reducing energy and resource use.

All designs will then be subject to life-cycle resource and cost analysis and the results compared with new small houses. The outcomes of this evaluation will identify whether, in terms of resource and
energy consumption as well as cost benefits, there is any difference between housing for older people so they can age in place and the new developments which government and policy makers are encouraging and which mean senior citizens have to move.

6. Conclusion

This paper sets out to make a case for a life-cycle assessment of ways of allowing ageing in place in more suitable houses. This approach acknowledges that houses in New Zealand are under occupied, especially when it comes to the small households of an ageing population (Davey et al., 2004). The traditional housing model is likely to change because of changes in family size and lifestyle and population composition. Furthermore, the possibility of emigrants now of retirement age returning to New Zealand is another trigger in the growth of the ageing population and its influence on the property market (Statistics New Zealand, 2013d). The current market response of private retirement villages is not suitable for many older people who want to stay in their own communities and other ways have to be found of making appropriate types of housing, of which this project is a small step in this search.

References


**Abstract:** Design contributions to contemporary complex hospitals, based on the study of flows and the successive spatial readjustments they are subjected to, favor the preparation of architectural programs that are more capable of meeting the needs of their users. The Cancer Institute of the State of São Paulo (Instituto do Câncer do Estado de São Paulo – ICESP) is a large high-rise building, located in Brazil, in the metropolitan area of São Paulo, in a high-density urban region with a built area of approximately 82,500 m². The architectural aspects of this building that emerge from the Post-Occupancy Evaluation – POE approach, in terms of functionality, through the evaluation of its flows, aiming at identifying their impacts on patients and the work of the staff, are presented. It is hypothesized that the continuous application of POE can ensure that flows remain appropriate during the life cycle of this type of building, bringing benefits such as: a) the best addressing of users’ needs; b) the reduction of contamination cases deriving from the unwanted intersection of flows and c) the assurance that the means of circulation inside the building meet its daily need.

**Keywords:** Post-Occupancy Evaluation – POE, functionality, hospital facilities; flow of users.

**1. Introduction**

In today’s scenario, hospital buildings tend to lose their original functionality and new technologies render them obsolete quickly (Thomazoni, 2009). The study of operative flows in a hospital building, that is, of users, materials, equipment and corpses, in light of the successive spatial readjustments they are subjected to, helps to preserve the concept of humanization and elects the most appropriate design processes to better meet the expectations of users and generate safe and quality care.

As Voordt (2016) has pointed out, end-user satisfaction, enhancing productivity and stimulating innovation are highly prioritised; which values are prioritised depends on the organisational objectives, target group, available budget, position in the life cycle of design, construction and use and external context, in particular governmental policy. In Brazil, the operationalisation into concrete design choices and strategic management of buildings-in-use is still underdeveloped. In addition to this, the benefits arising from recent and new technologies, with impacts on the pre-established flows in the hospital
building, such as: the results of the implementation of the pneumatic mail system, the advances in Information Technology – IT and in the Information and Communication Technologies in Healthcare – ICTH, as well as in Telemedicine and Preventive Medicine, are irrefutable in the identification of improvements that affect the architectural aspects of this type of building.

2. Objective

The evaluation of verticalized hospitals on a regular basis, with a focus on functional aspects, can ensure that the flows of users, materials, equipment and corpses are kept appropriate, aiming at identifying their impacts on patients as well as on the staff and their work which may be directly or indirectly related to health care. This article highlights the relevance of the POE results with a focus on flows to improve the quality of the design process.

3. Methodology

As the research was conducted, the scarcity of literature on flows in contemporary complex hospital buildings in Brazil and around the world became apparent. Abroad and more recently, the approaches on hospitals correlate the POE to the analysis of the efficient control systems of the building. In the USA, the publications of The American Institute of Architects – AIA, the Washington State Hospital Association – WSHA and the Design & Health World Congress & Exhibition, an annual world congress that aims to increase the knowledge of the interdisciplinary science of design and health (International Academy of Design and Health, 2015), stand out. In Brazil, flows are studied conceptually and can be dealt with in events, congresses and issues of specialized magazines, but they frequently have neither mappings and drawings nor conclusions by architects themselves. The lack of accurate visual information can be identified as a major cause for the delay in the application of the technical findings to new designs (Kowaltowski, 2006).

An interview script was prepared containing ten questions about five different aspects: a) the integration of flows that are external to the hospital with the internal ones; b) whether the study of flows can contribute to the development of better hospital designs and to the changes and extensions of the building; c) the intersections of undesirable and desirable flows and of spontaneous occupations; d) the physical sectorization; e) the POE in the routine of hospital architecture firms and on the interdisciplinary contribution to new hospital designs.

For the understanding of the healthcare design of contemporary and complex high-rise hospital buildings through the POE approach, as to its operative flows, an evaluation of a case study on the Cancer Institute of the State of São Paulo – ICESP (in Portuguese) was performed. The evaluation was supported by the analysis of the existing literature, the study of the main Brazilian legislative and normative requirements, interviews with eight experts of interdisciplinary backgrounds and with architects that are specialists in hospital architecture, as well with fifteen ICESP’s healthcare professionals.

For the application of the POE to the case study, regarding the analysis of flows and their functionality, the main Brazilian normative reference is the ANVISA RDC 50 (National Health Surveillance Agency, 2002) which deals with the technical regulation for the planning, programming, development and evaluation of the design of Health Care Facilities. This regulation presents the sectorization of health care buildings divided into eight functional units, which favors the analysis of the flows involved: (1) Outpatient and Day Hospital Services; (2) Immediate Care; (3) Inpatient Services; (4) Diagnostic Support and Therapy; (5) Technical Support; (6) Education and Research; (7) Administrative Support; (8) Logistical Support.
Critical areas ("environments where the risk of the transmission of infectious agents is greater, in which risky procedures are performed with or without patients or where immunocompromised patients are present" (National Health Surveillance Agency, 2002, p. 63)) impacts on flow aspects in environments such as the kitchen, operating rooms, central sterile supply storage and laundry area (Karman, 1995, p. 109). Among the design recommendations on the intersection of contaminated material flows, several precautions can be eliminated with the confinement and the protection of contaminated materials at their source, i.e., with the correct packaging technique and with safe transportation. Under these conditions, the intersection of laundry carts, clean clothes carts, trash carts, food carts, dirty material carts and sterilized material carts is acceptable, allowing the elimination of routes, doors, walls and resources used to prevent the transfer of potentially pathogenic contaminants.

3.1. The case study

The case study is a contemporary complex hospital specialized in cancer treatment that provides about 54,000 medical services a month. The building is located in the metropolitan region of São Paulo, Brazil, in a high-density urban area, with a 440 bed-capacity and it has been in operation for six years. The building has a built area of approximately 82,500 m², 28 floors (112 meters high), one of highest hospitals in the world. Its vertical typology has a system of three vertical blocks interconnected horizontally: the main one, where health care services take place and the two lateral ones, for the circulation of patients, companions and visitors. On each floor, care teams are located and circulate in the Core of the building while patients, companions and visitors reach the main tower through the two lateral blocks (Figure 1).

![Figure 1: Core and user flow on floor plan. (source: Thomazoni, 2016)](image)

Although different authors may adopt different sectorizations for healthcare buildings, the analysis of user, material, equipment, and corpse flows in the building, that is the focus of this case study, was carried out according to the eight functional units defined by National Health Surveillance Agency (2002).
As shown in Figure 2, the functional organization is arranged in such a way that activities requiring a high turnover of users are placed on lower floors while those of low turnover are placed on higher ones.

3.2. The methodological procedures

The methods and techniques applied and selected with a focus on people, environments and the institution took into account their aim, time, the limitations of data collection in a healthcare building, the systematization and analysis of data, the availability of financial and human resources and the access to information. In order to do that, the most appropriate tools from the theoretical and methodological framework used in researches in the area of Post-Occupancy Evaluation were applied. According to Ornstein et al. (2009), the use of POE tools for new buildings and the remodelling of existing ones help to constantly update master plans of occupation, especially in the case of large and complex buildings, such as healthcare facilities.

For the case study, in a four-month period in 2014, through weekly visits, the following POE tools and techniques were applied: a) survey of the occupation history; b) study of the sectorization by functional units; c) study of the architectural designs; d) reconnaissance visits; e) technical visits/walkthroughs and wayfinding; f) checklist application; g) visual records; h) organizational chart analysis for the definition of interviewees; i) 15 semi-structured interviews with key personnel; j) observation of user, equipment, material and corpse flows. The research involved twenty-one ICESSP users, encompassing eight functional units. The semi-structured interviews with key people addressed the viewpoints of cancer patients, since it was not possible to have contact with patients themselves.
The following people were interviewed: Director of Building Infrastructure and Clinical Engineering; Architect; Building Infrastructure Manager; Building Engineering Manager; Director of Operations and IT (Information Technology); Outpatient Functional Unit and Day Hospital Manager; Diagnosis and Therapy Functional Unit Manager; Directors’ Medical Assistant; Infectious Diseases Medical Coordinator; Infectious Diseases Nurse; Ambulatory Coordinator; Director of Education and Research; Administrative Director; Surgery Center Nurse Manager and Director of the Emergency Department.

4. The new and recent technologies

In Brazil, among the recent technological developments with effects on pre-established flows in hospital buildings, it is possible to mention the implementation of the pneumatic mail, advances in IT, ICTH and Telemmedicine. The pneumatic mail system changes and systematically unburdens the flows of materials, allowing the optimization of its internal logistics. The purpose of the automatic multi-station system is to link several sectors through tubes connected to stations and terminals, which, by vacuum and compressed air, enable the safe transit of materials, such as documents, samples for pathological analysis, blood bags and others. The efficient transport of these items implies a reduction in circulation by care teams and otherwise inside the building, creating greater speed, efficiency and safety.

For those in charge of IT, the digital mapping of the processes that are carried out in the health care institutions increasingly enables them to strictly control the flows of users, materials, equipment and corpses in the hospital building. Among the digital systems, it is possible to mention the digital signage, which shows the paths to be followed by patients and the environments to which they must go, decreasing erroneous foot traffic and enabling users to improve their wayfinding capability. In addition, the intelligent use of vertical transport systems for elevators can lead the passenger to the most convenient elevator, reducing waiting times and the number of stops.

According to the Massachusetts Institute of Technology (1992), three criteria determine the navigability of a space: a) whether the navigator can discover or infer his present location; b) whether a route to the destination can be found; and c) how well the navigator can accumulate wayfinding experience in the space. Among the ICTH advances, it is possible to mention the implementation of digital simulation centers for the practice of health care procedures and the computerization of medical records with the creation of the Electronic Patient Record – EPR. Among its contents, the EPR has the patient identification, the evolution of his or her treatment, the preparation and the diagnostic decision-support system, which reduces the occurrence of errors, providing greater patient safety. The evolution of the ICTH with the implementation of the EPR brings positive results for health care professionals, patients, managers and other groups involved in healthcare services. The EPR makes it possible for the automatic sharing of information with other professionals and institutions that are taking care of the patient. This enables the continuity of a comprehensive healthcare in the institution, between institutions and within a region (city, state or country). As to the flows of users, materials and equipment in the hospital environment, the EPR precludes the logistics of the daily flow of inbound and outbound physical records. In addition, it reduces the control processes of those records, which can be checked by the members of the team wherever they are. Therefore, preventing them from having to travel to do their job, which is something that alters their flows, ICTH provides them with some extra time, which can be used to take care of a greater number of patients.

According to the ATA (American Telemedicine Association, 2014), the main international organization to speak for the use of advanced remote medical technologies, Telemedicine combines cost reductions
with the expansion of medical activities and it is also important in the remote updating of exam results and in the promotion of technical discussions.

Defined as the set of technologies and applications that enable the remote performance of medical activities, Telemedicine has been applied in hospitals and health care institutions that seek the help of leading institutions for consultation and the exchange of information and as a way of offering continuous care for the prevention, diagnosis and treatment of diseases. It has also been applied in the discussion of clinical cases, diagnostic aid, care of patients with chronic diseases, the elderly and high-risk pregnancies. Telemedicine helps to reduce the burden on hospitals, reducing their internal flows and giving priority to cases that require immediate hospitalization.

5. Results

In terms of the results, the processing of the data collected through the POE tools enabled the analysis of the operative flows involved in the case study. Flows were studied according to four categories (users, materials, equipment and corpses) and their direction. Fourteen subcategories of flows were mapped as it can be seen in Figure 3. The analysis was conducted for each floor and functional unit and it contains: the photographic survey, design considerations on functional aspects and flows as well as the diagnosis and flow map (Figure 4). The dotted lines represent two-way flows while solid lines represent the one-way ones on the floor plans.

Based on interviews with ICESP professionals, from the users’ point of view, the following considerations are presented: a) Healthcare-related professionals unanimously considered the centralized location for care services appropriate, since it allows immediate interaction for decision making about patients, while these and their companions should take the peripheral routes; b) Management quality came up as the conditioning aspect of the flows in the building; the adaptation of processes with changes in flows, but without physical alterations favoured the continuity of care, such as: the implantation of dedicated elevators and non-exclusive ones that generated more use flexibility, the implementation of a valet service in an area where vehicles are boarded and disembarked and the outsourcing of several services (laundry, pharmacy, maintenance shop and kitchen); c) The two different situations of sectorization and flows are arranged with one or two circulation corridors, according to the care provided by each functional unit; on outpatient floors, two circulation rings are established so as to separate doctors from patients, preventing the latter to approach the former out of their offices. The other healthcare functional units present a single corridor for user circulation (see Figure 5).
From the point of view of experts, out of the aspects set at the time of the design of the building, vertical terms, more important than the proximity between similar functional units is the efficiency of upright transportation, assigning units that generate more circulation to lower floors. It can be noted that
activities that require less circulation are found on higher floor while those requiring more foot traffic are in operation on lower ones.

According to design specialists, the constitution of the main tower in two wings with the central core allows physical readjustments to be performed with the isolation of either one of them. The Core has dedicated, but nonexclusive, elevator use and its location affords easy access by care teams and otherwise, without intersecting points with patients and companions. As to restrictive aspects, the constitution of the building by interconnected towers highlights the disintegration between them, which, on plan, limits its versatility and the core-centered care impels patients to follow long paths.

Regarding the external environment, being the building a skyscraper situated in a high-density region, user circulation is intense and causes traffic jams in the neighboring areas, making access to the building difficult for both drivers and pedestrians. Especially on the ground floor, the excessive flow of users produces overcrowding at peak hours in the lobby, elevator lines in the lateral towers and teeming circulation areas, with the resulting undesirable intersection of users, especially of patients, companions and visitors, which brings also to light the inefficiency of the vertical transport.

Advances in IT and ICTH applied to healthcare buildings reduce physical circulations and save time. The digital mapping of all the processes that are carried out in the building increasingly helps in the strict control of the flows of users, materials, equipment and corpses in its interior. The contextual changes are relevant as much as the increase in the number of services provided to patients is associated with the improvement of medical techniques and IT, such as the time reduction in radiation therapy, nuclear medicine therapy, microsurgery and robotics surgery. As a result, there is a growth in patient turnover within the building.

As for the interview script applied, three approaches considered the mapping of flows supported by graphic tools in the analysis. As a result, the six following aspects were predominant:

a) The study of external flows should be considered in light of the potential of the building site;

b) The architectural design should create the conditions for expansion in accordance with a Master Plan;

c) Flows derive from the sectorization whose core activities should be near and also provided with nearby circulations;

d) Among the problems caused by unwanted intersections, the main ones are those involving the risk of contamination and overcrowding resulting from the overuse of the physical capacity;

e) Among the positive intersections, the ones that facilitate activities and travels, offer shortcuts, afford changes and expansions, give the building the characteristic of versatility and improve wayfinding can be mentioned;

f) In Brazil, the interdisciplinary research associated with environmental psychology, design and POE is part of the academic environment and, for all respondents, the study of flows is essential to make the hospital architecture more efficient and user-friendly.

The POE applied to this high-rise health-care building allowed to consider that, although it is assumed that patients have to travel shorter distances in a hospital environment, this premise is only valid for the horizontal circulation. In the vertical circulation, sectorization is performed according to patient necessity of circulation on each functional unit, that is, functional units with more patient turnover should be
located on lower floors. The centralized location of the healthcare staff on the floor plan affords immediate decision making about the patient’s health and brings benefits for all.

The improvement of wayfinding, with contributions to a prompt health care assistance, helps in finding, guiding, choosing the path, and the identification of the user’s destination. The efficient wayfinding system sets users on the right path, preventing losses to their care. For Barbosa (2015), it is possible to propose a matrix to evaluate accessibility to the building based on wayfinding elements, such as circulations, decision points at intersections and others that enable the user to play his part with greater ease, safety and independence, considering the analysis of their flows. Based on the aforementioned aspects, which result from the analysis and application of the POE tools, it is possible to promote the understanding of the occurrence of the different operative flows in the hospital environment through the creation of a graphic tool. As consequence, the study of flows can give support to new architectural design programs and readjustments in pre-existing hospital buildings, contributing to fill the void in the area of design process on the subject, and making hospital architecture more efficient and user-friendly.

6. Discussions

In Brazil, the association of hospitals in a network with divisions according to complexity levels gives the user the possibility of receiving care in different units (clinics, polyclinics, etc.), which implies the progressive relief of hospital use. Other typologies of hospital buildings designed for patients who are subjected to low-risk and short-stay procedures, such as day hospitals have also come up (BROSS, 2006). The healthcare system, along with Telemedicine, promotes a new internal arrangement for the building and, as a result, the undesirable intersections of flows in ordinary hospital buildings are likely to become somewhat less common.

The choice of a unique vertical hospital building is due to the problems that derive from the complexity of its flows. The unavailability of large sites in high-density urban areas makes verticalization the optimal solution to complex healthcare facilities as long as its horizontal expansion is restricted. Implanted in a small area, the ways to access the building are few, limiting the diversity of flows that lead to its exterior. In addition, the adaptability within the building makes the enlargement of some of its sectors possible while causing the reduction of others. The vertical typology guides the sectorization of the hospital building by the overlapping of its sectors, and not by their proximity in accordance with a functional organization, which places activities involving the circulation of fewer users on higher floors. The choice of a new complex hospital building for this POE is justified as it brings, from its conception, the physical consequences of new and latest technologies incorporation in architectural design. A follow-up would be interesting, on investigation of the changes of flows in this hospital building along its life-span.

For similar case studies, from the results of this POE case study, it is possible to consider that normative contents point towards the most modern physical rearrangements for contemporary complex hospitals, enabling the exclusion of routes and the indiscriminate use of elevators. The study of operative flows in hospital buildings is of interest to the multidisciplinary teams involved in the course of its operation. Whenever possible, the implementation of management resources should precede physical alterations. Flows depend on the healthcare system of each country and cultural factors. As examples of flow conditioning by the healthcare system, it is possible to mention the layout with or without locker room dividers in Intensive Care Units and the presence of one or two corridors in surgery centers for the transport of both clean and dirty materials. Cultural factors are also flow determinants. One example is the presence or absence of a hotel area for companions connected to the hospital complex. Another one
that should be mentioned is the corpse itinerary, which can follow different service or healthcare routes, with impacts on the layout of the building.

A broader research on the subject, adding international experiences certainly would contribute with the results, as that can indicate new approaches that consider cultural diversity and different health-care systems. Besides, further similar studies, using a larger sample of similar hospitals would greatly collaborate to the improvement of the proposed methodology, which aims at a better architectural design quality and at giving support to designers and hospital management teams.

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**References**


Design and validation of a low cost indoor environment quality data logger

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Abstract: The appraisal of indoor environment quality in residential dwellings presents a range of technical challenges. Indoor environment quality (IEQ) is often described as having thermal, visual, aural and olfactory dimensions, each of which is assessed subjectively by the resident. While it is possible to objectively assess physical parameters relating to each aspect of IEQ, either directly or indirectly, resident satisfaction with the environment is determined subjectively so must be inferred. In the field study of thermal comfort (FSTC) approach, objective physical measurements are collected simultaneously with resident preference and sensation information, usually via a diary or written survey. This research paper explores a new approach to residential IEQ appraisal which extends the FSTC approach to the visual, aural and olfactory dimensions using a low cost data collection system based upon the Arduino microcontroller platform. The paper describes the design developed, presents early validation results and draws preliminary conclusions.

Keywords: IEQ, Data Logger, Arduino, Microcontroller, Occupant perceptions

1. Introduction

Indoor environments which satisfy the needs of building occupants are an important goal of building designers. Understanding how buildings actually perform in this regard is likely to be an important pathway to developing improved designs in future. One such technique for evaluating the performance of existing buildings, of which the indoor environment is an element, is the Post Occupancy Evaluation (POE) (Baird et al., 1996; Nicol and Roaf, 2005). While such studies can provide important information as to the established views of building occupants they often require additional environmental data to interpret. Theory building which links building attributes to occupant perceptions is not possible from survey data alone, as the referent environmental conditions which may contribute to survey responses are missing. This is problematic from a building design standpoint as survey outcomes lack the requisite physical environment information needed to make them actionable. This paper will investigate a data
collection approach which overcomes this shortcoming by integrating the collection of occupant satisfaction data and indoor environment data using a single logging device.

2. Background

A ‘multi-sensory’ approach (Dubois et al., 2007) is often applied when undertaking building evaluation. POE studies frequently consider occupant satisfaction across dimensions which could be considered as sensory, while also addressing factors that could be ‘occupant’ or ‘occupant need’ related (Preiser, 1983). With the exception of the occupant’s assessment of ‘overall comfort’, temperature, air, light and noise are commonly used to describe indoor environments in buildings and form the structure of POE survey’s such as the Building User Survey (BUS) (Leaman, 2010).

Lai et al. (2009) describe evaluation of Indoor Environment Quality (IEQ) in residential buildings as having four components: thermal comfort, Indoor Air Quality (IAQ), visual comfort and aural comfort. Evaluation of the components of IEQ can be undertaken by employing approaches similar to those used to assess thermal comfort, whereby occupants are asked to assess the environment they experience while at the same time physical parameters such as temperature are collected, enabling models to be developed relating inhabitant assessments to environmental outcomes (Lai et al., 2009).

Differences between the POE approach and the Field Study of Thermal Comfort (FSTC) approach are described by Nicol and Roaf (2005, p. 339):

One important difference between a POE of a building and an FSTC is that whereas the former is concerned with the performance of the building, the latter is more concerned with the responses to a building (or other environment such as a vehicle or out of doors) of its occupants. In the POE, the occupant provides a subjective measure of a building and acts effectively as its ‘memory’ (so that questions are in a form such as ‘how often is the building hot in summer?’)...In the FSTC the occupant reports on his or her own feelings at the time of the survey (‘I feel hot now’). (Nicol and Roaf, 2005, p. 339)

An advantage of the FSTC approach described by Nicol and Roaf (2005) when seeking to understand occupant satisfaction is that it enables a connection between satisfaction and objective environmental variables and behaviours to be established. The connection is useful as it allows for the possibility of a model to be built linking environmental parameters to expected satisfaction or dis-satisfaction of occupants.

Collection of both occupant and physical environmental data can be undertaken using logging equipment, an approach which many thermal comfort and some IEQ studies have employed in the past. A common and reliable approach is to employ time-stamped paper surveys to collect occupant data which are later synchronised with time-stamped environmental data which are often collected using multi-channel electronic logging equipment such as the HOBO U12-13 (Daniel et al., 2014). Alternatively, occupant data can also be collected using electronic loggers which simplifies post processing activity as surveys do not need to be keyed and in some cases data is automatically synchronised with environmental measures (Williamson et al., 1989). Opportunities to collect occupant subjective data electronically have become more practical as smart phone technology has become widely available, as illustrated by the approach employed by Saman el al. (2013).
3. Application requirements and constraints

The following section outlines the main objectives of the proposed logger designed to survey IEQ. At the outset, it is recognised that in seeking to parametrically characterise IEQ a reduction of occupant experience is being undertaken. The usefulness of the resultant parameters are limited and require considered interpretation in concert with the perceptions of the occupant. Adopting the four domains of IEQ commonly described, Bluyssen (2009) identifies a list of parameters in each domain (Table 1).

Table 1: IEQ parameters of interest. Adapted from Bluyssen (2009, p. 7).

<table>
<thead>
<tr>
<th>Thermal Comfort</th>
<th>Lighting quality</th>
<th>Acoustical quality</th>
<th>Air Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (air and radiant)</td>
<td>Luminance and illuminance</td>
<td>Sound levels(s) and frequencies</td>
<td>Pollution sources and air concentrations</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>Reflectance(s)</td>
<td>Duration</td>
<td>Types of pollutants (allergic, irrational, carcinogenic, etc.)</td>
</tr>
<tr>
<td>Air velocity</td>
<td>Colour temperature and colour index</td>
<td>Absorption characteristics</td>
<td>Sound insulation</td>
</tr>
<tr>
<td>Turbulence intensity</td>
<td>View and daylight frequencies</td>
<td>Reverbervation time</td>
<td>Ventilation rate and efficiency</td>
</tr>
<tr>
<td>Activity and clothing</td>
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</tbody>
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Ideally, a characterisation of the indoor environment would address each of these parameters, however this is likely to be technically challenging. It is, however, possible to select a range of parameters from within this group which are likely to be assessable using readily available sensors and a data logger.

The accuracy of measurements undertaken needs to be understood when interpreting results from the data logger. When undertaking basic measures of the environment important rules regarding instrument accuracy have been established when assessing thermal comfort and other domains of IEQ. For a selection of likely measures, recommended accuracies have been compiled in Table 2. Accuracies have been drawn from the thermal comfort literature and documentation provided with measurement equipment which is commonly used in industry for the said purpose.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Accuracy</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
<td>10 to 30 Deg C</td>
<td>+/- 0.2 Deg C</td>
<td>ASHRAE Std 55 - 2013</td>
</tr>
<tr>
<td>Mean Temperature</td>
<td>10 to 40 Deg C</td>
<td>+/- 1 Deg C</td>
<td></td>
</tr>
<tr>
<td>Air velocity</td>
<td>0.05 to 1 m/s</td>
<td>+/- 0.05 m/s</td>
<td></td>
</tr>
<tr>
<td>Humidity</td>
<td>0 to 80%</td>
<td>+/- 5% RH</td>
<td></td>
</tr>
<tr>
<td>CO2 concentration</td>
<td>0 to 10000 ppm</td>
<td>+/- 75 ppm + 3 % of measured value (to 5000 ppm)</td>
<td>Testo IAQ Probe (Testo 480 family)</td>
</tr>
<tr>
<td>Illuminance</td>
<td>0 to 100000 Lux</td>
<td>Class C according to DIN 5032-7</td>
<td></td>
</tr>
<tr>
<td>Sound Level</td>
<td>30 to 130 dBA</td>
<td>+/-1.0 dBA</td>
<td></td>
</tr>
</tbody>
</table>

In addition to physical parameters, a logger must be able to collect the subjective occupant assessment of the environment. In the FSTC approach it is common to employ accepted categorical scales for this
purpose, comprising up to seven points (such as the ASHRAE and Bedford scales described by McIntyre (1978)). It is also common to incorporate free-form responses to open ended questions, especially where paper based surveys are employed (Daniel et al., 2015). The number of survey questions used in a longitudinal study employing a FSTC approach is likely to be small as it is recommended that such surveys be kept as simple as possible (Nicol et al., 2012).

Minimising disruptions to normal household activities and avoiding “subject fatigue” (Nicol et al., 2012, p. 115) are also important considerations in the design and installation of any logging devices. Any logging device placed into the home needs to be small enough to enable participants to locate the device for convenience while at the same time achieving the measurement goals of the researchers. Survey instruments, too, must be quick and easy to use, yet clever enough to avoid habitual participant responses.

Once collected, data need to be stored securely and reliably in a manner which reduces disruption to research participants. In a residential setting, longitudinal studies can be undertaken for extended periods for up to a year in duration (Williamson et al., 1989). A logger should be able to retain collected data for as much of this period as possible. A period of six months, which many commercially available temperature and humidity loggers achieve, is considered an appropriate minimum duration. Reliability of storage may also be improved if data are communicated regularly to the researcher. Telemetry of this nature highlights any data collection problems in a timely fashion allowing timely rectification. Close to ‘real time’ data collection may also enable a more agile data collection approach which adapts to changing study events and allows study methods to evolve as knowledge grows.

Consistent with the principle of minimising participation burden, particularly in longitudinal residential studies, the logger should be able to operate autonomously for as long as possible. In a residential setting, powering the logger from mains power is to be avoided as it introduces problems of participant compensation for electricity used and the potential for problems if the electricity supply is interrupted. Battery life should therefore be able to support the six-month data retention periods described above.

Lastly, it is important that the logger be able to be constructed from readily available components at a reasonable cost. As commercially available temperature and humidity loggers can be purchased for approximately AU$100-200, a budget of AU$500 is proposed as an objective. This budget would not include assembly which is assumed to be undertaken by the researcher and assistants.

4. Logger design

The logger design developed is based upon an Arduino Mega micro-controller board (Arduino, 2016). The Arduino Mega is selected to coordinate measurements and manage data as it is well supported and has a vibrant on-line community, dedicated to solving the many technical challenges associated with its application. Of the many forms of the Arduino microcontroller board available, the Mega is selected because of its large array of input output ports which allow the simultaneous connection of many different sensors. A downside of the Mega is that it is not designed for low power applications, making it not suited to extended operation under battery power. This problem and a proposed solution are discussed further below. Importantly, the Arduino Mega employs a simple and easy to learn programming language based on the Processing language (Fry and Reas, 2014).

One of the great strengths of the Arduino microcontroller is that many boards can be enhanced through the addition of ‘shields’. One such shield, the Grove Mega Shield by SEEED Studio, is designed
Design and validation of a low cost indoor environment quality data logger specifically for the Arduino Mega board, providing for 21 standardised four-wire ports for the connection of sensors. The arrangement facilitates the robust connection of sensors to the Arduino-Mega board and allows for standard sensors which are available pre-wired to be easily connected.

![Data logger prototype and sensors.](image)

<table>
<thead>
<tr>
<th>Key</th>
<th>Measure</th>
<th>Sensor manufacturer and name</th>
<th>Description</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Air temperature</td>
<td>Maxim Integrated, DS18B20</td>
<td>Semiconductor temperature sensor employing band gap principle. Mounted beneath radiation shield.</td>
<td>+/- 0.5 Deg C</td>
</tr>
<tr>
<td>B</td>
<td>Globe temperature</td>
<td>As above</td>
<td>As above, however is mounted within 40mm black ball.</td>
<td>+/- 0.5 Deg C</td>
</tr>
<tr>
<td>C</td>
<td>Relative Humidity</td>
<td>Sensirion, SHT21</td>
<td>Capacitive relative humidity sensor.</td>
<td>+/- 2 %RH</td>
</tr>
<tr>
<td>D</td>
<td>Light intensity and colour</td>
<td>TAOS, TCS3200</td>
<td>Array of photodiodes, some of which are placed under red, blue and green filters. Provides measures of clear, red, blue and green light.</td>
<td>not stated</td>
</tr>
<tr>
<td>E</td>
<td>Sound level and frequency</td>
<td>DF Robot, Sound analyser</td>
<td>7 band filter based on MSGEQ7 processor. Provides amplitude of sound when filtered through each of 7 bands.</td>
<td>not stated</td>
</tr>
<tr>
<td>F</td>
<td>Air velocity</td>
<td>Modern Device, Wind Sensor rev P</td>
<td>Low cost anemometer employing the hot-wire principle.</td>
<td>+/-0.5 m/s Prohaska &amp; Watkins (2014)</td>
</tr>
<tr>
<td>G</td>
<td>Particles in air</td>
<td>SHARP, GP2Y1010AUF</td>
<td>Optical dust sensor. Uses infrared light emitting diode and receiver to sense light affected by particles.</td>
<td>not stated</td>
</tr>
<tr>
<td>H</td>
<td>- not shown</td>
<td>Wisen Electronic Co, MM21</td>
<td>Employ Non Dispersive infra-red (NDIR) principle to measure CO2 concentration.</td>
<td>+/- (50ppm +5% measured value)</td>
</tr>
<tr>
<td>I</td>
<td>Occupant presence</td>
<td>Manufactured in China, Unbranded</td>
<td>Motion sensor employs infra-red sensor to detect motion.</td>
<td>3 to 5m range within zone</td>
</tr>
<tr>
<td>J</td>
<td>Vote button</td>
<td>Momentary switch</td>
<td>Momentary switch</td>
<td>not applicable</td>
</tr>
<tr>
<td>K</td>
<td>Touch screen</td>
<td>Excamera, Gameduino 2</td>
<td>Resistive touch sensitive screen and graphics processor</td>
<td>not applicable</td>
</tr>
</tbody>
</table>

Sensors are selected for the logger which address each domain of IEQ described in Table 1. Where possible, digital sensors are selected as this simplifies connection with the Arduino-Mega. For example, Maxim Integrated DS18B20 sensors are selected for temperature measurement (both air and globe) as they contain on-board sensing and analogue to digital conversion (ADC) systems. This simplifies hardware aspects of connection to the Arduino Mega versus analogue components such as a thermistors or thermocouples which are both likely to require additional components to match effectively to the Arduino’s internal ADC. The digital approach is possible for temperature, humidity, and CO2 sensors all of which employ serial interfaces for communication with the Arduino.

Light, particles and occupancy behaviour sensing employ a slightly different connection approach, however these sensors too can be characterised as digital. The light and particle sensors employ Pulse Width Modulation (PWM) to communicate their measurements with the Arduino Mega. This approach involves varying the duration of digital output pulses to indicate a measured quantity (such as light intensity) which are timed by the Arduino Mega. These durations are then represented as measurement...
outcomes for each sensor. The occupancy sensor is even simpler, indicating a digital ‘high’ value when motion is sensed within the field of view.

Two sensors selected, the air velocity sensor and the sound sensor, use the Arduino Mega’s ADC directly. The air velocity sensor employs the same principle used in hot-wire anemometers to measure air movement. As air flows over the sensor it cools a resistive element, changing its resistance and therefore the current flowing through it. The sensor requires a dedicated power supply for this purpose and generates a voltage output signal which is proportional to the velocity of air flowing over the sensor. The signal is then converted to a measurement value by the Arduino Mega’s internal ADC. The sound sensor also employs a single channel of the Arduino Mega’s ADC which it uses to communicate sound intensity in each of seven frequency bands. The sensor is digitally synchronised by the Arduino using a dedicated software library.

These chosen sensors are arranged into the logger as shown in Figure 1. Accuracy and measurement principles for each sensor are also shown in Figure 1. When selecting sensors cost is an important consideration which is typically traded off against accuracy. Sensors selected represent the best ‘value’ when it comes to cost and accuracy.

In addition to sensors, a number of other components are also connected to the Arduino Mega. First among these is the touch screen used to collect subjective observations from the building occupant(s). A touch screen is selected for this purpose as it appears to overcome a number of problems apparent with other approaches. When collecting information from the occupant, it is possible to employ alternative technologies such as the use of Smart-phones or tablets (Saman et al., 2013). Smart-phones have the advantage of typically being owned by occupants so don’t need to be provided by the researcher and are good at collecting information. A downside of Smart-phones is that there are a range of platforms in current use, making development of data-collection platforms a significant hurdle. Data collection platforms that use generic software infrastructure such as web-based applications (for example Qualtrics) overcome this problem, however they often lack functionality such as the ability to push survey requests to study participants. Coordination between logger and Smart-phone also becomes a challenge particularly if votes are required under particular environmental conditions. In consideration of these issues the simplest approach appears to involve adopting an ‘on the logger’ data collection approach, similar to previous studies (Williamson et al., 1989; Chan et al., 1999; Daniel et al., 2014), in this case employing a touch screen rather than dials or vote buttons.

Other devices connected to the board include a battery-backed Real Time Clock (RTC) for time stamping data and a 2.4 GHz radio for communicating with remote sensors. Remote sensors are based on an Arduino derived design (Devduino distributed by SEEED Studio) which are capable of measuring a limited (three) number of sensors remote to the data logger within a 50m range. These sensors provide for the capability to measure occupant adaptive responses such as opening of windows or changes to heating and cooling device settings, or other data of interest.

To communicate data in real-time (or close to real time) a 3G cellular modem is incorporated. This modem requires a Subscriber Identification Module (SIM) card, identical to those used in mobile phones, giving the data logger a phone number and a phone account which can be pre-paid. This identity makes it possible for the logger to send data over the cellular network as real-time data points or as a pre-formatted Comma Separated Value (CSV) file which is posted to a File Transfer Protocol (FTP) account.
The last device connected to the Arduino Mega is the power controller which is needed to achieve an extended operating time on battery power. The power controller is a separate device which is based on an Arduino Pro Mini microprocessor which can switch the Arduino Mega off to save power. Typically, the logger draws approximately 300 mA of current, on average, and it is expected that this can be further reduced to 200 mA by carefully switching off sensors until they are required for a measurement. At 200 mA continuous load, battery life is still only 1.9 days so further power optimisation is required. By switching the Arduino Mega and sensors off between samples, power consumption is significantly reduced. Battery life under this approach is estimated at 160 days (sampling every thirty minutes) with more work being undertaken to increase this period.

Software for the logger is written in the Arduino Integrated Development Environment (IDE) which is based on the Processing language (Fry and Reas, 2014). Although the authors have had some basic programming experience, the language is effectively self-taught and is easy to learn. The resultant code builds heavily on work completed by the Arduino community who have invested significant effort in developing libraries and algorithms needed to operate the sensors and devices incorporated into the logger design.

Mounting the micro-controller, sensors and touch-screen present significant challenges. The objective of a logger that can be employed in a residential environment necessitates a small footprint, making packaging extremely challenging. A laser-cut screen bezel is also added to retain the touch screen and hide the rough edges of the hole cuts underneath. The battery for the logger is moved from within the box to underneath the device to improve access and allow easy checking of charge status (not shown in Figure 1).

Overall the total material cost of the logger is A$531, excluding the seven hours required to assemble it. The most expensive components are the CO2 sensor (A$138), the touch screen (A$82) and the cellular modem (A$42). When compared to the reference equipment, the Testo 480 series IEQ kit which costs approximately $14,000 to purchase, the logger cost is remarkably small.

5. Early results

In order to undertake a preliminary assessment of the logger’s measurement performance two types of test approach are adopted. The first involves placing the logger and a reference instrument into the same environment and assessing differences in measurement outcomes. The second involves subjecting the logger to known stimuli and subjectively assessing the range of resulting measurements.

In the first test the logger and a reference instrument are placed in a small (3m x 3m) office over a 20 hour period in June and the results are recorded. The reference instrument is a Testo 480 logger connected to a hot wire anemometer probe; an IAQ probe capable of measuring CO2 concentration, air temperature and humidity; a 150mm globe thermometer; and a plane illuminance light sensor (the instrument was last calibrated in 2013). The reference logger samples the environment at 1 minute intervals. A smoothing algorithm is applied to apparently noisy sensors which involves averaging 50 readings over a 5-10 second period (air velocity, sound, particles). All other sensors are recorded without averaging. Both loggers are synchronised so that results could be compared based on internal time stamps.

Results for the air temperature and globe temperature tests are shown in Figure 2 and Figure 3, respectively. Both figures show the logger to be capturing variation in the temperature well although an
offset exists in both cases. The air temperature measurement of the logger reads a value almost one degree higher than the reference instrument. This offset is found to vary in response to air velocity, reducing to almost zero at air velocities over 1 m/s which may suggest that the sensor is being heated by circuitry within the enclosure. The globe temperature variation is smaller and does drift a small amount. The comparison shown in Figure 3 adjusts the reference instrument globe temperature by approximately + 0.2 degrees (based on Humphreys (1977)) to allow for the smaller globe size of the logger (reference instrument 150 mm; logger 40 mm). Further testing in higher radiation environments will be required to prove the accuracy of this sensor.

The results of air velocity measurements are shown in Figure 4. The sensor is shown to be relatively insensitive at velocities under 0.15 m/s. Further testing has shown good differentiation of velocities over 1 m/s, however below 0.5 m/s the sensor is unresponsive. This problem could be due to the non-linear calibration equation provided by the manufacturer based on wind tunnel tests at higher velocities.

CO2 sensor results (Figure 5) show good identification of events (people entering and leaving the room) however the sensor drifts in relation to the reference instrument. Some of this drift may be reduced by employing an algorithm to recalibrate the logger once every 24 hours. Other manufactures, including Testo who produced the reference instrument employ such algorithms to address sensor drift.

A second, less precise approach is adopted to test the more complex sensors for light colour and sound. The single light sensor on the logger contains four measurement elements, each measuring red, green, blue and unfiltered light levels. The sensor is designed for detecting the colour of objects at close range rather than the colour of ambient light. To test the sensor, it is subjected to four colours of light using an iPad screen in a darkened room (white, red, green and blue). Results for each colour detected by the sensor are recorded and their differences compared as shown in Figure 6. Results suggest good distinction of colour, however as yet lack calibration.

For the sound analyser a similar approach is adopted whereby a stimulus was generated and the response measured. For this sensor a signal generator (again based on iPad application) is employed to generate white noise and a range of tones. The response of the logger to each tone is recorded as is the response of a reference instrument, in this case a Testo 816 sound level meter. The Testo 816 is capable of measuring sound levels in decibels which are A-weighted to better match the varying sensitivity of the human ear to frequencies across the audible range. Results shown in Figure 7 show the logger to be most sensitive to mid-range frequencies (1 kHz to 6.25 kHz). There appears to be reasonable potential to convert the logger results to a calibrated A-weighted result in future.

6. Conclusions

Early results have shown some differences between the logger and reference equipment however there appear to be good opportunities to reduce these differences and improve accuracy in future. The results presented reflect outcomes prior to any calibration or tuning effort, so it is expected that once calibration activities are completed, accuracies will improve. With the exception of air velocity and CO2 concentration, sensors appear responsive and suitable for calibration. Resolving shortcomings in air velocity and CO2 concentration will firstly involve altering software algorithms governing the control of these sensors, which if unsuccessful will progress to hardware alterations and lastly, sensor replacement. Further work planned will seek to reduce the differences seen in all measures with a view to deployment in a field study of IEQ in residential apartments in Melbourne.
Figures 2 & 3: Air temperature comparison & globe temperature comparison

Figures 4 & 5: Air velocity comparison & CO2 concentration comparison

Figures 6 & 7: Logger response to white noise & Logger response to coloured light
References


Commercial and academic buildings’ performance – comparative analyses of occupants’ perceptions

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Abstract: The BUS Methodology was used by the authors and their collaborators to survey 55 buildings in which the 4000plus occupants scored 45 factors related to their perceptions of the performance of these buildings. The aim was to analyse these scores in different ways to elicit any differences in users’ perceptions. Unlike some previous analyses where the focus was on the average scores for each building, here it is individual occupant’s scores being considered. Following analysis of the response rate to each question and a comparison of the two methods, full tabulations of the average scores are presented and compared for four paired sets of users – sustainable vs conventional building users, New Zealand vs overseas building users, New Zealand sustainable vs New Zealand conventional building users, and commercial vs academic building users. Overall, it was evident that the users of the sustainable buildings were scoring them better than the conventional buildings, both for the entire database and for the New Zealand buildings; and while academics tended to score their buildings worse than commercial building users the differences in the averages, while significant in many cases, were small numerically. Key findings and their implications for user perception based benchmarking are summarised.

Keywords: Commercial Buildings, Academic Buildings, Occupants Perceptions.

1. Introduction

The landmark PROBE Studies (Postoccupancy Review Of Buildings and their Engineering) carried out during the 1995-99 period investigated, analysed and published data on the performance of 16 large-scale commercial and academic buildings (BRI, 2001/2). Apart from reviewing available documentation on each building, the research team undertook three specific studies – a questionnaire survey of the occupants, an analysis of total energy consumption, and a pressure test of the whole building. Inspired by these studies and thanks to the generosity of Building Use Studies Ltd (the developer of the questionnaire) a large number of researchers have since used the questionnaire to survey commercial and institutional buildings in their home localities in different parts of the world (Jahnkassim et al, 2004; Thomas and Baird, 2006; Turpin-Brooks and Viccars, 2006; Vandenberg and Thomas 2010; Dixon, 2010;
Lenoir et al, 2012; Bunn and Marjanovic-Halburd, 2016). The present authors have undertaken such surveys both worldwide and in their home country of New Zealand, and have carried out a range of analyses and comparisons as their dataset has grown. These analyses have been based on the building occupants’ scores for the 45 or so factors on which they rank the building’s attributes on a 7-point scale mainly. They have ranged from comparisons of sustainable with conventional buildings (Baird, Leaman and Thompson, 2012), through detailed analyses of the distributions of respondents’ scores in sustainable buildings (Baird and Thompson, 2011) and determination of the common factors of the better performing buildings (Baird, 2013), to detailed analyses of specific factors such as temperature, lighting, acoustics, control, health and productivity (Baird and Field, 2010; Baird and Thompson, 2012; Baird and Dykes, 2010; Baird and Lechat, 2009; Baird and Oosterhoff, 2010), as well as advocacy for the incorporation of scoring of this nature to be incorporated into building sustainability rating tools (Baird, 2009). Inevitably, the undertaking of such a large number of surveys and analyses brought up a number of methodological issues and provided further analytical opportunities. Amongst the more interesting methodological issues were the response rates to the different questions and what differences there might be between averaging scores by building and by individual respondent. Amongst the analytical opportunities afforded by the increasingly large number of surveys undertaken were the possibilities of comparing commercial vs academic buildings, sustainable vs conventional and New Zealand vs overseas. The aim of this paper is to explore some of these.

2. The buildings and the BUS questionnaire

55 buildings were surveyed by the authors and their collaborators, and around 4,560 occupants have scored 45 factors related to the performance of these buildings. The number of respondents varied from building to building, the smallest having just 14 and the largest some 342 staff, with an average of around 83 per building. All the buildings housed either commercial or academic activities (40 and 15 respectively) and the occupants were surveyed using the BUS Methodology. Several other groupings lent themselves to analysis: 39 of the buildings had sustainability credentials while 16 were conventional; 33 were located in New Zealand while 22 were in a range of overseas countries (Australia, Canada, England, India, Ireland, Japan, Malaysia, Reunion Island and the USA. Of the 33 in New Zealand, 17 were sustainable and 16 conventional. The questionnaire used was the standard two-page office version developed by Building Use Studies (2016) for use in the Probe investigations (Cohen et al, 2001). These were distributed personally which helped to ensure a very high response rate from the staff present in the building, 80 to 100% being the norm. The questionnaire first elicits background information on matters such as the age and sex and location of the respondent, and how long they normally spend in the building. The following forty-five questions ask the respondent to score a range of aspects of the building on a seven-point scale - see note (b) on Table 2 for further details. The forty-five questions were grouped in the following categories and order:

- **Operational** – Image to visitors, Space in building, Space at desk, Furniture, Cleaning, Meeting rooms availability, Storage arrangements, and Facilities.
- **Environmental - Winter** - Temperature (overall and whether it is too hot/cold, stable/varies) and Air (whether it is still/draughty, dry/humid, fresh/stuffy, odourless/smelly and overall).
- **Environmental - Summer** - Temperature (overall and whether it is too hot/cold, stable/varies) and Air (whether it is still/draughty, dry/humid, fresh/stuffy, odourless/smelly and overall).
- **Environmental – Lighting** (overall, whether there is too much or too little Natural Light and Artificial Light, and whether there is Glare from sun and sky or from the artificial lights).
Commercial and academic buildings’ performance – comparative analyses of occupants’ perceptions

- **Environmental – Noise** (overall, and whether there is too much or too little from colleagues, other people, inside sources, and outside sources; and the frequency of unwanted interruptions).
- **Personal Control** - of heating, cooling, ventilation, lighting, and noise; and
- **Satisfaction** - design, needs, comfort overall, productivity, and health.

Tables 1 and 2 (see later) list a selection of these factors, together with ‘shorthand’ versions of each of the questions to which the users were asked to respond. In the case of ‘Image to visitors’, for example, users were asked “How do you rate the image that the building as a whole presents to visitors?”; in the case of ‘Noise Overall’, users were asked “How would you describe noise in your normal work area?”; and in the case of ‘Comfort Overall’ users were asked “All things considered, how do you rate the overall comfort of the building environment?”

**3. Response rates to individual questions**

While the preamble to the questionnaire makes it clear that respondents were not required to score every question, in practice most respondents scored most of the questions. However, the percentage not responding to a particular question averaged out at 8.4%, ranging from 0.9% to 25.8% sufficiently large to raise potential methodological issues – were some questions of particular relevance and attracting a particularly high response, or were some being avoided because they were more difficult than others, or was ‘questionnaire fatigue’ setting in as respondents reached the end of the list, for example? Non-responses to operational factors tended towards the low end of that spectrum, ranging from 0.9% for cleaning to 4.8% for storage, with image at 1.4%. Questions about temperature and air overall in winter were not scored by 7.7% and 6.7% of respondents respectively, but the more detailed questions within this category were avoided by around 11% of respondents. These numbers more than doubled for summertime conditions with an average of 24.5% of non-responses for all the questions in this category. Lighting overall and noise overall had 3.8% and 4.5% non-responses respectively and in both of these categories the more detailed questions had similar rates of non-response, while personal control non-response rates were close to 5.0% in every case. In the satisfaction category, design and needs were 1.5% and 2.4% respectively; while comfort overall, health and productivity, the final three questions of the two-page questionnaire, had non-response rates of 3.9%, 5.4% and 7.7% respectively. Overall, it would appear that the questionnaire has been successful in eliciting responses to the majority of its questions and there is little indication of ‘fatigue’ setting in between its initial and final questions – in this case design at 1.5% and health at 5.4% respectively. The productivity question “Please estimate how you think your productivity at work is decreased or increased by the environmental conditions in the building” is potentially difficult but was avoided by only 7.7% of respondents. The set of questions concerned with wintertime conditions had rather higher non-response rates, particularly at the more detailed levels where they averaging around 11%; while the identical set for summer conditions averaged 24.5%. It is suspected that the level of detail being sought under these headings was beyond the experience or memory of many respondents or was seen as unnecessarily repetitious. By contrast, the building design and image to visitors aspects, with non-response rates of 1.5% and 1.4% respectively, were scored by nearly everyone, and cleaning came in at a lowly 0.9% - clearly all aspects that respondents were able to score readily.
4. Averaging scores by building or from individual responses?

Up to now the authors have followed the common practice of reporting the scores from such surveys in terms of the means and standard deviations for each factor, and comparing these directly to other buildings or to benchmarks based on the scores for other similar buildings. However, it has been suggested that this could give undue weighting to the scores from smaller buildings with fewer occupants. The alternative that has been proposed and which has been used in some comparative analyses (Newsham et al, 2013; Schiavon and Altomonte, 2014) is to amalgamate the individual scores for all the buildings of a given type for comparison (say) with buildings of another type; that is calculating the individual respondents’ averages for a group of buildings as opposed to calculating the average of the building averages for that group. From a methodological point of view it was of interest to assess the extent of any differences between the two approaches. Table 1 summarises and compares the means and standard deviations, averaged by building and averaged by respondent for a sample of factors in this dataset where the differences were statistically significant. As expected, the mean values are of the same orders of magnitude in both cases but the SD values for the respondents scores range up to three times that for the buildings, reflecting the larger numbers of respondents involved (over 4,000) compared to the 50 or so buildings. Overall, significant differences were found in 28 of the 45 factors – for the sample listed, six of them were higher (and in these instances better) when averaged by respondent, and the scores for three were worse. Some of the differences were relatively large. In the case of comfort overall, for example, the difference was 1.43 on the 7-point scale, and differences greater than 1 were found for lighting overall, air overall in both summer and winter, and space at desk. The meeting room availability and storage arrangements suitability scores on the other hand were reduced when averaged by respondent, and the score for health went down from a creditable 5.34 to a more modest 3.93. More detailed analysis is needed to elicit the reasons for these differences but in the meantime researchers should be cognisant of these matters when analysing and interpreting their data.

### Table 1: Comparison of mean perception scores for a sample of factors.

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>Averaged by building</th>
<th>Averaged by respondent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Space at desk(^4)</td>
<td>5.33</td>
<td>0.452</td>
</tr>
<tr>
<td>Meeting rooms availability</td>
<td>5.08</td>
<td>0.932</td>
</tr>
<tr>
<td>Storage arrangements suitability</td>
<td>5.08</td>
<td>0.862</td>
</tr>
<tr>
<td>Facilities meet work requirements</td>
<td>4.36</td>
<td>0.712</td>
</tr>
<tr>
<td>Air overall in winter</td>
<td>3.12</td>
<td>0.562</td>
</tr>
<tr>
<td>Air overall in summer</td>
<td>3.15</td>
<td>0.769</td>
</tr>
<tr>
<td>Lighting overall</td>
<td>3.91</td>
<td>0.790</td>
</tr>
<tr>
<td>Comfort overall</td>
<td>3.40</td>
<td>0.521</td>
</tr>
<tr>
<td>Health</td>
<td>5.34</td>
<td>0.864</td>
</tr>
</tbody>
</table>

NOTES: unless otherwise noted a score of 7 is best on these predominantly 7-point scales; superscript \(^4\) implies a score of 4 is best.

An asterisk indicates there was a significant difference between the building and respondent averages – t-test at the p<0.01 level or better.
5. Comparisons based on the averages of individual respondents’ scores

Methodological issues aside, the main aim of the paper was to compare a number of categories based on the individual respondents’ scores rather than the building scores. In the case of sustainable vs conventional buildings for example, this could be more appropriately phrased as a comparison of the perception scores of the users or occupants of sustainable buildings versus the users of conventional buildings. Table 2 lists the average scores for each of the 45 questions in the survey for, in turn, all of the following paired categories: sustainable building users (SUS) vs conventional buildings users (CON); New Zealand building users (NZ) vs overseas building users (OS); users of New Zealand sustainable buildings (NZS) vs users of New Zealand conventional buildings (NZC); and commercial building users (COM) vs academic building users (ACA). Significant differences are indicated with an asterisk on the second category of each pairing. In what follows, these differences will be summarized for each pairing.

Table 2 – Average scores for each of the questions for eight paired groupings of building user

<table>
<thead>
<tr>
<th>Column Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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Air - fresh/stuffy

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Air - odourless/smelly

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Sun&Sky Glare-none/too much

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Artificial light - too little/much

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Art'l light Glare - none/too much

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Noise - Overall

|----------|------|-------|------|------|------|-------|------|------|

From colleagues – too little/much

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From other people-too little/much

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From inside - too little/much

|----------|------|-------|------|-------|------|------|------|------|

From outside - too little/much

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Interruptions – none/frequent

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Lighting

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NOTES:

a – The means listed in this table are the mean of the individual respondent scores (as opposed to the averages of the mean scores for each building which could have a slightly different value).

b – Unless otherwise noted, a score of 7 is ‘best’; superscript 9 implies a score of 9 is best, superscript 4 implies a score of 4 is best, superscript 1 implies a score of 1 is best.

c – Number of respondents is approximate as it varies from question to question – see Section 3

* - Denotes a significant difference – t-test at the p < 0.01 level or better.

5.1. Sustainable building users (SUS) vs conventional buildings users (CON)

The relevant data are listed in columns 1 and 2 of Table 2. There it can be seen that users of the conventional buildings scored seven of the eight operational factors significantly lower than users of the sustainable buildings. In the case of image to visitors the difference was nearly 1.5 points on the 7-point scale, but averaged half that for the other factors. Temperature and air overall were also scored
significantly lower by the conventional building users, by about 0.4 points on average in this case – with the more detailed factors in that set mostly the same or worse. In the case of the conventional building users, both lighting and noise overall scored significantly lower than the sustainable by around 0.3 points, again with the more detailed factors in that set the same or worse. Personal control factors exhibited a similar trend but it should be noted that (in response to a separate question) only around one-third of users rated personal control as important.

Finally, the users of sustainable buildings scored all of the satisfaction factors significantly better by an average value approaching 0.8 points. Overall, a very good ‘report card’ for the sustainable buildings and a set of findings that concur broadly with those of Baird, Leaman and Thompson (2012) whose study compared a worldwide set of sustainable buildings with a UK-based set of conventional buildings, though with data based on building-averaged scores rather than user-averaged.

5.2. New Zealand building users (NZ) vs overseas buildings users (OS)

The aim of this analysis was simply to make a preliminary assessment of how New Zealand commercial and academic buildings were performing in relation to their overseas counterparts. Columns 3 and 4 of Table 2 list the average scores for the NZ and overseas building users respectively. In the case of the operational factors, the overseas users scored all eight higher than NZ users, significantly so in four cases. In the temperature and air in winter group, overseas users scored their conditions significantly better in several instances, and while there were no significant differences in temperature overall and air overall in summer, the more detailed factors gave mixed messages but with differences usually less than one-quarter of a point.

In the case of lighting only one factor was significantly different, though the numerical difference was only 0.05 in favour of the overseas users, whose averages tended to be slightly better than the NZ users for all the other lighting factors too. While the scores for noise overall were not significantly different, those between the various components were – mostly in favour of the overseas users. All of the personal control factors were scored significantly better by the overseas users, again noting that only around one-third of users rated this as important. The satisfaction factors gave the clearest indication that the overseas users rated the performance of their buildings better than NZ users rated theirs – all five factors were significantly better, by around 0.4 points on average.

Overall, on the basis of this sample of buildings, the overseas users were scoring the performance of their buildings better than the NZ users were scoring theirs. Given the results of the analysis presented in Section 5.1 this was not unexpected as all of the overseas users were in the 22 buildings with sustainability credentials and had been selected to be surveyed for that reason, while the 33 New Zealand buildings were almost equally split 17:16 between sustainable and conventional – highlighting to the need for care when sampling and benchmarking building performance.

5.3. NZ sustainable building users (NZS) vs NZ conventional buildings users (NZC)

The previous analysis having highlighted these sampling issues, the aim here was simply to compare the performance of the sustainable and the conventional commercial and academic buildings located in New Zealand, the average scores for which are listed in Columns 5 and 6 respectively of Table 2. In the case of the operational factors seven of the eight were scored significantly better by the sustainable building users by an average of 0.85 points on the 7-point scale – only space at desk was similar and very close to the ideal score (of 4 in this case). In the case of temperature and air overall in both winter and
summer, the users of the sustainable buildings scored significantly higher with a difference averaging around 0.6 points, while scores for the more specialised factors tended to favour the sustainable buildings where the air was scored fresher and more odourless than in the conventional buildings. A similar story is evident for the lighting, noise and personal control factors, while significant differences in average scores for the satisfaction factors range from 0.76 to 1.08 (average around 0.9), again in favour of the sustainable building users. Clearly the NZ sustainable buildings were outperforming the conventional ones from the users’ point of view on average.

Of course, that is not to say that every user scored the sustainable buildings better than the conventional ones. As evidenced by the standard deviation figures listed in Table 1, there was a wide variation in the individual scores. While there were users who scored both types of building at the lower end of the 7-point scale, nevertheless, the predominant trend was for the users of sustainable building to score these factors higher.

5.4. Commercial building users vs academic buildings users

Given the mix of 40 commercial buildings (26 sustainable; 14 conventional) and 15 academic buildings (12 sustainable; 3 conventional) in the database, the opportunity was taken to investigate whether there were differences between these two groups of users, whose average scores are listed in Columns 7 and 8 of Table 2. In the case of the operational factors the average scores for commercial building users tended to be better than for the academics in most cases, but then only marginally so and with just three statistically significant (desk space, cleaning, and facilities with an average difference less than 0.3 points).

In winter any differences between the overall temperature and air scores tended not to be statistically significant, while in summer they were, favouring the sustainable building users, but by only by around 0.2 points. While the commercial building users scored their lighting overall significantly better, little difference was apparent for its various components. In the case of noise, academic users appeared to be slightly more noise sensitive than their commercial counterparts with a worse score overall and for every component factor bar noise from colleagues. The academics scored personal control better than commercial users, with the exception of noise and cooling where the difference was not statistically significant.

The satisfaction factors were all scored significantly better by the commercial building users, by an average of around 0.4 points. Overall, the academics appeared less satisfied with the performance of their buildings, though other than the satisfaction factors and the consistency amongst the noise factors, the differences were not overly dramatic.

6. Discussion and conclusions

6.1. Methodological issues

The BUS Methodology questionnaire had been reduced to a compact double-sided A4 sheet from its multi-page antecedent used in sick building syndrome studies. Nevertheless, it still contained 45 questions in addition to 15 or so concerned with the respondent’s background, leading to concerns about potential questionnaire fatigue due to their sheer number. In practice the non-response rates averaged 8.4% overall and there was no evidence of any significant drop-off in response rate between the initial and final sets of questions. The detailed sets of questions concerned with temperature and air
had lower response rates, but even here the ‘overall’ questions had rates well under 5.0%. Overall, a reassuring result, reinforcing the reputation of this methodology in eliciting high response rates. When it comes to benchmarking the performance of buildings from the users’ point of view, two main approaches have gained currency – averaging by building or by user. Put to the test for this sample, statistically significant differences were found in the averages for 28 out of the 45 factors scored by the users. Significant differences ranged from 0.20 to 1.43 on the 7-point scale, but with the user-based average significantly better than the building-based average for 16 factors, and worse for 12, no obvious or consistent pattern emerged. Clearly, further investigation of this issue is needed, but in the meantime researchers must be fastidious in reporting the type of benchmarking they are using.

6.2. Comparative analyses based on user averages

Four sets of comparisons were carried out to see what differences existed between the users’ scores. The first of these, Sustainable vs Conventional, indicated that users of sustainable buildings were scoring them better than conventional; while the second, New Zealand vs Overseas, indicated that users of overseas buildings were scoring them better than New Zealand. While the differences noted were significant, potential biases in the samples should be noted in that while the sustainable buildings are a mix of overseas and New Zealand, all of the conventional buildings are in New Zealand; and as a corollary, all of the overseas buildings are sustainable. Nevertheless it was seen as worthwhile to report these matters to highlight the need for care in building selection, even when the focus is on the user.

The third comparison, between sustainable building users and conventional building users, but with both data-sets limited to buildings located in New Zealand, was designed to avoid the potential biases of the previous two. Even here the 17 sustainable buildings have a 10:7 ratio of commercial to academic, while the 16 conventional have a 14:2 ratio of commercial to academic, so care is necessary in interpreting the differences between the two sets. Nevertheless, a consistent pattern emerged in which a statistically significant difference emerged in the scores for 35 of the 45 factors. Of these 35, 32 of the differences were in favour of the users of the sustainable buildings. On that basis one can confidently assert that the users’ perceptions of sustainable buildings were better than those for conventional buildings. The fourth comparison undertaken was between commercial and academic building users. Here, 21 significant differences emerged, 17 in favour of the commercial building users and 4 favouring the academics. It is difficult to speculate on the reasons for this trend from these data alone – further work is envisaged that will analyse the comments of the users as well as their scores.

Overall, it can be seen that while there are methodological issues for researchers to be cognisant of the evidence that the occupants’ perceptions of sustainable buildings are better than for more conventional buildings continues to mount, whether averaged by building or by individual user.

Acknowledgements

Special thanks to Adrian Leaman of Building Use Studies for his inspirational enthusiasm for building evaluation and his generous licensing arrangement of the BUS Methodology for researchers world-wide.

References


Understanding architectural and social-psychological influences on occupant behaviour in commercial buildings

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Abstract: The aim of this paper is to advance the understanding of social-psychological and architectural parameters influencing occupant behaviour and resulting operational energy consumption in office settings. Existing knowledge on occupant behavior is reviewed from an architectural and social-psychological perspective. The identified parameters are visually mapped using the framework of Integral Sustainable Design (ISD). Conclusions are drawn concerning the interrelationship and interaction of parameters and the direction of future interdisciplinary research.

Keywords: Occupant behaviour, office architecture, group norms, energy consumption

1. Introduction

Both residential and commercial buildings consume about 60% of world electricity, therefore the building sector is the largest producer of global greenhouse gas (GHS) emissions (UNEP 2016). On the other hand, buildings offer the greatest potential for reducing significant GHG emission in both developed and developing countries. Yet, the vast majority of energy studies (e.g., in engineering fields) focus on technological fixes for improving energy efficiency rather than human-centered energy behavioral analysis and environmental changes (Sovacool, 2014).

In addition to that, the majority of existing studies on occupant behaviour focuses on occupants’ interactions with single building technologies or controls, not with the architectural experience of a building as a whole; and very little knowledge is currently available on how the architectural design of a building predefines human behaviour. Ching (1996) proposes three orders that, when mutually reinforcing and contributing to the singular nature of the whole, constitute a work of architecture, which has more to offer to people than the sum of its physical or technological parts. These are, the physical (form and space, solids and voids, interior and exterior), the perceptual (sensory perception and recognition of the physical elements by experiencing them sequentially in time) and the conceptual (comprehension of the ordered or disordered relationships among a building’s elements and systems,
and responding to the meanings they invoke). These three orders are consciously and subconsciously interpreted by occupants and are likely to influence their responses to and actions in buildings.

While recent policy makers have emphasized technological innovations and/or tighter environmental regulations as necessary preconditions for improving energy efficiency, a growing number of social scientists have recently argued nudging energy behaviors that could influence energy efficiency and have a potential impact on grand goals such as reducing GHG emissions (Dietz, et al., 2009). Non-price nudge such as normative feedback can significantly influence energy savings (Goldstein, Cialdini and Griskevicius, 2008) and mounting evidences show that behavioral changes could be just as effective as technological changes (Karatasou, et al. 2014). Therefore, more attention needs to be paid to social-psychological or behavioral factors that could influence energy efficiency (e.g., Abrahamse & Steg, 2009; Dietz et al., 2009). The current literature on individual-level energy saving such as social-psychological factors, however, mainly focuses on households or private contexts. Studies on energy saving behavior in the organizations or public domains and their social-psychological drivers are rarely investigated (Chen & Knight, 2014; Lo et al., 2012). Regarding building design and behavioral modeling, human influence and interactions need to be considered by thoroughly conceptualizing occupants’ psychological factors relating to decision-making processes. These decision processes tend to be complex due to the diverse characteristics of occupants (e.g., habits or culture) and other structural factors (e.g., organizational policy) beyond building design and technology. This paper reviews the currently available literature from a multidisciplinary viewpoint, and then uses DeKay’s framework of Integral Sustainable Design (DeKay and Bennett 2011) to map the common ground and the interrelationship between the disciplines.

2. Literature review

2.1. Architectural factors

DeDear and Brager (1998) suggested a differentiation between air-conditioned and naturally ventilated buildings for thermal comfort assessment, because the presence of openable windows in naturally ventilated buildings increased levels of perceived control. With regard to lighting control systems the ease of use nature of the task, the number of persons in the room and the distance from windows, lighting concepts (Galasiu and Veitch 2006, Reinhard and Voss 2003), location of the light switch (Bordass et al 1993), age, degree of fatigue and cultural background, the atmosphere of the room regarding the interior design (Galasiu and Veitch 2006), and the external daylight conditions at the arrival at the office (Moore et al 2003) were identified as influential parameters. Inkarorjít (2005) investigated reasons for why people open and close blinds in offices, and observed relationships with the brightness of the workspace surfaces and the perceived spaciousness of the room. Boubekri and Boyer (1992), suggested psychological implications of blind opening, such as cheering up the atmosphere in a room by increasing the level daylight and or sunlight. The nature, placement, accessibility and effectiveness of such controls predefines their use by occupants. E.g. controls which are hidden, complicated to understand, not easily accessible or likely to interrupt colleagues will be interpreted by occupants as less inviting to operate and could thus decrease the perceived level of control. Kwok and Rajkovich (2010) citing Norberg-Schulz referred to this as “switch-rich” design.

Spatial layout of the floor plan arrangement of a building is another architectural parameter which influences and predefines the use of a building. Leaman and Bordass (2010) identified workgroup size, spatial flexibility, and building depth as key variables influencing productivity in buildings. These
parameters are architecturally expressed in the spatial organisation, i.e. the spatial relationships between spaces. Ching (1996) differentiates between centralised, linear, radial, clustered or grid organisation, each suggesting a different nature of the relationship and hierarchies between spaces to occupants. These relationships may impact occupant presence, as well as usage patterns.

Kwok and Rajkovich (2010) citing Norberg-Schulz discuss the importance of transitional spaces as an opportunity for experiencing thermal delight and energy savings. They define transitional spaces as those which are neither clearly indoors nor outdoors. This implies that the relationship between indoors and outdoors is one of communication rather than separation, and thus influences the use of the space by occupants.

The facade defines the relationship between the interior and the exterior environment. This is particularly evident in the presence and functionality of windows. Air exchange rates can multiply according to window opening type, opening angle as well as size and placement within the façade (Richter et al 2003). Tsangrassoulis et al (1997) highlighted the potential implications of different activated shading devices on discharge coefficients for windows and resulting ventilation effectiveness. Herkel et al (2008) found that size and placement of windows had a significant impact on occupant’s window opening behaviour. Yun et al (2008) found that night ventilation depends on façade design and perception of security. These physical properties have perceptual and conceptual implications which can affect occupants interaction with the building envelope consciously as well as subconsciously.

Another important parameter influencing the design as well as the subsequent use of a building is the immediate context of the site and the neighbourhood. Geros et al (2005) investigated the heat island effect as an influence on air temperatures, wind speed and direction and thus as an indirect impact on natural ventilation effectiveness. Inkarorjit (2005) identified visual privacy and security and visual contact with the outside environment as influential parameters on blind operation.

With regard to night ventilation, the size, protection and accessibility of windows together with the perceived security in the neighbourhood predefines their potential for night ventilation (Roetzel et al 2010). Galasiu and Veitch (2006) observed a dependency of the likelihood of shading opening from the quality of view. View, task, sunlight and atmosphere seem to be more important for visual comfort than external and internal illumination (Galasiu and Veitch 2006). With regard to window size, occupant satisfaction increases with window size, but decreases with the number of mullions (Galasiu and Veitch 2006). Preferred window size was also found to be dependent on the view content (Ne’eman 1970). When a view provides attractive features like open space or greenery, bigger windows are preferred. For a monotonous view like a close building façade or sky without a skyline, the preferred window size is smaller, compared to complex views (Inui 1980). The preferred size and placement of windows also varies dependent on the location of occupants in the room and their view angles (Ne’eman 1970). Additionally people prefer views including nearby as well as distant elements, to those of limited range (Tuaycharoen and Tregenza 2007). This indicates that the context of the building site can have significant influence on occupant’s interaction with the building and its controls.

As argued by Jencks (1973) it is the nature of architecture to “help explain and dramatise certain social meanings”. In office architecture the implications of social meaning are little discussed. Leaman and Bordass (2007) introduced the concept of “forgiveness” of occupants towards deficiencies in green as opposed to conventional buildings. They referred to ‘green’ buildings as those where the design brief required the buildings to achieve lower environmental impact. Deuble and DeDear (2012) identified natural ventilation as one feature of green design. Evans and McCoy (1998) investigated the impact of architectural design on human health by linking architectural order to stress. Key architectural design
parameters impacting on stress were clarity or comprehensibility of building elements and form, object’s sensory characteristics, the ability to alter the physical environment or regulate exposure to one’s surroundings and the potential of design elements to function therapeutically. It can be argued that an architectural design which is perceived as intimidating is less likely to facilitate occupant’s interaction with the space and its controls compared to a design which actively empowers occupants to interact with its architecture in a more democratic manner. The design of controls, spatial relationships, building envelope and the site context therefore determine the “personality” of a building, which consequently predefines the behaviour of occupants in it.

2.2. Cultures and group dynamics

In this paper, we have narrowed down the concept of cultures but considered group dynamic as one of the important cultural factors affecting occupant behaviors in commercial buildings. Although there is a growing recent emphasis on the investigation between occupants and building environment interaction, engineering researchers often use advanced sensors to model occupant behaviors to solve building energy issues while ignoring the social-psychological or group factors that determine occupants’ acceptance and behaviors. Incorporating the concept of social influence or network factors for energy behavioral interventions is widely documented. For example, social messages, such as reciprocity, appear to be the most effective at gaining occupant compared with foot-in-the-door and direct message methods (Khashe et al., 2016). A study conducted among 24 university buildings found that group level feedback and peer education resulted in a 7% and 4% energy reduction at work, respectively (Carrico and Riemer 2011). Other studies also highlight that group-level feedback may promote a sense of collectiveness and help achieve a desired outcome of pro-environmental behaviors (Truelove, 2010). Recent evidences indicate that the three components in the theory of planned behavior (TPB) (Ajzen, 1991), including attitudes, subjective norms, and perceived behavioral control, significantly influence occupants’ energy behaviors at the workplace (Greaves, Zibarras, & Stride, 2013). For example, Greaves et al.’s study determined that the TPB explained 61% of variance in employees’ intention to turn off their computers when leaving their desk and 53% of variance in intention to recycle at work (Greaves, Zibarras, & Stride, 2013).

Another important group dynamic factor relating to occupant behavior is called group norms. Norms – culturally shared beliefs about how people behave or how they should behave (Cialdini and Trost, 1998) – are powerful determinants on people’s behaviour in many areas (e.g., Aarts and Dijksterhuis, 2003), especially on environmental behaviors (Goldstein, Cialdini, and Griskevicius, 2006). Many social-psychological theories, including the focus theory of normative conduct, the value-belief-norm theory, and the theory of planned behavior propose that norms exert an influence on people’s intentions and behaviors relating to energy or pro-environmental issues (Ajzen, 1985; Cialdini et al., 1990). Instead of examining only one type of norm, scholars have distinguished the differences between descriptive norms (prevalence of people’s actual behaviors) and injunctive norms (prevalence of how people should behave) (Cialdini et al. 1990) and suggested it is useful to consider both types of norms at the same time (Rivis & Sheeran, 2003). A great number of studies show that group norms influence workplace energy use and environmental behaviors (Andrews and Johnson, 2016; Norton et al., 2015; Yun et al., 2013). For example, Chen and Knight (2014) found that injunctive norms (perception of group members’ approval on energy saving) and perceived behavioral control have direct and positive effects on energy conservation intention among Chinese utility company employees. In addition, there are correlations between employees’ perceptions of supportive organizational norms and their environmental behaviors (Norton, Zacher, & Ashkanasy, 2014), as well as group norms and more general organizational
Understanding architectural and social-psychological influences on occupant behaviour in commercial buildings

citizenship behaviors (Kidwell, Mossholder, & Bennett, 1997). Further, normative feedback and messages focusing on environmental concerns are important in promoting energy conservation and collective behaviors (Lindenberg, & Steg, 2007; Xu, Arpan, Chen, 2015); but the long-term effect is generally unknown. One study recently discovered normative messaging positively influenced the long-term durability of behavioral change (Anderson & Lee, 2016). The long-term effect of energy behavior change in Anderson and Lee’s study was twice as prevalent in occupants with high concern for social norms. Besides the individual-level factors, organizational or structural factors are crucial in influencing occupant behaviors in commercial buildings. Specifically, top management support and organizational culture are key determinants in explaining workplace pro-environmental behavior (Tudor, Barr, Gilg, 2008; Young et al., 2015).

3. Conclusions

While the sections above discuss the social-psychological and architectural influences separately, it is evident that both perspectives share a common interest in the perceptual experience and cultural interpretation of the built environment. A theoretical framework that aims to unite these different perspectives into one conversation is Integral Sustainable Design (DeKay and Bennett 2011). ISD aims to integrate qualitative and quantitative perspectives on a given subject. The framework is based on four quadrants, which are represented with dotted lines in figure 1. The upper left quadrant explores individual perception of occupants, the lower left quadrant explores the cultural interpretation of collective individuals, the upper right quadrant explores performance and behaviours and the lower right quadrant considers systems and relationships. Each quadrant is a reminder that any given subject can be investigated from more than one perspective. The simultaneous investigation of multiple perspectives will lead to a more holistic understanding of the topic. In this paper the framework of ISD is used to explore various influences on occupant behaviour and the resulting impact on energy consumption. In this case the two left hand side quadrants are related to the discipline of sociology and psychology, and the right hand side quadrants are related to the discipline of architecture. Influential parameters as identified in the above literature review are mapped into the four quadrants of Integral Sustainable Design, and their relationships illustrated (figure 1).

Figure 1 illustrates strong links between the architectural (right hand quadrants) and socio-psychological (left hand quadrants) parameters. The interrelationships between these parameters and how they can impact on the resulting energy consumption of a building require further research. This research will be inherently interdisciplinary in nature. Theories, methodologies, and disciplinary insights derived from social science, architecture, and engineering will be required to identify effective strategies for lowering energy use. For example, engineers or computer scientists often attempt to define and model occupant behavioural patterns in buildings in relation to overall building energy use. However, the “real-life” measured building energy use is often different than the previously modelled building energy use because the modelling assumptions originally made did not account for social and psychological factors that may indirectly affect occupant behaviours. In contrast, in the social science disciplines, the importance of social behavioural and economic factors affecting energy use has been gradually recognized; however, whereas the commonly used self-reported survey and interview methodologies typically address social, psychological, and economical issues, these have not been used in conjunction with accurate energy usage and feedback for behavioural change in real-time or in a cumulative manner through building technology. As discussed earlier, design based on social factors is
an important area when examining occupant behaviours in buildings. Occupants’ interactions (and expected interactions) with buildings may change dependent on the types of design or architectural strategies implemented in a given building. Further research is required to help architects and designers to better understand the interface between the occupants and buildings based on observed behaviours and social factors that may not have been previously considered. Blending disciplinary insights and methodologies from each of these disciplines will provide a more holistic understanding of energy consumption and occupant behaviour.

Figure 1: architectural and social-psychological parameters influencing occupant behaviour mapped into the four quadrants of Integral Sustainable Design.

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Aural related implications of the open plan office

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Abstract: The open plan office is now a standard design approach for new and retrofitted commercial buildings. The open work environment is considered to improve communication and collaboration between colleagues, facilitating more efficient and faster responsiveness and decision making. The removal of walls in open plan offices allows for an increase in the density of occupants and is also advantageous in aiding effective air distribution. However, research has shown that the benefits of improved access to colleagues can be overshadowed by the impact of increased noise, visual related disturbances and a loss of privacy. This paper reports on a post occupancy evaluation of a number of commercial office buildings (Green Star rated and non-rated buildings) in Adelaide, South Australia, focusing on acoustic privacy in the buildings as perceived by the occupants. The evaluation found that occupants in the Green Star rated buildings had a decreased satisfaction when compared to the occupants in the non-rated buildings particularly in relation to their perceptions of noise overall, noise generated from within and outside of the building, the frequency of unwanted interruptions and also privacy. Occupants expressed concern that these factors were affecting their overall comfort, productivity and health. The similarities and differences between the buildings and their occupants will be discussed. Through identifying and learning from the aspects impacting on aural comfort, we can change our approach to the design of work places and improve the built environment.

Keywords: office buildings; occupant satisfaction; post occupancy evaluation; noise

1. Introduction

It is estimated that 30 percent of our lifetime is spent at work (IAC, 2016). Given this high percentage it is important that these spaces provide us with the same qualities we expect from other environments. Commercial buildings designed and constructed following ‘green’ principles are credited with reducing negative impact on human health and providing internal environments which result in high levels of occupant satisfaction and increased productivity (Chong, 2007). Research by Wagner et al (2007) found that buildings which “meet the occupants’ needs for comfort and workspace quality” are conducive to
healthier and more productive personnel. It has been found however, that the inclusion of ‘green’ characteristics can negatively impact on an occupants’ experience of the internal space (Leaman and Bordass, 2001; 2007; Turner and Frankel, 2008; Baird et al, 2012). For example, increased levels of daylight is encouraged in ‘green’ principles, but this can result in increased glare discomfort for occupants (Leaman and Bordass, 2007). Kim and de Dear (2013) found that dissatisfaction of “‘noise level’, ‘sound privacy’ and ‘visual privacy’ tended to increase considerably in open-plan layouts compared to private offices”. ‘Green’ principles promote open-plan offices for increased penetration of light and distribution of air (Den-Ouden, 1981). The above studies highlight a clear conflict between expectations and actual user experiences.

This paper reports on a post occupancy evaluation of a number of commercial office buildings in Adelaide, South Australia. The main aim of the research was “to determine if commercial office buildings in the City of Adelaide which claim to be ‘green’ are indeed outperforming non-green buildings not only in their environmental performance but also in their ability to provide internal environments which result in higher satisfaction to the occupants” (Menadue, 2014). The research included assessment of energy and water consumption, building design, the analysis of internal environment measurements and the results of occupant surveys. In this research, ‘green’ buildings were divided into two groups; ‘Green Star’ referring to new or retrofitted buildings assessed and accredited by the nationally accepted environmental performance rating tool Green Star, which commenced in Australia in 2003 (GBCA, 2015) and ‘Green Intentions’ buildings which incorporated green features not found in buildings of a similar age, but had not been assessed against an environmental rating tool. ‘Non-green’ buildings claim no green credentials and will be referred to as ‘Conventional’ buildings in this paper.

This paper focuses on the results of investigations into aural related disturbances and the impact of these disturbances on perceived privacy of building occupants. The investigations include occupant satisfaction surveys and also review of the internal arrangement of the office spaces. This paper is a continuation of the earlier publication by the authors (Menadue et al, 2013) which reported on the correlation between dissatisfaction with noise and visual disturbances and occupants’ sense of overall comfort and perceptions of health in a building which in turn can impact on perceived productivity.

2. Research method

The research involved extensive field work to evaluate commercial office buildings in the city of Adelaide, post occupancy. The comparison of ‘green’ and conventional buildings allowed more recent buildings in Adelaide to be directly assessed against buildings which were ‘typical’ of their era. It is important to note that the majority of commercial construction in the last decade in Adelaide is Green Star rated, meaning the conventional buildings in this study were older. Also, Adelaide is typical of most Australian cities with only 2-3 percent of building stock being replaced each year (ASBEC, 2008).

As this paper focuses on aural issues in internal spaces, only methods for collecting data relating to these aspects will be discussed.

2.1. Building selection

Various approaches were undertaken to identify buildings to include in the study, such as contact with building management companies, management of organisations within the buildings and government officials. All participating buildings needed to be located in the Adelaide CBD, have been occupied for at least 12 months prior to the study commencing and have at least 80 percent of their lettable area for
commercial office activities. Other than these stipulations, there was no restriction on size of building, number of floor levels or date of construction. In all, nine buildings participated in the study with a combined total of 135,000m² of net lettable floor area. The study included four buildings in the 'Conventional' category described in Table 1 (building A to D). The ‘Green Star’ category also had four buildings (Table 2, building E to H), while the single building in the ‘Green Intentions’ category is described in Table 3 (building J).

Table 1: Characteristics of the Conventional buildings.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Building number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Construction period</td>
<td>late 1970s</td>
</tr>
<tr>
<td>Occupancy type</td>
<td>owner occupied</td>
</tr>
<tr>
<td>Net lettable area</td>
<td>7020m²</td>
</tr>
<tr>
<td>Average floor plate area</td>
<td>640m²</td>
</tr>
<tr>
<td>Floor levels (above ground)</td>
<td>11</td>
</tr>
<tr>
<td>Number of occupants</td>
<td>450</td>
</tr>
<tr>
<td>Area per occupant</td>
<td>15.6m²</td>
</tr>
<tr>
<td>Façade type</td>
<td>concrete facade</td>
</tr>
<tr>
<td>Extent of glazing</td>
<td>small and evenly distributed</td>
</tr>
<tr>
<td>Floor arrangement type</td>
<td>mix of cubicles with high, low and no partitions</td>
</tr>
</tbody>
</table>

Table 2: Characteristics of the Green Star buildings.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Building number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E</td>
</tr>
<tr>
<td>Green Star rating</td>
<td>5 Star as built</td>
</tr>
<tr>
<td></td>
<td>2007</td>
</tr>
<tr>
<td>Construction period</td>
<td>multi-tenanted</td>
</tr>
<tr>
<td>Occupancy type</td>
<td>31000m²</td>
</tr>
<tr>
<td>Net lettable area</td>
<td>1500m²</td>
</tr>
<tr>
<td>Average floor plate area</td>
<td>21</td>
</tr>
<tr>
<td>Floor levels (above ground)</td>
<td>2000</td>
</tr>
<tr>
<td>Number of occupants</td>
<td>15.0m²</td>
</tr>
<tr>
<td>Area per occupant</td>
<td>glazed and concrete facade</td>
</tr>
<tr>
<td>Façade type</td>
<td>80% high performance double glazing</td>
</tr>
<tr>
<td>Extent of glazing</td>
<td>mix of cubicles with low and no partitions</td>
</tr>
<tr>
<td>Floor arrangement type</td>
<td>mix of cubicles with low and no partitions</td>
</tr>
</tbody>
</table>
Table 3: Characteristics of the Green Intention building.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Building number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction period</td>
<td>2005</td>
</tr>
<tr>
<td>Occupancy type</td>
<td>owner occupied</td>
</tr>
<tr>
<td>Net lettable area</td>
<td>485m²</td>
</tr>
<tr>
<td>Average floor plate area</td>
<td>242m²</td>
</tr>
<tr>
<td>Floor levels (above ground)</td>
<td>2</td>
</tr>
<tr>
<td>Number of occupants</td>
<td>45</td>
</tr>
<tr>
<td>Area per occupant</td>
<td>10.5m²</td>
</tr>
<tr>
<td>Façade type</td>
<td>glazed, clad and masonry</td>
</tr>
<tr>
<td>Extent of glazing</td>
<td>under 50%</td>
</tr>
<tr>
<td>Floor arrangement type</td>
<td>cubicles with no partitions</td>
</tr>
</tbody>
</table>

2.2. Occupant satisfaction survey

Occupants in the study buildings were surveyed to obtain data on their satisfaction with the internal thermal, light and aural conditions; the workplace environment and their perceptions of their personal overall comfort, health and productivity. The online survey was in the form of yes/no and seven point scale questions with many of the questions including a comment box for additional feedback. This research used the Building Use Studies (BUS) survey under licence with modifications permitted, such as additional questions on privacy (aural and visual) and organisational based issues such as communication in the workplace, work group morale and personal happiness with work. The BUS survey has been used extensively in other research studies in Australia (Leaman et al, 2007, Paevere and Brown, 2008) and internationally (Baird, 2010) including the PROBE studies in the UK (Leaman and Bordass, 2001).

In the spring of 2010 the survey was distributed by building and organisation representatives via email circulation lists, with a follow up email two weeks later. The survey was circulated to approximately 2600 building occupants with over 600 responses received. Although all participating organisations within the nine study buildings agreed to partake in the survey, ultimately responses were only received from seven of the buildings with no survey responses from buildings D and H.

2.3. Analysis

For the occupant survey questions with a scale response, a mean score was calculated from individual responses for each building and also for each category of building. In addition, both quantitative and qualitative results from the survey were analysed using SPSS software and NVIVO software respectively. Quantitative question responses were statistically analysed using multiple linear regression to identify predictor variables for overall comfort, productivity and health, which were considered the 3 key issues to occupant satisfaction. Qualitative results were coded by emergent themes within each survey question to identify key topics raised by the survey respondents.

The following section focuses on the survey questions related to aural related disturbances and the impact of these disturbances on perceived privacy within the building. And finishes with a discussion on the correlation of responses to these questions and how occupants rated their overall comfort, productivity and health.
3. Results

When responding to questions in the survey, building occupants were asked to consider the typical work conditions experienced in their normal work area. Relative to noise, the survey questions cover the issues of Noise Overall, Noise from Colleagues, Noise from Other People, other Noise from Inside, other Noise from Outside and the frequency of Unwanted Interruptions. These questions were on a 7 point scale (Menadue, 2014).

Figure 1 compares the mean responses to the noise questions in the survey for the Conventional, Green Star and Green Intentions buildings. For ease of reading the data expressed in the spider graph (Figure 1), the Unwanted Interruptions question which had an optimum response of 1 has been transposed to 7. For example, where the actual mean response of a question with an optimum response of 1 is 4.69 (shown in the table data) in the spider graph it will be presented as 2.31 (7 - 4.69) (Menadue, 2014). Table 4 lists the mean and standard deviation for each question in the Conventional and Green Star buildings along with the statistical significance of the difference in their means. Table 5 provides this information comparing the Green Star and Green Intentions buildings.

![Figure 1: Conventional buildings, Green Star buildings and the Green Intentions building – mean responses to ‘noise’ survey questions](image)

It is found in both of the comparisons that the occupants’ of the Green Star buildings have a lower level of satisfaction for noise related issues. It is seen that the difference in mean response to Noise Overall when the Conventional and Green Star buildings are compared and also when the Green Star and Green Intention buildings are compared is statistically significant indicating diverse perceptions of noise are occurring.

Figure 2 shows the response distribution within the three building categories to the six noise related questions in the occupant survey. For all questions related to this issue the Green Intentions building received the closest to optimum mean score, while the Green Star Buildings received the worst scores of the three building types for Noise Overall, Noise from Colleagues and Others, Noise from both Inside and Outside and occupants in the Green Star buildings suffered from the most Unwanted Interruptions.
Table 4: ‘Noise’ survey question results for Conventional and Green Star buildings

<table>
<thead>
<tr>
<th>Question</th>
<th>Building category</th>
<th>Optimum</th>
<th>Mean ± Standard deviation</th>
<th>Significance of mean difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise overall</td>
<td>Conventional</td>
<td>7</td>
<td>4.24 ± 1.83</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>Green Star</td>
<td></td>
<td>3.43 ± 1.83</td>
<td></td>
</tr>
<tr>
<td>Noise from colleagues</td>
<td>Conventional</td>
<td>4</td>
<td>4.85 ± 1.42</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>Green Star</td>
<td></td>
<td>5.48 ± 1.27</td>
<td></td>
</tr>
<tr>
<td>Noise from other people</td>
<td>Conventional</td>
<td>4</td>
<td>5.04 ± 1.53</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Green Star</td>
<td></td>
<td>5.32 ± 1.44</td>
<td></td>
</tr>
<tr>
<td>Other noise from people</td>
<td>Conventional</td>
<td>4</td>
<td>4.60 ± 1.45</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>Green Star</td>
<td></td>
<td>4.98 ± 1.55</td>
<td></td>
</tr>
<tr>
<td>Noise from other people</td>
<td>Conventional</td>
<td>4</td>
<td>4.01 ± 1.84</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Green Star</td>
<td></td>
<td>4.38 ± 1.75</td>
<td></td>
</tr>
<tr>
<td>Noise overall</td>
<td>Green Star</td>
<td>1</td>
<td>4.69 ± 1.81</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>Green Intention</td>
<td></td>
<td>5.12 ± 1.55</td>
<td></td>
</tr>
</tbody>
</table>

1 Building category with closest to optimum mean score is highlighted
2 T-test for significance of difference in means

Table 5: ‘Noise’ survey question results for Green Star and Green Intention buildings

<table>
<thead>
<tr>
<th>Question</th>
<th>Building category</th>
<th>Optimum</th>
<th>Mean ± Standard deviation</th>
<th>Significance of mean difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise overall</td>
<td>Green Star</td>
<td>7</td>
<td>3.43 ± 1.83</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>Green Intention</td>
<td></td>
<td>4.95 ± 1.56</td>
<td></td>
</tr>
<tr>
<td>Noise from colleagues</td>
<td>Green Star</td>
<td>4</td>
<td>5.48 ± 1.27</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Green Intention</td>
<td></td>
<td>4.71 ± 0.78</td>
<td></td>
</tr>
<tr>
<td>Noise from other people</td>
<td>Green Star</td>
<td>4</td>
<td>5.32 ± 1.44</td>
<td>p&gt;0.05, not significant</td>
</tr>
<tr>
<td></td>
<td>Green Intention</td>
<td></td>
<td>4.71 ± 1.49</td>
<td></td>
</tr>
<tr>
<td>Other noise from people</td>
<td>Green Star</td>
<td>4</td>
<td>4.98 ± 1.55</td>
<td>p&gt;0.05, not significant</td>
</tr>
<tr>
<td></td>
<td>Green Intention</td>
<td></td>
<td>4.43 ± 1.33</td>
<td></td>
</tr>
<tr>
<td>Other noise from people</td>
<td>Green Star</td>
<td>4</td>
<td>4.38 ± 1.75</td>
<td>p&gt;0.05, not significant</td>
</tr>
<tr>
<td></td>
<td>Green Intention</td>
<td></td>
<td>3.81 ± 1.66</td>
<td></td>
</tr>
<tr>
<td>Noise overall</td>
<td>Green Star</td>
<td>1</td>
<td>5.12 ± 1.55</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Green Intention</td>
<td></td>
<td>4.00 ± 1.95</td>
<td></td>
</tr>
</tbody>
</table>

1 Building category with closest to optimum mean score is highlighted
2 T-test for significance of difference in means

Survey respondents were able to provide comment in relation to noise issues. Below is a summary of the comments from occupants in the Conventional and Green Star buildings; the worst effected by noise. In the Conventional buildings the highest percentage (28%) of respondents’ comments related to noise from colleagues discussing how voices easily travelled across the open plan environment with these voices generally being part of phone or meeting conversations, described by one respondent “as a result of our work practices and needs”. This issue was also raised in the Green Star Buildings with the noise in Green Star building E said to travel between floors where the multistorey atrium was next to work spaces. Almost a quarter (23%) of comments in the Conventional buildings and almost a third (30%) in the Green Star buildings related to other noise from inside such as fax machines and printers,
phones ringing and the constant hum of HVAC systems. In the Green Star Buildings, 54% of comments regarded issues such as a lack of sound proofing of meeting rooms and quiet rooms and also the proximity of meeting rooms and circulation spaces to work areas. The issue of lack of sound proofing was also raised in the Conventional buildings along with the noise generated by large work groups gathering for meetings, training or social events in the open plan area because the buildings do not provide other areas such as large meeting rooms for them to gather in. Many respondents in the Green Star buildings spoke of wearing headphones to minimise noise which they described as a consequence of the open plan floor (Menadue, 2014).

![Figure 2: Response distribution to survey ‘Noise’ questions](image)

Another question in the occupant satisfaction survey asked respondents to rate their personal workspace visual and acoustic privacy, specifically on their ability to work effectively. Figure 3 shows the distribution of responses to this question within the three building categories. Again the Green Star
building received the farthest from optimum mean score of 2.59. The Conventional building received a mean score of 3.18, while the Green Intention building rated closest to optimum, with a mean score of 4.50. The comments from occupants in the Green Star buildings relating to the issue of privacy indicated that the problem was created by the open plan layout. The low partitions between work stations meant respondents felt their computer screens could easily been seen by others with one respondent saying they felt “self-conscious”. Also, conversations could easily be heard across the floor with respondents often overhearing what they believed were confidential work related conversations between management and other staff. One respondent suggested “proper privacy screens so we can have some time out from constantly seeing and hearing others all day every day” (Menadue, 2014)

![Figure 3: Response distribution to survey ‘Privacy’ question](image.png)

Given the poor satisfaction level for acoustics and privacy within the Green Star buildings it is worth reviewing the spatial arrangements of the floor plates. Figure 4 shows a typical floor in each of the three building categories. The Green Star buildings are all recent construction or substantial redevelopments and have been designed for an open-plan office. There is efficiency of spatial arrangement evident in the plan with plant, vertical transportation and amenities typically located on eastern and western facades and offices and meeting rooms internalized to maximise connection to natural light and external views in the open-plan space. This results in large expanses of open area providing workspaces for up to 50 occupants. These large expanses combined with low partitions result in high visual exposure and ease of noise passage. The Conventional buildings have all introduced open-plan workspaces in recent renovations of the floor plates. Typically the partitions were higher in the Conventional buildings creating greater visual separation. Also, the size and shape of the floor plates, with centrally located plant, vertical transport and amenities divide the floor plate into smaller work zones. The Green Intentions building was designed to similar spatial principles as the Green Star buildings but on a much smaller scale. The fewer occupants combined with employees who were involved in the design process and therefore had a greater understanding of what the building was trying to achieve resulted in occupants more tolerant of noise and privacy, although unlikely less affected.
In Menadue (2014) variables with strong correlations to the three key issues of occupant satisfaction: overall comfort, productivity and health, were identified. Correlations between noise and privacy variables and the key issues were only identified in the Conventional and Green Star buildings (Table 6). Despite some dissatisfaction identified with variables in the Green Intentions building the key issues rated well with overall comfort 6.14 (optimum 7), productivity 3.5 (optimum 1 on a nine point scale) and Health 5.65 (optimum 7) with noise and privacy not found to influence perceptions.

In the Conventional and Green Star buildings occupants’ dissatisfaction with Noise Overall were more likely to also have dissatisfaction with overall comfort and feel less productive, while perceptions of health were also impacted by Noise Overall in the Green Star buildings. Again, in the Green Star buildings, dissatisfaction with aural and visual privacy also correlated to dissatisfaction with overall comfort and reduced perceived productivity.

### Table 6: Relationship between key satisfaction issues and noise and privacy

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Variable</th>
<th>Building category</th>
<th>Coefficient of determination (r²)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Comfort</td>
<td>Noise overall</td>
<td>Conventional</td>
<td>0.166</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>Noise overall</td>
<td>Green Star</td>
<td>0.151</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>Privacy</td>
<td>Green Star</td>
<td>0.196</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>Productivity</td>
<td>Noise overall</td>
<td>Conventional</td>
<td>0.149</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>Noise overall</td>
<td>Green Star</td>
<td>0.231</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>Privacy</td>
<td>Green Star</td>
<td>0.126</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>Health</td>
<td>Noise overall</td>
<td>Green Star</td>
<td>0.075</td>
<td>p&lt;0.01</td>
</tr>
</tbody>
</table>

### 4. Conclusion

The results of this research and others discussed in this paper highlight that there is still much to learn from buildings in operation. Occupants’ satisfaction with acoustics and privacy is typically low particularly in the Green Star buildings of this study. Further research is required into the sources and nature of the noise as well as the expectations of the occupants to truly understand the impact.
Investigation needs to be undertaken into methods for monitoring noise levels within work environments which are unobtrusive. Visible equipment and awareness of ‘sound’ monitoring is likely to result in occupants making behavioural changes. The idea of learning from post occupancy evaluations of buildings is not new, Hillier and Penn (1994) referred to it as the ‘virtuous circle’. Improving occupant satisfaction in buildings will only come from understanding the root of the problems (Leaman and Bordass, 2007).

**Acknowledgements**

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**References**


Adaptive comfort actions and passive cooling interventions: implications from a Brisbane school

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Abstract: In subtropical southeast Queensland, a common approach to improving thermal comfort in existing classrooms is to use air-conditioners. However increasing reliance on air-conditioners in schools adds to energy costs and increases carbon emissions. Greater understanding of low energy approaches to improving thermal comfort is needed to address this problem. This paper increases understanding of low energy approaches to improving thermal comfort in existing school buildings. In a case study school in Brisbane the impacts of a number of passive cooling interventions to classroom buildings and their surrounds were studied together with the current adaptive behaviours of teachers during perceived over-heating in classrooms. The impact of the interventions on classrooms was evaluated through quantitative data, classroom temperature, collected over 2012 to 2015 and qualitative data, perceptions of teachers of the classrooms, through an online questionnaire and semi-structured interviews with teachers and the Principal in 2015. This paper discusses key findings from the case study: current adaptive actions of teachers and the social and cultural aspects of thermal comfort in classrooms. A significant finding was that air-conditioning some classrooms and not others in the school was seen as an equity issue. Implications from this study could inform a pathway for low energy occupation of classrooms in southeast Queensland.

Keywords: adaptive comfort; adaptive behaviours; passive cooling; overheated classrooms.

1. Introduction

The link between thermal comfort and energy use in buildings has increased over the last twenty years due to the need for communities to reduce their greenhouse gas emissions, and to reduce the impacts of climate change (de Dear et al. 2013). Within the field of thermal comfort research, the adaptive comfort approach suggests that occupants of naturally ventilated buildings can be comfortable in a higher range of temperatures, if they have ways of adjusting their environment to suit them (Nicol, Humphreys and Roaf 2012). Increasing adaptive behaviours in existing buildings is seen as a pathway to low energy occupation. New sustainable buildings can be designed using passive design principles to provide comfort for occupants, reducing the use of cooling and heating devices. Yet, even if all new buildings were zero carbon buildings (they produce energy on site to balance out the energy used for
construction, materials and to run the appliances in the building over its expected life), they would “make a very small dent in the emissions of the building stock as a whole” (Swan and Brown 2013). Herein lies the ‘wicked problem’, of how to maintain thermal comfort in existing buildings and lessen building emissions to reduce impact on climate change (Roaf, Nicol and de Dear 2013). Swan and Brown (2013) suggest improving existing building stock by retrofitting and framing the problem as socio-technical in nature to gain greater understanding of the link between buildings and occupants.

Overheating in summer is a problem in existing classroom buildings in subtropical southeast Queensland. Older timber classroom buildings were originally constructed with little or no insulation to resist heat from solar radiation. Clusters of individual buildings are surrounded by asphalt surfaces, another source of heat to classrooms. A common solution to achieving thermal comfort in overheated houses, offices or schools in Australia, as in other developed countries, is to install energy intensive air-conditioning (Roaf et al. 2010). Greater understanding of low energy approaches to improving thermal comfort in existing schools is needed.

This is the second paper reporting from a research project on a case study Brisbane school, where four passive cooling interventions were retrofitted to classroom buildings and their immediate surrounds (Kuiri 2015). The interventions were: 1) stack ventilation 2) cool roof 3) shade sails over courtyards and 4) schoolyard greening, as shown in Figure 1. The research project had three aims. Firstly, evaluate the impact of the four passive cooling interventions. Secondly, understand what is perceived to be an acceptable comfort zone for the classroom occupants. Thirdly, explore the adaptive behaviour of teachers during times of perceived over-heating in classrooms. The first paper (Kuiri 2015) discussed the background of the research project, the case study school, Brisbane climate, attributing factors to overheating of classrooms, the passive cooling strategies, and the results of applying an overheating metric developed by de Dear and Candido (2012) to classroom temperatures. This paper discusses key findings from the qualitative phase of the mixed methods case study: the current adaptive behaviours of teachers in the school and the social and cultural issues influencing thermal comfort in classrooms. At the end of the paper implications of these findings that could inform a low energy approach to occupation of classrooms in South East Queensland are discussed.

2. Literature

The Adaptive Comfort Model holds promise in the aim of increasing energy conserving behaviours. The Adaptive Comfort Model suggests that occupants can be comfortable in a higher range of temperatures in naturally ventilated buildings if they have ways of adjusting their environment to suit them. Nicol, Humphreys and Roaf (2012) suggest that people react in ways that tend to restore their comfort if they experience a change that produces discomfort. Examples of adjusting the environment are by opening windows to increase cross-ventilation, using blinds to control solar gain on glazing and glare, and turning on ceiling fans to increase air movement for a cooling effect (Nicol, Humphreys and Roaf 2012). The Adaptive Comfort Model is based on extensive field studies providing statistical data to define the conditions that a percentage of occupants (80% and 90%) find thermally comfortable, in naturally ventilated buildings. These studies revealed a relationship between an indoor comfort zone (temperature band 5 degrees wide for 90% of the population) and the monthly mean of previous days’ outdoor temperature (de Dear and Brager 2002). The Adaptive Comfort Model was first included in American Society of Heating, Refrigeration and Air-Conditioning Engineers Standard (ASHRAE) 55 in 2002. There are a number of conditions for using the Adaptive Comfort Model; that there is no mechanical cooling system, the windows are easily operable, the occupants are free to adapt their
Adaptive comfort actions and passive cooling interventions: implications from a Brisbane school

clothing to indoor/outdoor conditions to a range of 0.5 to 1.0 clo (lightweight clothing) and that the occupant have metabolic rates ranging from 1.0 to 1.3 met (near sedentary level) (ASHRAE 2013). The adaptive comfort zone varies seasonally. In summer, warmer indoor temperatures are acceptable to occupants compared to cooler indoor temperatures in winter. Nicol, Humphreys and Roaf suggest understanding the adaptive comfort approach to design comfortable buildings and encourage thermal comfort research in regions to better understand specific complexities of obtaining comfort (2012).

Thermal comfort studies of children in naturally ventilated classrooms in tropical and sub-tropical Asian countries question whether it is necessary to air-condition classrooms, as has been the practice in Western countries (Wong and Khoo 2003, Kwok & Chun 2003, Puteh et al. 2012, Hwang et al. 2009, Yang and Zhang 2008). Japanese school children in naturally ventilated environments were satisfied with conditions well outside the adaptive comfort zone, although the children did prefer being cooler (Kwok and Chun 2003). In their study of school children in New South Wales schools, de Dear et al (2015) found children preferred an acceptable summertime temperature range of 19.5°C to 26.6°C, lower than the ASHRAE adaptive comfort zone and that children in schools from places with more varied outdoor temperature had higher adaptability (de Dear et al. 2015). Understanding how occupants adapt could be studied further in a school.

Although, thermal comfort studies of children’s adaptive behaviours in classrooms in Brazil and Venice have shown that teachers, rather than children, have control of the classroom environment; this is attributed to children having restricted spontaneous movement in the classroom to comply with discipline codes (Bernardi and Kowaltoski 2006) or teacher’s preference taking precedence over children’s preferences (De Guili, Da Pos and De Carli 2012). A more direct research approach is to ask teachers of their adaptive actions in the classroom.

Studying occupants of naturally ventilated houses with high environmental values in Darwin, Daniel et al (2015) found these Australian householders ‘thermal mavericks’ live in wider temperature ranges than the ASHRAE adaptive comfort zone; they suggest this relationship could be relevant for occupants of other building types. Moloney and Strengers (2014) studied Australian householders ‘Going Green’ and argue that energy conserving actions are narrowly defined as being either small actions (turning lights off when not in use) or large actions (installing solar panels) and suggest exploring everyday social practices to provide more ways of reducing household energy consumption. They recommend studies be done of social practices of people in other building types, to increase the scope of energy saving behaviours. An interesting study in California investigated the effect of persuasive messages delivered to householders promoting energy and water conservation by measuring the corresponding use of energy or water in the household after receiving the messages (Nolan et al. 2008). Each message was written in one of five ways: descriptive norm (what your neighbours are doing to conserve energy), self-interest (conserving energy saves me money), environment (reduce my impact on the environment), social responsibility (conserving energy is socially responsible) and information-only (conserving energy has these quantitative effects). The most influential message was written in the descriptive norm.

A study of domestic retrofits in the United Kingdom used a social-technical framework with a mixed method research approach, to understand the link between social aspects of lifestyle to the technical workings of their retrofitted households (Chiu et al 2014). A similar mixed method approach has been used in this case study to evaluate the impact of the retrofitted passive cooling strategies together with perceptions of the teachers in the classrooms. In addition, understanding the influence of social factors to thermal comfort such as performing the role of teacher is sought. A framework for understanding a complex problem that involves subjective viewpoints of people and their roles in system (or...
organization) of people is offered by Soft Systems Methodology (SSM) (Checkland & Poulter 2006). SSM can be understood as a learning cycle that investigates different points of view of a problematic situation that is then assembled into list of actions to improve the situation; a process used in action research (Checkland & Poulter 2006).

Other studies reviewed were those that involved evaluation of the environment and impact on productivity of the occupants. In the seminal study of the impact of daylighting on academic performance in Californian schools, Heschong and Mahone Group collected and analysed both quantitative environmental data of the schools and qualitative data from the occupants (2003). Post occupancy evaluations of buildings typically obtain a tally of occupants’ perceptions of environmental factors including thermal comfort, noise, glare, humidity, air quality and amount of daylight, from questionnaires (Deuble and de Dear, Leaman and Bordass 2007). If followed up with semi-structured interviews other factors influencing the occupant’s satisfaction with the environment could be revealed (Leaman and Bordass 2007; Heschong Mahone Group 2003; Deuble & de Dear 2014) or insights not obvious to the researcher (Yin 2014). These methods, a questionnaire followed by semi-structured interviews, were used in the qualitative phase of this case study research.

Figure 1: Case study group of buildings with interventions (source: Author, 2016)
3. Methodology

The research design was a single case study (Yin 2014) with a mixed method approach for analyzing the quantitative and qualitative data (Creswell 2014). Quantitative data, classroom temperatures, were collected by HOBO data loggers set for half hourly intervals placed inside classrooms before and after interventions, from 2012 to 2015 (refer Figure 1). Three methods were used to analyse the classroom temperature; the overheating metric developed by Candido and de Dear (2010) for the Australian schools study (de Dear et al. 2015) was the first method used. The results from the temperature analysis and the impacts of the passive cooling strategies are merely noted in this paper and results from the temperature analysis are intended for more detailed discussion in another paper. The methods used to collect and analyse data in the qualitative phase of the study were 1) Online anonymous questionnaire to all classroom teachers and 2) Semi-structured interviews with the Principal and seven teachers who occupied classrooms with interventions. Key findings from the qualitative phase of the study are discussed in this paper. The design of the questionnaire and interviews are discussed next.

3.1. Questionnaire and Interviews

All classroom teachers in the school were invited to participate in an anonymous online questionnaire. The questions were grouped; evaluation of passive cooling strategies and teacher’s perception of heat inside classrooms (Questions 1 to 10), exploration of current adaptive actions in the school (11–22), exploration of energy conservation practices by teachers (29-32), air-conditioner use (23-28), teacher’s age and gender (33-34), children’s age range (35) and an open question (Q36) for teachers to add any other comments. Out of the 34 classrooms, 19 teachers began the questionnaire, 13 (a proportion of 30%) responded to most questions including Question 11 about their adaptive actions in the classroom and 7 provided comments at the end. For Question 35 there were no responses from teachers of children aged 4 to 6, so it is inferred that no Prep teachers (from Buildings O and P, not in the case study group), answered the latter part of the questionnaire. Question 24 asked whether the classroom had air conditioning or not and this yes/no response allowed responses to be grouped into teachers who occupied naturally ventilated (NV) classrooms or air-conditioned classrooms (AC). Questions asking
about teacher’s perceptions of heat inside classrooms focused on the most recent summer term, Term 1 of 2015 (27 January to 4 April).

The semi-structured interviews had similar questions to the questionnaire but enabled teachers to provide more in-depth answers. Seven teachers were interviewed who occupied buildings A B C D. Five of these had occupied the same building from 2012-2015. The Principal was asked additional questions about the workings of the school.

4. Qualitative results

4.1. Impacts of the passive cooling strategies on classrooms

From the questionnaire, the time of day that more than half (7 out of 12) of respondents in both NV and AC classrooms felt uncomfortably hot inside their classroom was in the last teaching session of the afternoon (1.55-2.55pm). Most respondents (7 out of 9) in NV classrooms felt uncomfortably hot for more than half of Term 1. Two teachers in NV classrooms felt uncomfortably hot in the middle session (11.25am-1.05pm) and another three in NV classrooms all through the school day (8.55am-2.55pm).

In the interviews, some teachers summarized that the passive cooling strategies alone were not enough to provide comfort for on hot days in summer terms, especially months of November December, January, February and parts of March. High humidity in summer was perceived as an uncomfortable factor that could not be reduced by increasing air movement using ceiling fans or opening windows. Although, Teachers in Building B had perceived less discomfort from heat in Term 1 compared to previous years. Also, Teachers in B and D commented in shoulder seasons (April/May and September/October) the classrooms were comfortable.

4.2. Current adaptive behaviours

In the questionnaire, Question 11 listed fourteen adaptive actions and teachers were asked to rate on a five-point scale how successful the action was in reducing discomfort from heat, refer to Table 1. Most teachers responded to all of the actions listed, indicating that they had practiced these at some time. Where classrooms had it, the action that was always successful was ‘to turn on the air-conditioner upon arriving in the morning.’ Generally successful actions were to ‘increase air movement by using ceiling fans’ and ‘opening windows’. Actions that had varying responses of success were ‘encouraging children to drink water’ or ‘spraying them with mist’. Allowing children ‘to spread apart’ or ‘sit under fan of near windows’ or ‘changing the scheduled learning activity’ were sometimes successful. Leaving the classroom to a cooler location were practiced by some teachers and regarded as sometimes successful in reducing discomfort from heat. In the interviews some year one and two teachers said that this action was problematic for a whole class, as children require writing surfaces and materials that they need to keep with them and teaching resources needed for learning activities are on display are kept in the classroom. Commonly practiced in outdoor locations near the classroom was ‘one-on-one time’ between a child and adult, or small groups of children with an adult reading books. A child’s voice is more easily heard when away from the background noise of children in the classroom. Another common action was scheduling more intense teaching in the morning. Teachers observed the effects of heat on children, especially in the afternoon, as lethargy and irritability that impacted on their learning. Teachers observed children returning to classrooms after having active breaks on hot days were overheated “as red as beetroots” and unable to cool down in a warm classroom.
Table 1: Question 11, Current Adaptive Actions.

<table>
<thead>
<tr>
<th>Question 11: Over summer terms do you engage in any of these actions? If you do please rate how successful the action is?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Action</td>
</tr>
<tr>
<td>1) Open windows or doors to increase air movement</td>
</tr>
<tr>
<td>2) Turn ceiling fans on to increase air movement</td>
</tr>
<tr>
<td>3) Turn ceiling fans up to highest setting</td>
</tr>
<tr>
<td>4) Encourage children to drink more water</td>
</tr>
<tr>
<td>5) Allow children to leave classroom to fill up water bottles</td>
</tr>
<tr>
<td>6) Spray children with water mist to cool them</td>
</tr>
<tr>
<td>7) Fan children to cool them</td>
</tr>
<tr>
<td>8) Ask children to spread apart</td>
</tr>
<tr>
<td>9) Allow children to change seats to sit under fan or near windows</td>
</tr>
<tr>
<td>10) Allow children to take off socks and shoes</td>
</tr>
<tr>
<td>11) Change scheduled learning activity</td>
</tr>
<tr>
<td>12) Leave the classroom and move to cooler location</td>
</tr>
<tr>
<td>13) Turn on AC upon arriving in classroom in morning</td>
</tr>
<tr>
<td>14) Turn on AC when it gets hot during the day</td>
</tr>
<tr>
<td>Other actions</td>
</tr>
<tr>
<td>15) We also pour water over our heads and have wet face washers</td>
</tr>
<tr>
<td>16) Leave windows open at night</td>
</tr>
<tr>
<td>17) Pull down blinds to stop direct sunlight</td>
</tr>
<tr>
<td>18) Wet towel around teacher’s neck.</td>
</tr>
</tbody>
</table>

Questions from 12 to 22 asked particulars of window and ceiling use in classrooms. Most teachers opened windows and/or switched on ceiling fans in the morning and closed or switched off the same when leaving the classroom at the end of the school day. Increasing air movement by ceiling fans was limited due to fans being too far away from people to be effective at cooling (fans mounted on 4.1m ceilings) or too noisy at higher speed. Fans on high speed were disruptive to children when doing cutting and pasting paper activities and turned down or off. Half of the teachers (5 out of 10) used windows effectively for cross ventilation and perceived the best breezes to come the south, from the direction of the school oval. Usually in Brisbane the best prevailing breezes in summer are from the north to southeast. The location of the school on the south slope of a hill could be reducing the amount of breezes reaching the classrooms (Kennedy 2012).
4.3. Emergent themes from the study

A significant finding in the school was the situation that some classrooms being air-conditioned and others not, was an equity issue. Teachers perceived as unfair the expectation to perform the role of teacher in an uncomfortable warm classroom alongside peers in comfortable air-conditioned classrooms. For the open question at the end of the questionnaire all seven respondents stated that air conditioners should be installed to all classrooms. This sentiment was echoed in both teacher and Principal interviews that all classrooms should have the same controls available to teachers for providing comfort from hot or cold weather conditions. Other findings were: that some teachers perceived air-conditioned environments to be the social norm for professional workplaces in Brisbane; naturally ventilated classrooms were perceived as things of the past; and air-conditioned classrooms were increasing in other schools as the social norm. Another theme that emerged from interviews was that maintaining an expected professional appearance of teachers is limited in clothing choice when teaching in warm conditions. Women wore lightweight clothing that was not obvious beach or house wear. The Principal commented on how he could wear a tie due to his office being recently air-conditioned.

Current energy conservation practices included turning off lights and appliances when not in use, small actions (Moloney and Strengers 2014) in keeping with recommendations from the Department of Education. Some teachers suggested that energy saving practices that limit air-conditioner use should be the same for everyone in the school, teachers and administration staff.

5. Discussion

In this case study it was found that retrofitted passive cooling strategies to the school impacted on classroom temperature. Before the interventions, classrooms were warmer than the outside temperature by 3°C for the entire afternoon. After the interventions, classroom temperatures were reduced in the duration of overheating in the afternoon, some only reaching outside temperature for short periods of time. However the classrooms were not cool enough to be within the comfort zone. When outside maximum temperature on summer days are over the upper comfort zone threshold, averaging 28°C for summer months, it follows that there are times when classrooms with open windows and doors and thin-skinned walls will reach outdoor temperature. In the study of Australian school children by de Dear et al, cooler temperatures were preferred than the comfort zone (2015). However, Daniel et al. (2015) showed that individuals living in houses in Darwin regarded temperatures above the comfort zone as acceptable due to environmental values influencing their occupation of their houses.

Previous thermal comfort studies of school children suggest that an Adaptive Comfort Model for children needs to be different from that for adults (Teli et al 2012; de Dear et al 2015). Most conditions for using the Adaptive Comfort Model are met in this school except for two; that windows should be easy to operate and the metabolic level of the occupants be sedentary. In the case study school it was found that inoperable windows prevented teachers from using them to improve their comfort. Also, teachers observed children to be active on hot days during breaks, possibly elevating their metabolic rate to 3.0-4.0 met. Back in the classroom time needed to pass before their met levels were lower and nearer a sedentary level of 1.2. Active children possibly require cooler classroom conditions than that suggested by the Adaptive Comfort Model in ASHRAE 55.

This study revealed current adaptive actions of teachers to reduce theirs and the children’ discomfort from heat in naturally ventilated classrooms. These actions have limitations but an awareness of when they are effective could inform a low energy approach to occupying classrooms.
6. Implications

From this study arises the question ‘how can schools in south-east Queensland improve thermal comfort levels in existing classrooms using low energy approaches?’ Knowing what times of the day and year comfortable and uncomfortable temperatures generally occur in the classroom can increase low carbon behaviours. Especially in lightweight timber buildings that are affected by outside temperature swings. Mornings (9.00 to 11.00am) are generally the coolest time of the school day. The research identified months of the year when the classrooms with retrofitted interventions were within an acceptable comfort range, May and September. In these months air conditioners should be kept off. In shoulder seasons adaptive actions such as using open windows for cross ventilation, scheduling less intense activity in the afternoon or moving the class to cool locations outside could occur. In summer, an air conditioner could be turned on later in the morning (10.30am) on hot days, even later (12.00pm) on warm days, only as required to cool the classroom for the afternoon. In winter, the air conditioner could be used to warm the classroom on cold mornings then turned off for the afternoon when the sun has warmed the surroundings outside. Changing the habit of turning the air conditioner on in the morning and leaving it run for the full day, to being aware of when to switch it on and off during the day and year, could have enormous implications for schools, financially and environmentally.

The equity issue that emerged from the study was discussed as the notion that all teachers should have the same resources available to them to provide thermal comfort to children and themselves. Another way of viewing the idea of teachers as a social group with the same actions available to all, is that if the group followed a belief that low carbon behaviour is important, then all would be acting together as a collective effort rather than individual effort (Kania and Kramer 2011). In a school the challenge to overcome is that individuals hold different levels of adherence to low energy behaviours and acceptance of comfort (de Dear and Brager 1998). However if a group of teachers valued sustainable occupation of their classrooms highly, they may limit air conditioner use and practice a range of adaptive actions to occupy their classroom instead. Especially if they knew that neighbouring teachers were acting in ways to conserve energy (Nolan et al 2008). A Principal would have a leading and coordinating role in this action. If left up to the individual, there could be some teachers putting more effort into saving energy, but others not giving it any thought, following a habit of cooling all day every day in summer using air conditioning. Observing the latter behaviours could be discouraging to those teachers trying to conserve energy (Ockwell et al 2009). Increasing the range of adaptive behaviours of teachers in classrooms, combined with retrofits to buildings and surrounds to reduce heat load, are key pathways towards low carbon occupation of classrooms in southeast Queensland.

7. References


Non-normative use of windows and artificial lighting in selected South Australian primary schools

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Abstract: Lighting design in education facilities is acknowledged as important. Design advice, guidelines, and standards about daylight and artificial lighting design provide normative expectations about explicit lighting levels required and implicit use patterns. In a mixed methods post-occupancy evaluation of selected primary schools in Adelaide, South Australia, it was observed that while daylight and artificial lighting design configurations largely conformed to normative design expectations, the use patterns did not. Artificial lighting was not always used when total lighting levels were below the relevant standard. Windows were obstructed with various items such as student work, pedagogical display, furniture, and other means. This paper reports the observations, proposes pedagogical reasons for non-normative behaviour based on surveys, and discusses the observed occupant spatial agency.

Keywords: School buildings; daylight; building performance evaluation; post-occupancy evaluation

1. Introduction

In school infrastructure, the level of daylight in primary schools has been associated with improved student performance (Heschong Mahone Group, 1999; Barrett et al., 2015), although it has been noted elsewhere that the effects of lighting on students has been found to be complex and inconsistent (Higgins et al., 2005, p. 20). Design advice promotes ‘natural’ lighting as needed for good learning (Nair and Fielding, 2005, p. 74; OECD, 2006). The underlying premise of the design advice and standards for windows is that they will be used as installed, with glazing free from obstruction.

This research reports a component of a post-occupancy study of case study primary schools (Pearce, 2016). The fieldwork was undertaken during the 2012 school year and presents inductive qualitative evidence for real world use of windows and glazing. This was prompted during initial visits in which it was observed that window glazing was often covered with pedagogical materials, which raised questions about normative use of window glazing and the presumptions of a spatial designer.

The expectation of education lighting is complex. Historically, Australian education was influenced by trends from the UK, and North America (Campbell and Proctor, 2014, p. xiv). This is evident in the early focus on natural light and ventilation for health and hygiene imported from the UK (Orr, 2011).
century, British attempts to design schools solely using passive energy techniques to reduce energy use resulted in large variations in lighting levels and glare (McKennan, 1985). Despite the glare, students were found to prefer to be near windows ‘to see what is going on’ in addition to nature (Stewart, 1981). This privileging of daylight has not always been successful: open plan classroom principles based on British designs, overheated in the extreme Australian summer due to large areas of glazing (Angus et al., 1979, p. 18). Notably this problem was occurring prior to the integration of Information and communication technology (ICT) into teaching pedagogy (Winterbottom and Wilkins, 2009) its lighting consequences. This suggests conflicting lighting design intentions between hygiene factors, technology in pedagogy, and climate might be expected in current designs.

In local practice, there are two sources of design standards for school daylighting design. With the objective of minimising the use of artificial light, daylight is encouraged with focus on use of appropriate shading and skylights to control glare and contrast (DECS Capital Programs & Asset Services, 2010). However, the Building Code of Australia (BCA) provides only proportional design guidelines, i.e., size of window, not quality of light, (Australian Building Codes Board, 2014, Section F.4). Thus, daylight quality and quantity relies on the architectural design interpretation.

Artificial lighting design in schools is driven by a range of standards and statutory inputs. Overlooking the extensive energy efficiency prescriptions, the BCA refers to local standards (AS/NZS 1680.0) for illumination levels (Table 1). The local public education authority refers the designer to other parts of this suite of standards (AS/NZS1680.2.2) for more specific illumination levels about ‘rooms dedicated to the use of computers’ (DECS Capital Programs & Asset Services, 2010).

Given that all classrooms under study had been built or renovated in the ten years prior to the fieldwork, these standards were considered as the benchmark. Thus, all rooms should achieve a minimum light level at all locations in the room; however, given the range of activities that occur in a contemporary classroom, it was difficult to nominate a single appropriate illuminance level.

<table>
<thead>
<tr>
<th>Design input</th>
<th>Input type</th>
<th>Lighting purpose</th>
<th>Level or prescriptive standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCC BCA 2014 F4.4</td>
<td>Statutory</td>
<td>Lighting to BCA class 9B buildings (schools)</td>
<td>AS/NZS 1680.0. (no year listed) safe movement</td>
</tr>
<tr>
<td>AS/NZS 1680.2.2:2008</td>
<td>Standards</td>
<td>Office and screen based tasks</td>
<td>General task 320 lx Screen-based task areas 160 lux</td>
</tr>
<tr>
<td>Table E1</td>
<td></td>
<td></td>
<td>Classroom general use 240 lux Computer rooms see AS1680.2.2</td>
</tr>
<tr>
<td>AS/NZS 1680.2.3:2008</td>
<td>Standards</td>
<td>Specific applications - Educational and training facilities</td>
<td>Art activities 400-800 lux</td>
</tr>
<tr>
<td>Table D1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Case studies and methods

The post-occupancy study used a mixed methods research approach to compare occupant use and perspectives with observed building fabric and services. This approach, although informed by contemporary building post-occupancy evaluation methods, was grounded in social science mixed methods discussions (Teddlie and Tashakkori, 2009).

Four case studies schools, coded as Yellow, White, Orange and Red, participated on the condition that they were not identified publically (Table 2). All participant schools were located in the Adelaide metropolitan area, South Australia. All had occupied their buildings for more than five years and represented a mature occupation rather than the initial occupancy phase. Through negotiation,
participant classrooms were selected to include older primary school students and enable student surveys. Out of the four schools, twenty teaching spaces (classrooms and library/resource spaces) were observed (indicated by school code suffix, e.g. Yellow.1) for use and environment. Across the schools, 147 student participants, aged 10-13, were recruited from eight classrooms. Staff were recruited from all areas of the participating schools (N=44).

Table 2: Summary of case study schools (at 2012)

<table>
<thead>
<tr>
<th>School / Yr opened</th>
<th>Approx. floor area</th>
<th>Enrolment Area/student</th>
<th>Building construction description</th>
<th>Day Lighting strategy</th>
<th>Award or heritage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow / 1877</td>
<td>1415 m²</td>
<td>178</td>
<td>7.9 m²</td>
<td>Buildings include stone buildings over 100 years old, block veneer and permanent lightweight.</td>
<td>Large glazing, no overhangs, Internal blinds</td>
</tr>
<tr>
<td>White / 2003</td>
<td>4580 m²</td>
<td>613</td>
<td>7.5 m²</td>
<td>Greenfield school &lt; 10 years old. Brick veneer/lightweight construction</td>
<td>Overhangs and internal blinds north, clerestories south</td>
</tr>
<tr>
<td>Orange / 1998</td>
<td>4300 m²</td>
<td>597</td>
<td>7.2 m²</td>
<td>Greenfield. Construction 60/40 solid mass and lightweight transportables.</td>
<td>Overhangs, reflective film (permanent), or small windows (trans)</td>
</tr>
<tr>
<td>Red / 1877</td>
<td>3130 m²</td>
<td>324</td>
<td>9.7 m²</td>
<td>All buildings except 2 (lightweight &amp; masonry veneer) &gt; 50 years. Old buildings solid stone/brick. Interior renovations.</td>
<td>Large glazing, no overhangs, internal blinds</td>
</tr>
</tbody>
</table>

The effects of occupation on the school buildings was observed as a non-obtrusive ethnographic approach (Liamputtong and Ezzy, 2005, p. 101) and recorded using systematic photography and field notes. In some classrooms, environmental loggers with light sensors collected illuminance levels (Figure 1). These were supplemented with spot measurements using a handheld light meter (CEM DT-8820).

Figure 1: logger backing detail and installation example

A study-specific self-completed questionnaire was developed to capture a range of student and staff perspectives about their buildings and grounds. Open response questions were analysed using post-coded using thematic analysis, i.e., without an *a priori* code strategy (Liamputtong and Ezzy, 2005, p.
Results presented here show summary code categories. These graphs represented collated and normalised thematic detail codes across schools. The five-point scale and multiple-choice questions presented use descriptive and inferential statistics.

4. Findings

4.1. Observed lighting design and use

4.1.1. Views, lighting design, and permanent modifications

All case study classrooms had both artificial lighting and daylight. Artificial lighting was typically T5 lamps in either hung or surface mount luminaires. Daylight was available from a mixture of user level windows, skylights and clerestories, with some film on glazing and some interior blinds. The older buildings were without exterior verandas or shade devices. Views out of the classroom varied. The permanent Orange School buildings had views onto bag racks. The White, Red and Yellow schools had high sills (greater than 1000 AFL) so views were restricted to sky when seated, particularly with blinds down where installed. When standing, Yellow.3 had attractive long distance views opposite to the teaching wall.

Three types of permanent modifications to windows were observed - internal blinds, window film, and a veranda extension (Table 3). These modifications had the effect of changing both the daylighting design and solar gain of the original designs. There is also evidence that the east windows to Yellow.2, Yellow.3, and possibly Red.5, were either not built as drawn or had been enlarged, suggesting that action has been taken throughout both buildings lives to change light levels. During the study period, the north overhang on White.1 was extended to double in size. Prior to this, it was observed the occupants had been attempting to control the daylight with scrim curtains.

<table>
<thead>
<tr>
<th>Daylight modification</th>
<th>Description</th>
<th>Observed</th>
<th>Approximate year of retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal blinds</td>
<td>Opaque or translucent blinds</td>
<td>Yellow.2, 3</td>
<td>2003</td>
</tr>
<tr>
<td></td>
<td>retrofitted</td>
<td>Red - all</td>
<td>c2006 renovation</td>
</tr>
<tr>
<td>Film</td>
<td>Tinted/reflective film</td>
<td>Orange - all</td>
<td>After 2001 school extension</td>
</tr>
<tr>
<td></td>
<td>retrofitted-permanent bldgs</td>
<td>Yellow.1</td>
<td>2008</td>
</tr>
<tr>
<td>Veranda extension</td>
<td>Extension of overhang to</td>
<td>White.1</td>
<td>2012 – observed during inquiry</td>
</tr>
<tr>
<td></td>
<td>control light</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All classrooms had fixed projectors or interactive white boards (IWB) retrofitted, except Orange.6, which had had the IWB integrated into the transportable building design. Some classrooms showed evidence of extensive modification and rectification, including retrofitting of window film (Orange School) due to IWB installation. The fact that these were pursued, despite cost and changes to relatively new buildings, suggests that IWBs represent a significant change in pedagogy.

4.1.2. Observed temporary modifications to windows

It was noted that display of student work and pedagogical materials extended beyond the installed pin boards to windows, doors, walls, cupboards, luminaires, and catenary lines overhead. Use of external windows for display was prevalent in White School, Orange School and Red School. Internally, display
was observed in all schools on internal windows, door glazing and sidelights. In addition to display, it was observed that windows were obstructed with materials that were clearly not pedagogical. Glazing obstruction by furniture was also observed: in one Orange School classroom, tall cupboards and shelves were placed in front of windows, suggesting storage took precedent over natural daylight. Observed obstructions fell into five types (Table 4), with some providing dual purpose, such as both glare control and pedagogical display. The consequences of this range of obstruction was reduced daylight and, potentially, reduced solar gains in winter from windows to the north.

Table 4: Glazing obstruction typology (B=interior blinds, int=interior window)

<table>
<thead>
<tr>
<th>Type</th>
<th>Observed obstruction</th>
<th>Observed purpose</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glare control</td>
<td>Ad hoc internal blocking with plain cardboard, obstruction by furniture.</td>
<td>Enable use ICT. Improve lighting conditions.</td>
<td>Yellow.3; Orange.2, 3, 5, 5(B), 6 (B); White.1, 2, 3, 4, 5</td>
</tr>
<tr>
<td>Display in</td>
<td>Directional display facing into the room.</td>
<td>Extension of general display beyond pin boards</td>
<td>Yellow.2 (B, int); Orange.1, 2, 3, 4, 5(B), 6(B), 7; White.1, 2(B), 3(B), 5(B); Red.1(B, 4)</td>
</tr>
<tr>
<td>Display out</td>
<td>Directional display facing out of the room.</td>
<td>Identity and artwork displayed to students outside of class</td>
<td>Yellow.2(B, int); Orange.3, 4, 7(int); White.1, 2(B), 3(B), 4(B), 5(B); Red.1(B), 4(B)</td>
</tr>
<tr>
<td>Bi-directional display</td>
<td>No obvious direction; makes use of daylight</td>
<td>Exploration of translucent artefacts</td>
<td>Orange.3; White.2 (B)</td>
</tr>
<tr>
<td>Obstruct view</td>
<td>Restrict view in and out.</td>
<td>Reduce distractions or increase security</td>
<td>Orange.7 (int), White.1 – view to adjacent public footpath</td>
</tr>
</tbody>
</table>

4.2. Measured light levels

Measurements were taken over the full school year. A sample using the late spring and early summer conditions of Term 4 (October to December) was selected to demonstrate a range of illumination conditions (Figure 2). All logged illuminance levels tended to be lower than recorded lux meter measurements. This is consistent with the observed lighting variations, and with the fixed wall installation location and vertical orientation of the environmental loggers (positioned to avoid conflict with learning activities) as compared to results from a horizontal lux meter placed on desks.

The logged illuminance levels tended to have between 25 - 75% of measurements below 200 lux, i.e., only suitable for screen based tasks adjacent walls except White.1 (north windows and large south clerestories), Red.2 (large north glazing, north and east clerestories) and Red.4 (tall north windows without shade devices). Moving away from walls, illuminance measured by the hand held devices showed a large variation, with some classes measured at more than the 800 lux recommended for artificial lighting for art activities, as in Orange.4, Orange.7, White.1, Red.2, and Red.4. In between these extremes of uses, there was a variation of observed illuminance levels ranging between 200 and 800 lux. Orange School (except Orange.4 and Orange.7), showed the least variation, which is likely due to the glazing modification (film) and obstruction and the consequent reliance on artificial lighting.

Glare was observed in Red.5 during a visit in August, in the form of direct sunlight on desks and walls from a tall and narrow north window. This window had no exterior shade device in its original design and its heritage listing prevented retrofitting. Glare was also present in sections of White.2, White.3 and
White.4 where the clerestory and sharp rake of the ceiling geometry was observed to create a transition from well lit, over the interactive white boards, towards the darker northwest corner.

Figure 2: Term 4 measured illuminance – logged light data (box plots) and hand held measurements

4.3. User perspectives of windows

4.3.1 Perceived light quality

Staff and students were asked to quantitatively rate their perspectives of their classroom lighting on five point scales (Figure 3). Given that lighting can be designed for adaptation with relative ease, it was expected that responses should tend towards good ratings. Students perceived that their lighting was appropriate for learning with daylight more appropriate than artificial light. Staff agreed with students about all aspects of lighting, except for perceptions of artificial lighting, which they rated as significantly more suitable.

One-way ANOVAs by school showed that there were no significant differences between schools in the staff responses. In the student responses, Orange School students were significantly less satisfied ($M=3.26$) with the daylighting than Red Students ($M=4.17, F(3,140)=2.79 \ p=0.043$). The light measurements recorded show that Orange.5, and to a lesser extent, Orange.4 were lower than those taken in Red.4 and Red.5. This was consistent with the observed fenestration, use of blinds, and use of windows for display: Orange.5 had small windows with opaque blinds down often and Orange.4 had...
tinting on the glazing and was used for display, whereas little display was found on the large Red School windows and blinds were translucent. Thus, this lesser access to daylight within the classroom likely explained the lower satisfaction by Orange School students.

<table>
<thead>
<tr>
<th>Lighting suits activities: Rare</th>
<th>3.8</th>
<th>3.54</th>
<th>Lighting suits activities: Rare</th>
<th>3.79</th>
<th>2.81</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daylight suitable: Rare</td>
<td>2.76</td>
<td>3.23</td>
<td>Daylight suitable: Rare</td>
<td>3.35</td>
<td>3.84</td>
</tr>
<tr>
<td>Glare: Rare</td>
<td></td>
<td></td>
<td>Glare: Rare</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Art. light suitable: Rare(1)</td>
<td></td>
<td></td>
<td>Art. light suitable: Rare(1)</td>
<td></td>
<td>3.55</td>
</tr>
<tr>
<td>Nearly always</td>
<td></td>
<td></td>
<td>Good light control: Rare</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3: Students' and Staff classroom light perceptions – five-point scale, all schools collated

Yellow students (M=3.77) identified that there was more glare than the other schools (Orange, M=2.33; White, M=2.63; Red, M=2.96; \( F(3,139) = 7.59, p<0.0005 \)). Yellow.3 had large windows facing north, east and south. All windows had white translucent blinds, which were observed to be used in conjunction with artificial lighting. In contrast, Red.5 had a similar configuration, with large east-facing windows, yet returned a lower score for glare, possibly due to less glare through the smaller north glazing. Another possibility is that, unlike Red.5’s IWB’ Yellow.3 used an older style projector onto a whiteboard so any deficiency in projection power would be affected by 270-degree daylighting.

Participants were given the opportunity to make additional comments and just under a third of student respondents provided a comment (32%), with most received from White and Orange Schools, with a similar response from staff (36%). Most student comments revolved around problems with light quality (level, glare, preference, use of blinds), whereas staff commented most on control of lighting conditions. This suggested different levels of interaction with lighting components: White School students were troubled by light levels on interactive white boards, which was consistent with the observed over-lighting due to clerestories, while Orange School students in the transportable buildings had concerns about the low lighting levels and blinds being permanently down. This was consistent with the relatively smaller windows and observed window blind configuration and obstruction by furniture.

4.3.2. Dynamic display and windows as pin boards

Staff participants from all schools (N=42) confirmed that in addition to pin boards, doors, walls, windows and overhead display was used (Figure 4). Additionally, six staff participants reported using other locations for display: three identified that they use 'wires', 'ropes' and 'lines' across the room. Two used hallways, and one indicated that they used cupboards and trolleys. All of these suggested that the pin board space alone is insufficient. Furthermore, staff take the initiative to use all classroom elements available for personalisation regardless of the intended primary purpose of the element. The survey also included a question to ask why staff found windows were useful for display. Responses were collected from White, Orange, and Red Schools (93% response rate). There were four main reasons for use (right, Figure 4): communication to people beyond the classroom; the need for more display space; the nature of the display itself; and obstruction. This was consistent with observations (Table 4).
Orange and Red School staff confirmed that, in addition to space constraints, windows provided opportunities to explore transparent or translucent materials, which was also observed in White during site visits. Obstruction was described by White and Red School staff for three reasons – solar control, reduce distractions or a bad view, and privacy. This was consistent with the site plan of these schools since, both schools had east and west oriented glazing, and both were adjacent to passing public foot traffic. There was also concern about passing foot traffic since, paraphrasing an incidental conversation with a White staff member, the campus had public access on the weekend so there should be no sensitive display on the windows. Internal visual intrusion was also raised when one staff member obstructed an internal window to reduce a ‘feeling of being inside a fish bowl’.

Figure 4: Proportional display locations by school, left, reasons for window display, right.

5. Discussion

Overall, non-normative use of windows fell into overlapping categories: pedagogical and communication display, and visual obstruction of unwanted light and views. The widespread adjustment of building fabric for personalisation and temporary installations suggested that users feel free to make the building fabric work to aid their activities. Display on windows, such as extensive display obscuring the full glazing area, was particularly intriguing, since it contradicted the notion that windows were to provide daylight in and views out. Display facing outwards extended the class pedagogy into the wider spatial environment, and in some cases, into the public visual communication. Some windows, however, were not used for display: these coincided with those with internal blinds or deliberate obstruction. The buildings in this study were not approached as spatially privileged by their occupants. Rather, users had spatial agency to engage with their built environment (Awan et al., 2011) and they used this to adapt and redefine areas not normally associated with display, as being appropriate for pedagogical display.

One trigger for modification of windows was the introduction of interactive white boards and all schools showed evidence of fabric changes to cater to this new technology. Prior to the installation of interactive white boards in the late 2000s, all schools had had significant funds invested in them to bring them to a consistent and contemporary functional educational quality, including the older Red and Orange Schools. Where teaching might have been moving away from the teaching wall, the introduction of interactive white boards consolidated the teaching wall and this, in turn, required better daylight and glare control. For the newer buildings (White and Orange Schools), this timeframe of change is remarkably short. The installation of interactive white boards is an example of how ICT is influencing space use when it is retrofitted to the building fabric, and how it changed the programmed design. This had a trickle-on affect where lighting design, particularly daylight, became problematic and leading to permanent modifications to control daylight, such as verandah extensions, and is consistent with educational ICT changes observed in other countries (Cardellino and Leiringer, 2014).
This raises the question as to whether this lighting-needs singularity could have been predicted. Even relatively new building stock (less than 10 years old) was modified, suggesting that designers do not attempt to anticipate effects of major technology changes on teaching: however, this may be difficult to achieve. It has been argued by educational researchers that the ‘grammar of school’ is a century old (Hattie, 2009, p. 9), suggesting a relative stability of school taxonomy, yet four years is considered to be long term in technology (Martin et al., 2011) and classroom climate changes yearly (Hattie, 2009, p. 1). Thus, the occupation profile is unpredictable even in the short term, making robustness for, say, 30-year minimum building life, difficult to achieve. From the perspective of designers around the year 2000, it is unlikely that they would have been aware of the possibilities offered by interactive white boards.

Staff also showed that they were willing to reduce the daylight provided by available glazing. This is in contrast to design advice and with evidence of improved performance with large windows, but is consistent with qualitative analysis of conflicting lighting effects (Higgins et al., 2005). Rather than incorrect use, it could be interpreted that staff substituted daylight with opportunity, citing logical reasons such as communication, display space, display type, and view control, which suggested that glazing was considered a pedagogical tool. Yet, students also stated their preference for blinds to be raised. This suggested that the spatial agency is restricted to teaching staff: students, in this case 10-13 year olds, may not have the social power to adjust their lighting conditions.

6. Conclusion

Designers are implored to save energy and provide connections to the outside world through appropriate fenestration design. This paper reports findings about window use from a larger post occupancy evaluation of selected primary schools in South Australia. It proposes three drivers for lighting modifications by users. First, it has been shown that, regardless of age, continuous permanent modification of the building fabric occurred in the case study schools, and it has been proposed that this is because the teaching and learning needs changed from the original design. In this study, it was deduced that the technological innovation of interactive white boards changed lighting needs, resulting in permanent and temporary modifications to lighting design. Second, glazing was often obstructed to meet varied lighting needs, and survey responses confirmed that these ranged from the need to obstruct unwelcome views to glare control. In some cases, where illuminance levels were low due to obstruction, artificial lighting was not used to compensate. This suggests that lighting needs are more nuanced and variable than what is suggested by guidelines and standards. Finally, spatial agency was demonstrated through the opportunities found in classroom glazing. Beyond the functional, pedagogical display and communication provided a delightful transience and atmosphere within rooms. Windows were more art galleries than daylight sources, possibly making daylight and artificial light design assumptions void. Thus, the building team (architects, interior designers, and engineers), should be aware of this non-normative use and try ‘collaborating with entropy’ (Till, 2009, p. 106).

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References


Simple strategies for improving the thermal performance of the NSW demountable classroom in four climates

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Abstract: This paper provides an overview of the results of a project that explores strategies for improving the thermal performance of the New South Wales Demountable Classroom in the diverse climates that occur across New South Wales, Australia. The climates in NSW vary between cool or mild temperate climates, subtropical climates and hot dry desert climates. The demountable classroom is expected to provide comfortable teaching spaces in any of these climates. The NSW Demountable Classroom was designed 50 years ago and accounts for 12% of all government classrooms across the state. The thermal performance of existing classrooms is poor. The project uses a design led methodology to develop strategies that can be implemented by community groups to improve the performance of individual classrooms in particular locations. The strategies are evaluated using a computer simulation model. Predicted thermal comfort and annual energy consumption are used as the benchmarks for performance. The results illustrate that there are multiple strategies and combinations of strategies for improving the thermal performance of lightweight buildings in all of the diverse climates of NSW and Australia. The results also demonstrate that some of the orthodox conventions of bio-climatic design need more thorough interrogation.

Keywords: Demountable classrooms, lightweight buildings, computer simulation, thermal performance

1. Introduction

The New South Wales demountable classroom is a lightweight, modular, relocatable classroom system designed by the NSW Governments Architects Office in 1965 (Mk I) and an updated version designed in the late 1970’s (Mk II). This classroom system was created to allow the government to respond to the rapidly changing demographics of communities across the state as well as emergencies created by disasters such as bushfires, floods or arson. There are 6000 of these classrooms across the state, accounting for 12% of all classrooms in state government schools (NSW Government, 2014).

The original design brief led to the creation of a rapidly deployable and relocatable, robust and necessarily lightweight modular system that is expected to create appropriate teaching space in any of the state’s diverse climates. 50 years later the need for these classrooms remains and they continue to
provide the state government and communities across the state with vital teaching spaces. The “demountable” has become a “pejorative” and they are widely regarded as providing inferior teaching accommodation. Communities regard these buildings as obsolete due to their thermal performance and their appearance (Slee and Hyde, 2015b). A baseline study of the thermal performance of these classrooms and review of literature illustrated that the concerns about internal environmental quality (IEQ) in the classrooms and its detrimental effect on teaching and learning in the classrooms are well founded (Slee and Hyde, 2015a)

The way in which students are taught has also changed over the last 50 years and these buildings are thought by some to be unable to provide the flexible accommodation that is required by contemporary pedagogy. A review of the original drawings reveals that, in fact, these buildings were designed to be adaptable and flexible and that the prefabricated industrial nature of the system lends itself to continuous improvement and adaption (Slee and Hyde, 2015b).

This paper presents the initial results of an analysis of “Solution Sets” designed to allow communities to improve the environmental performance of the demountable classrooms in their schools. The paper models the performance of classrooms on four existing sites across the state representative of the diverse climates in which these classrooms are expected to operate. The climates are Broken Hill (BH) (dry desert), Canberra (CB) (cool temperate), Williamstown (WT) (warm temperate) and Coffs Harbour (CH) (sub tropical).

1.1 The existing situation

The original buildings, many now 50 years old, are still used. The modules are occasionally refurbished at Cessnock or Golburn jails by prisoners. This refurbishment process adds a further socially progressive rehabilitation dimension to these buildings. The opportunities for adaption and modification offered by the industrial modular construction system have been largely ignored with the exception of the addition of split cycle air-conditioning units in about 2003. A detailed physical survey of the buildings during refurbishment and subsequent thermal analysis reveals that what limited insulation is present is rendered redundant by the quantity of thermal bridging within the construction system (Slee and Hyde, 2015a).

The diverse climates across NSW share a common feature of high levels of solar radiation and warm to hot summers. Extremely lightweight buildings such as these tend to exacerbate rather than reduce the thermal fluctuations in their local external environments (Pearlmutter and Meir, 1995, Cardinale et al., 2010).

2. Methodology

Buildings are an intrinsically complex system and exist within other complex environmental and social systems. Therefore there can be no single optimal solution to the challenges raised by function, climate or social contexts and therefore no simple route to find “the solution”.

The problem of the performance of Demountable Classrooms across the State of New South Wales, understanding how their performance can be improved and why this may be important from an environmental, social and economic perspective requires an approach that is integrative, that does not seek to identify a single optimal answer but accepts, implicitly, that no single optimal solution can be found for a problem consisting of so many indeterminate and interrelated variables.
Simple strategies for improving the thermal performance of the NSW demountable classroom in four climates

The scientific paradigm, based on the fragmentation of the problem and the isolation of individual variables (Buchanan, 1992) is very appropriate for establishing deep knowledge around very specific criteria, but for problems with the technical, cultural, social and economic constraints, their applicability is limited. This paper adopts a design led methodology because it seeks to put things together, to integrate, rather than to fragment. The design methodology has the advantage that it is permissive and ecumenical. It understands the value sociological and scientific paradigms of thought can contribute to the search for solutions.

It is clear from literature (Hacker et al., 2008, Cardinale et al., 2010, Smith et al., 2012) (etc.) that many of the individual aspects of the problems and symptoms of problems with the demountable classroom have been explored and strategies for improving individual areas of performance tested. It is also clear that little work has been done to integrate these strategies and knowledge and evaluate them holistically as a larger system. This is the task of this paper. The process of developing the “solution sets” (Slee and Hyde, 2014) involves a qualitative assessment to work out whether or not they are practical before a quantitative assessment using a computer simulation model to simulate the classrooms and a series of modified classrooms (table 2) in the four climates.

2.1 A computer simulation model

Table 1: Simulation assumptions

<table>
<thead>
<tr>
<th>Climate data:</th>
<th>A climate file based on data collected at local airports and collated to create “a typical year” by exemplary energy (Exemplary Energy, 2014).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupancy:</td>
<td>A standard school day was devised from 9am - 3pm with the teacher and some students arriving at 8am and leaving at 6pm. 30 students and 1 teacher. Occupancy was modelled for a 7-day week through the whole year (365 days) to maximise useful data.</td>
</tr>
<tr>
<td>Thermostat settings</td>
<td>The NaTHERS thermostat settings (NatHERS, 2012) because they respond to local climate. Heating: 20 deg. C / Cooling (varies): BH – 26.5°C; CB – 24.0°C; WT – 25.0°C; CH – 25.0°C. Natural ventilation occurs between these temperatures and heating or cooling is active below or above the temperatures respectively.</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Ventilation is based on 8 l/s per person and calculated based on the occupancy schedule. When the building is operating in naturally ventilated mode the ventilation rate is calculated based on local conditions by the software.</td>
</tr>
</tbody>
</table>

This paper adopts the methodology described in a previous papers on the same project (Slee and Hyde, 2015a, Slee and Hyde, 2016) and uses the established thermal simulation software Design Builder (Energy Plus). A model of the demountable classrooms is created using detailed survey information from physical surveys of existing buildings and original drawings. This information is used to calculate the overall U-value of various elements of the building using Therm 7 (THERM 7.3, 2015). It is important to emphasise that the model is comparative rather than absolute and is used to indicate how the performance of the building changes over a whole year compared to a base model. The results are compared using a multi-parameter sensitivity analysis (Smith et al., 2012, Hacker et al., 2008). The key assumptions in the simulation model are outlined in table 2 above. The classrooms operate using a mixed mode strategy with split cycle air conditioning units used to cool or heat the air inside the
2.2 Evaluation criteria

The primary objective of the research is to develop proposals that will improve the thermal performance and consequential indoor environmental quality of the classrooms. The second objective is to reduce the annual energy consumption which is electrical and measured in kilowatt Hours (kWh). The Green Star Council target energy consumption for heating and cooling in classrooms is 26.8 kWh/m².year (GBCA, 2009) in NSW irrespective of the local climate. The MK I classrooms are 72.1 m² leading to a GBCA target of 1932 kWh/year.

In order to assess the thermal performance in the simulation model we have chosen to use the adaptive comfort model to predict comfort. Specifically we have used the daily running mean formula proposed by de Dear and Candido (de Dear and Candido, 2012) for naturally ventilated buildings in NSW.

The demountable classrooms operate in a mixed mode. Some may argue that the presence of the split cycle cooling system means that the adaptive model is not appropriate. We have chosen to use it because:

- The adaptive comfort method considers comfort in response to the local outdoor climate that the students and teacher as they experience move between classrooms and the outside.
- The ventilation to the classrooms is direct from the outside either through open windows or a mechanical fan in the wall. There is no air handling unit.
- the split cycle unit cools or heats the air in the classroom when it is too cold or too hot and so it can be considered to be an adaptive strategy (Nicol and Humphreys, 2002).

The two criteria used to assess the performance of the classrooms are:

1. The total annual energy consumption of the building
2. The number of “degree hours” above or below the comfort zone. (number of hours multiplied by number of degrees above or below comfort zone)

3. Solution sets

The synthesis of individual strategies to create a series of solution sets for quantitative assessment follows two stages

3.1. Defining the resources available: Implementation strategies

If the environmental performance of the NSW demountable classroom is to be improved, particularly the internal thermal environment and other IEQ factors is to be improved then the strategies that are proposed need to be founded in the practical reality of the social and economic systems in which these classrooms exist. There are three possible approaches (Slee and Hyde, 2016): (i)To replace all existing demountable classrooms with a new design: Replacing 6000 functioning classrooms is an unrealistic financial and environmental cost. (ii) “Deep” refurbishment and upgrade in ‘factory’ conditions at Golburn or Cessnock jails. This strategy will take too long or, if carried out rapidly, remove too many classrooms from use to be practical. (iii) On-site refurbishment. On site refurbishment presents its own challenges as well as a number of opportunities for the use of climate specific adaption, social
engagement and the development of practical education experiences that can be integrated into the school curriculum.

This paper proposes following the third strategy. Solution sets that fit with the overall resources available to a community led approach must be relatively low cost, simple to implement, use readily available building materials and not impede the relocation of the classroom.

3.2. Solution sets

A baseline study by the author (Slee and Hyde, 2015a) identified the lack of insulation and extremely lightweight construction combined with the high levels of incident solar radiation as the three primary problems. Hi-tech strategies such as vacuum insulating panels or phase change materials cannot be considered because they do not meet the criteria for simplicity, availability and cost set out above. Strategies that may be considered include:

Shading

Fly roofs have been shown to be effective (Cardinale et al., 2010) and used to be used on these buildings. Shading using trees either around the perimeter (Akbari et al., 1997) or from locating the building under larger local trees (Chagolla et al., 2012).

An alternative to physical shading may be the use of High-emissivity paints. These are now readily available and simple to apply. The paints reflect solar radiation thus minimising the absorption of thermal energy from the sun. The paints are also good at emitting far infrared radiation, i.e. thermal radiation, so they are able to help keep the roof cool by dissipating or emitting the thermal energy absorbed by the roof or wall surface (Akbari, 2003, Gentle et al., 2011).

Resistive Insulation

There is very little resistive (bulk) insulation in the existing classrooms. Li et al (Li et al., 2013) observes that resistive insulation tends to be more effective in heating dominated climates. Other studies suggest that resistive insulation is useful in warm climates but that its utility rapidly diminishes with quantity (Giovanardi et al., 2008) and may become counterproductive (Masoso and Grobler, 2008).

Thermal mass

Thermal is traditionally recommended for buildings in warm climates with high diurnal variations and high occupancy. Traditionally mass is introduced using concrete (or masonry) and is, by definition, heavy and so too much may make the relocation of the building modules difficult. Studies by Slee et al (Slee et al., 2014) show that relatively small amounts of thermal mass can make a significant difference to temperature fluctuations and that more mass may not be useful.

3.2 Creating and modelling solution sets

This paper explores the effect of introducing the strategies outlined above in various pragmatic combinations that fulfil the requirements for low cost simple strategies. The materials used are insulation using 40mm and 80mm PIR board, thermal mass using 6mm, 18mm and 36mm Fibre cement sheet, a fly roof and high-e paint. The combinations or “solution sets” are set out in table 2 below.
Figure 1: The design builder model with elements numbered to refer to elements in table 2 below.
(3) Structural steel frame; (4) windows.

Table 2: Construction and U-values

<table>
<thead>
<tr>
<th>Solution Set</th>
<th>Walls (1 &amp; 2)</th>
<th>U-value W/m².K</th>
<th>Roof (5)</th>
<th>U-value W/m².K</th>
</tr>
</thead>
<tbody>
<tr>
<td>MX 01 Base</td>
<td>Steel framed panels</td>
<td>(1) 1.04</td>
<td>Foil-faced blanket</td>
<td>1.25</td>
</tr>
<tr>
<td>MX 02</td>
<td>40mm PIR insulation board</td>
<td>(1) 0.32</td>
<td>40mm PIR insulation board</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>6mm Fibre-cement sheet</td>
<td>(2) 0.73</td>
<td>6mm Fibre-cement sheet Fixed to existing ceiling.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fixed to inside on walls.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MX 03</td>
<td>80mm PIR insulation board</td>
<td>(1) 0.20</td>
<td>80mm PIR insulation board</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>6mm Fibre-cement sheet</td>
<td>(2) 0.42</td>
<td>6mm Fibre-cement sheet Fixed to existing ceiling.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fixed to inside on walls.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MX 04</td>
<td>40mm PIR insulation board</td>
<td>(1) 0.32</td>
<td>40mm PIR insulation board</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>18mm Fibre-cement sheet</td>
<td>(2) 0.73</td>
<td>18mm Fibre-cement sheet Fixed to existing ceiling.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fixed to inside on walls.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MX 05</td>
<td>40mm PIR insulation board</td>
<td>(1) 0.31</td>
<td>40mm PIR insulation board</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>36mm Fibre-cement sheet</td>
<td>(2) 0.72</td>
<td>36mm Fibre-cement sheet Fixed to existing ceiling.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fixed to inside on walls.</td>
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</tr>
</tbody>
</table>

MX 10 series is as above with a fly roof (i.e. MX 11 is the base building with a fly roof). MX 20 series has a High-E paint on the outside of the walls and roof.

Floor (6) | MX 01 Base: Plywood floor. | U Value: 2.11 W/m².K |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Improved floor (all other floors: R2.5 insulation between existing steel joists. Fibre-cement soffit to the underside.)</td>
<td>U Value: 0.70 W/m².K</td>
</tr>
</tbody>
</table>

The modelling process followed a staged approach. The exiting situation (base case) was simulated (MX 01). In stage 2 insulation was introduced to the classroom building (MX 02 and 03) with a 6mm Fibre-cement sheet to protect the insulation. In stage 3 thermal mass was added to MX 02 by increasing the FC sheet, (total of 18 and then 36mm) (MX 04 and 05). Stage 4 applied a fly roof to the building and repeated stages 1 – 3 (MX 11 – 15). Using the knowledge gained in stages 1 - 4 in stage 5 a high-E paint was applied to all the external surfaces of the base case (MX 21) and the case with the most thermal mass (MX 25).

4. Results and Discussion

The results are illustrated in figures 2 and 3. Note that the scale of the graph for the number of degree-hours above the comfort zone in Broken Hill extends to 3000 and not the 1500 degree hours shown on the graphs for the other three climates.
Simple strategies for improving the thermal performance of the NSW demountable classroom in four climates

Figure 2: The impact on comfort (degree-hours) and energy consumption (kWh) of adding insulation to the classroom fabric. (BH – Broken Hill; CB – Canberra; WT – Williamstown; CH – Coffs Harbour)

Additional insulation

The first stage of the exercise introduced 40mm and then 80mm of insulation to the building system (MX 02 and 03) to the walls and ceiling. The floor was also insulated. The simulation results indicate that in all climates insulating the floor and adding 40mm of insulation significantly reduces discomfort in the classroom, particularly the problem of overheating. There is also a significant reduction in annual energy consumption. Increasing the insulation on the walls and ceiling to 80mm makes no additional impact on reducing discomfort or reducing annual energy consumption. It is for this reason that the in all the other solution sets insulation was maintained at 40mm (MX 02).

Thermal mass

The introduction of additional thermal mass (F/C sheet) causes a small but significant reduction in both - over-heating and under-heating (fig. 3).

Fly roof and High-E paint

The introduction of the fly roof has the most dramatic effect on the comfort of people in the building and the annual energy consumption. The use of a high-e paint has a very similar effect. Both strategies significantly reduce the impact of solar radiation on the thermal performance of the building.

Overview

Overall the pattern of performance is the same across all of the four climates simulated even though they range from the famously benign climate of Coffs Harbour to the famously extreme desert climate of Broken Hill.
Figure 3: The impact on comfort (degree-hours) and energy consumption (kWh) of different solution sets in the four climates simulated.
The use of a fly roof or High-E coating is the most effective intervention, particularly given the ease of painting a classroom building or re-establishing the use of the fly roofs that exist but are no longer installed. The installation of insulation has almost the same impact on comfort and a greater impact on energy consumption compared to the fly roof in all climates except Coffs Harbour where comfort and energy consumption are improved if there is no fly roof but if there is a fly roof there is a slight reduction in performance. Additional thermal mass causes improvement or no significant change in all scenarios.

A second surprising observation is that while the introduction of thermal mass has a modest effect on improving comfort in all climates it only reduces energy consumption in the two more moderate climates of Williamstown and Coffs Harbour. In the two more extreme climates with higher diurnal temperature ranges where traditionally the use of thermal mass would be expected to be a more significant or effective strategy the effect on energy consumption is minimal, the effect on comfort is modest.

**Conclusion**

A series of simple, pragmatic and economic strategies for improving the thermal performance and consequential thermal comfort of the classroom users have been simulated using a detailed computer simulation model in four diverse climates from across NSW. The results were compared using a simple sensitivity analysis. The strategies were (i) Increasing the insulation levels, (ii) introducing thermal mass and insulation, (iii) reducing the impact of solar radiation on the building fabric. Overall the pattern of improvement in comfort and energy consumption is the same in all four climates despite the range of conditions that occur in those climates. Each of the strategies causes an improvement in comfort and energy consumption in each of the four climates. The two most effective solution sets are the introduction of insulation and strategies that reduce external solar gain on the building fabric (Fly roof or high-E paint). The introduction of thermal mass leads to further improvements in comfort and, particularly in the more moderate climates, additional reduction in annual energy consumption. The combination of all three strategies (MX 15 and 25) is overall the most effective but not always by a significant margin. The results illustrate that there are multiple strategies and combinations of strategies for improving the thermal performance of lightweight buildings in all of the diverse climates of NSW and Australia. The results challenge some of the assumptions in design guidance commonly used by practitioners (eg. www.yourhome.gov.au) (Hollo, 1986) and suggests that the orthodox conventions of bio-climatic design need more thorough interrogation.

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Evolution of buildings in four tropical regions with regards to thermal comfort

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Abstract: Recent climate projections suggest that tropical regions are very likely to warm more than the average global temperature rise. For the 40% of the world’s population in these regions, it is imperative the building industries come up with appropriate building design solutions for achieving thermal comfort. This study draws on the history of architecture, and the remarkable indigenous building techniques, which if properly adapted could make a great contribution to energy conservation and thermal comfort. This study conducts a review of the building morphology in four tropical regions (the Middle East, Africa, the Caribbean and the Pacific Islands). It includes a review of spatial composition, building techniques, forms and materials based on information ranging from early explorers to recent literature. Despite the diversity in continents, creeds, and cultures within the tropics, each region appears to have come independently to similar solutions in their struggle with similar environmental challenges whilst establishing basic regional characteristics. The paper concludes by adapting selected indigenous building solutions for improving thermal comfort in the tropical regions.

Keywords: Tropical regions, Traditional and contemporary architecture, Thermal comfort

1. Introduction

The first consideration when addressing the architecture of the tropics is the climate and the prevailing conditions that define the habitation in the region. The tropical climate zone is characterized by the tropical rainforest, tropical monsoon and tropical wet and dry savannah. According to the Koppen-Geiger climate classification, it is a region with a relatively constant temperature of 18°C and above throughout the year with seasonal variations dominated by rainfall (Linacre, 1997). The building response to thermal comfort within the tropics has evolved over time from the primitive era of natural conditioning to the present day reliance on mechanical cooling systems. According to Fitch and Branch (1960) primitive architecture revealed a commendable level of performance when judged in the light of modern building technologies. However, traditional methods and materials had disadvantages such as low durability, poor technology and fire risk in terms of their thatched roofs and wooden structures (Mariarty, 1976), but were particularly successful in the terms of energy conservation and thermal regulation. While traditional methods and materials are much better suited to the tropical climate than contemporary methods and materials their durability needs to be enhanced. The comparative study presented below will review the
architectural dynamics in the tropics, provide an insight into the thermal adaptation techniques from both eras, and recommend potential building design solutions. In order to achieve this goal, the general components, structure and methods in four tropical regions are analysed to provide an insight into the building morphology of the sub-groups. The main purpose of this is to provide an explicit understanding of the similarities that exists within the different tropical regions and the factors that influenced them, including religious, colonial, socio-cultural and physiographical influences; and to better understand their transfiguration and applicability in modern tropical architecture over the course of time. Reference will also be made to hybrid modern buildings within the tropics that have adapted traditional methods. This analysis will enable some implications to be drawn and recommendations made for optimal use of relevant thermally responsive traditional methods in modern buildings.

2. The Middle East

Islam has always had a profound influence on the architectural morphology of the Middle East. The traditional Islamic-Arab house had every form and space shaped by the people’s habits and tradition. The spatial composition was strictly defined by the particular role of men and women, with the public areas like the courtyard or sahn a domain for men and the private and family areas for women (El-Shorbagy, 2010). The symbolic religious and cultural emphasis on visual privacy was an essential element that influenced the building morphology and how it adapted to the hot-arid conditions. The building configuration had an inward-oriented composition with the courtyard as the focal point and plain external walls to prevent people from looking inside, however the courtyard provided natural ventilation and lighting into the building (see Figure 1). The resultant climate moderated and complemented the religious need for privacy (Bekleyen, 2011). These religious principles also governed the way of life and affected the built form in other tropical regions like Africa (Nigeria, Chad, Tunisia, Morocco, etc.) where Islam is practised.

2.1. The spatial composition

The advent of Islam found the sahn or courtyard concept an appropriate fit for its religious and social demands of privacy as well as providing a satisfactory response to the climate challenges of the hot and dry climate of the tropical region (El-Shorbagy, 2010). The spatial composition with the courtyard as the focal point permitted a layout that reduced the area of peripheral surface exposed to solar radiation with the circulation space from the majaz (entrance) shaded from the sunlight. The rectangular area (courtyard) is thus open to the sky, providing sufficient lighting and ventilation to the interior space as well as create a pattern of light and shade (Omidreza, 2012). A large number of courtyard houses are still in existence in the older districts of Cairo and in most regions within the tropics.
Evolution of buildings in four tropical regions with regards to thermal comfort

2.2. The building technique

The malkaf or windcatcher is an ancient architectural structure like a shaft rising above the building or in some cases mounted on the roof of the building (see Figure 2) with directional openings facing the prevailing wind often in combination with water containers for evaporative cooling as the air comes into the interior spaces (El-Shorbagy, 2010; Sulaiman, 2012). It traps the fresh air from outside and channels it down into the interior of the building. They were design and constructed to adapt to the local wind direction. The hot air escaping from the interior spaces was replaced by fresh air coming through the malkaf thus creating air movement regardless of the external air speed. In addition, the malkaf towering over the building served as a visual screening device preventing people outside from viewing into the building (Scudo, 1988). This cognitive mode of cooling was based on a deep pre-scientific understanding of the air movement by stack effect and by wind.

Figure 1: A general scheme of the courtyard thermal behaviour (Author, 2016).

Figure 2: The Malkaf or Windcatcher system shown for wind direction from left to right adapted from (El-Shorbagy, 2010).
The salsabil, usually situated in the middle of the courtyard, was an early exemplar of what is referred to in contemporary times as the fountain (Fathy, 1972). The salsabil basin depicted a geometrical projection of a dome supported by squishes. It is important to point out the relationship between the fountain and courtyard. The entire rhythm according to Gianni (1988) was a microcosm linking, in space and time, land and sky through the symbolic representation of each component. The courtyard open to the sky is drawn down into intimate contact with the interior spaces by reflecting it in a basin. Thus nature and space are brought into the house by their transposition into architectural forms and through symbolism (Scudo, 1988). The fountain not only served as a symbolic representation of culture and religion but also functioned as an evaporative cooler during the day when solar radiation was profuse. The Islamic-Arab culture disseminated this complex knowledge throughout the regions of Islam.

3. Africa

The complexity shrouding African architecture is due to the enormous variety of climates and environments that influenced building culture and settlement patterns all over the region (Elleh, 1997). This heterogeneity makes it impossible to speak of a typical African architecture. Even so, locally sourced natural building materials and typologies are ubiquitous in the region. Folkers (2010) provides a cour and case illustration to describe the typology – the cour served as the heart of the compound with the cases as the independent structures peripheral to the cour. The regional building culture is tailored to the environment in ingenious ways, as a result of the distribution of natural building materials and climate (Folkers, 2010). The morphology was a manifestation of spiritual beliefs, a balance with nature, and a cognizance of community inclusion and centrality.

3.1. The building form

The spatial composition of the African house was a reflection of spiritual beliefs, community and family life. This was made possible by integrating family assemblies and worship spaces, as well as sacred spaces apportioned for deities. In most part of western Africa the shrines were open to the central courtyard, with the sidewalls open to enhance visibility of the figurine (Denyer, 1978). The taxonomy of house forms included round, oval and rectangular plans, free standing with diameters greater or equal to height, often with verandas, and with building units arranged in clusters around the courtyard. The courtyard offered a wealth of opportunity for seasonal and daily migration with the shady recesses serving as buffer zones (DeKay, 2014). Folkers (2010) described the African house as organic and cosmogonic, designed to accommodate the time cycle of generations all tied to the cour also known as the courtyard (see Figure 5). The emphasis on fortification and protection inevitably also had an effect of the spatial composition. A paradigm is the Kasbah, the thick walls of which evolved out of defensive necessity, and insulated the interior from excessive thermal variations (Elleh, 1997).

3.2. The building techniques and materials

Climatic conditions stimulated two basic necessities: thermal insulation and ventilation, each of which was met by judicious selection of locally available natural materials. In most parts of equatorial Africa, the thick-walled timber and mud houses were predominant. This technique produced a cage-like structure, expanding as it sets and strengthening the structure (Beswick, 2010).

Indigenous builders developed ingenious ways of shading parts of the building façade whilst simultaneously increasing the radiation of heat stored by the walls during the day. In most part of Africa,
very thick thatched roofs were used to insulate the internal space from solar radiation. Ventilation was provided by the erection of lattice like walls enabling air movement through the interior (Dmochowski, 1988). In northern Africa, the tent was preeminent due to its functionality and practical adaptation to the climate and nomadism, however as nomadism died out, there was a need for more permanent structures. As a result of these changes, the Kasbah an indigenous housing style in northern Africa was developed during the mid-7th centuries. This was made of stone or earth (clay) with the interiors well furnished with glazed stones and tiles (Elleh, 1997). The thick stone walls provided the desirable time-lag effect in response to the low nocturnal temperatures. In the tropical rainforest regions, houses were built of indigenous bamboo and decorative tied mats which were used for the roofs, doors and walls. This system was an adaptation to the constant rainfall of over 2500mm/year (Denyer, 1978). The bamboo provided insulation to heat gain, whilst aiding airflow due to its porous nature.

4. The Caribbean

In the Caribbean, architectural innovation was influenced by tradition, the availability of building materials and the climate. The region had a particularly rich blend of West African, North and South American, European and indigenous Antillian heritage (Edwards, 1983).

4.1. Early building materials and techniques

The earliest dwellings in the Caribbean were the huts of the Amerindians also known as the bohio, a rudimentary structure made of posts, with either open woven walls or walls made of straight sticks or reeds, interwoven together between the posts which was beneficial for thermal comfort. They were generally round in plan, though occasionally oval and without foundations or proper floors. The roofs were conical and made from palm frond thatch or reeds. The early huts were naturally conditioned from the fierce solar radiation and provided protection from the wind. They were quick and easy to erect and compatible with the climate and nomadic culture of the tribes (Gravette, 2000).

4.2. Evolved building forms and techniques

Early colonial structures were built of wattle and daub and palm thatched during the early sugar-slave trade period. Later, the chattel house was introduced in a linear house form, based directly on its African antecedent (Edwards, 1983). They were either square or oblong in plan and connected in multiple units built symmetrically of timber clapboards on a coral rock base, with a ridged or hipped roof - the gables allowed ventilation through louvers. They were simple to build and easy to move when a worker changed employer. European influence brought a transition from the medieval huts to cabins. These cabins were made of timber frames with masonry filling, lime concrete floors and corrugated iron roofing sheets (zinc). The whole structure was often raised from the ground to allow air circulation, which both cooled the house and protected the wood from insects (see Figure 3). Wherever possible, the houses incorporated a veranda to provide shade and cool air circulation for thermal comfort. Other passive cooling methods prominent in Spanish colonies included the cooler window (see Figure 4). This was an exemplary ventilation method for it had a sash window with louvers at each side of the wooden diagonal-work ‘ventilator’ (Buisseret, 1980).
5. The Pacific Islands

Despite distinct regional practices in the design and construction of vernacular buildings in the Pacific Islands, a tradition of minimalist building construction comprised primarily of locally sourced vegetative materials is the most common. Unlike some other tropical regions where resistance to heat flow was of primary concern, buildings in the Pacific Islands were an adaptation to earthquakes and tropical cyclones that occurred frequently (Taylor, 2014).

5.1. The Building techniques and materials

Possibly the most important priority of settlements was their resilience. In Fiji, Samoa and Tonga, the traditional buildings (bure and fale) had a number of wind and thermal resistance characteristics. The houses were built of palm thatch with relatively steep hipped roofs, well interwoven (using significant amounts of sennit) with no windows and few doors. The porosity of the building materials prevented excessive heat build-up within the interior spaces. In Samoa, the fale was a frame structure with no walls
and the wind could simply blow through the structure; mat walls were lowered down to seal the building when required (Campbell, 2009). Across the islands architectural spaces were typically organized in a regular compound system consisting of single cell huts (bure and fale) associated with open spaces (courtyards) for daily living and ceremonial activities (Austin, 2001).

### 6. Observation

A number of common features have been found in the different tropical regions. These features are independent of location, social organisation or religious affiliation. Though each tropical region is unique, they are all inextricably linked through shared patterns of climatic adaptations and by surprisingly specific but similar cultural forms and colonial influences that have evolved and diffused to meet their shared requirements. Building construction is determined by the distribution of naturally available building materials, one exemplar being palm thatch which is available and readily used in most tropical regions. Table 1 provides a summary of building evolution in the four tropical regions, highlighting the common features of traditional building and their modern adaptions. These modern adaptations provide the recommended design methods and materials for tropical regions. One typical modern adaptation as shown in Table 1 is the windcatcher system – combining the concept of passive design and availability of high-tech controls, the contemporary windcatcher (monodraught) transcends conventional borders. The monodraught is designed in an aerodynamic form with the ability to convert the absorbed the wind power into electricity (Omidreza, 2012). In some case, the modern adaptation provides good durability as well as thermal comfort - an example is the thatch and aluminium roofing system, the aluminium roof had better longevity and provided good insulation through its reflective surfaces (Amasuomo, 2016; Givoni, 1976; Mariarty, 1976).

Figure 5: An adapted image showing the evolution from the compound to compact housing system adapted from (Mumagi, 2004)
<table>
<thead>
<tr>
<th>Building form, techniques and materials</th>
<th>Regions</th>
<th>Influences</th>
<th>Thermal benefits</th>
<th>Recommendation/Modern adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Courtyard compound housing system</td>
<td>Middle East, Caribbean, Africa and Pacific island</td>
<td>Religious and cultural influence; Middle east and African heritage</td>
<td>Enhances the airflow through the open layout into the building. Adaptive space migration, aids air circulation.</td>
<td>Atrium, courtyard</td>
</tr>
<tr>
<td>Veranda</td>
<td>Middle East, Caribbean, Africa and Pacific island</td>
<td>Response to climate and culture</td>
<td>Openings to the circulation and transitional spaces enhancing the airflow through the courtyards into the rooms</td>
<td>Veranda, Lobby</td>
</tr>
<tr>
<td>Windcatcher</td>
<td>Middle East</td>
<td>Arab-Islamic influence</td>
<td>Increases natural ventilation</td>
<td>Monodraught, modern windcatcher, chimney/exhaust cowls/roof vents</td>
</tr>
<tr>
<td>Evaporative cooling</td>
<td>Middle East</td>
<td>Climatic influence; Arab-Islamic influence</td>
<td>Ventilation air; In hot regions, the higher humidity is beneficial</td>
<td>Indirect evaporative cooler, evaporative pre-cooling</td>
</tr>
<tr>
<td>Mud architecture</td>
<td>Middle East and Africa</td>
<td>Availability of local material and response to climate</td>
<td>Low thermal capacity; holds little heat and cools easily at night. Thermal insulation, time lag effect</td>
<td>Reinforced and stabilized adobe bricks, clay/mud hybrid composition</td>
</tr>
<tr>
<td>Brick and stone</td>
<td>Middle East, Caribbean, Africa and Pacific island</td>
<td>Response to climate and colonial influence</td>
<td></td>
<td>Concrete hollow blocks, adobe brick, pre-cast concrete walls, veneer stones</td>
</tr>
<tr>
<td>Wood, reeds, sticks and bamboo</td>
<td>Caribbean, Africa and Pacific island</td>
<td>Availability of local material and response to climate</td>
<td>Thermal insulation, improves airflow</td>
<td>Wood, bamboo</td>
</tr>
<tr>
<td>Thatch roof system</td>
<td>Caribbean, Africa and Pacific island</td>
<td>Availability of local material and response to climate</td>
<td>Pores in roofs improve airflow, thermal insulation</td>
<td>Aluminium roofing sheets, roof tiles, roof vents</td>
</tr>
<tr>
<td>Window louvers and shutters</td>
<td>Middle East, Caribbean, Africa and Pacific island</td>
<td>Colonial influence</td>
<td>Increases natural ventilation by directing the airflow</td>
<td>Wing walls, window louver blades, shutter windows</td>
</tr>
<tr>
<td>Cooler windows</td>
<td>Caribbean</td>
<td>Colonial influence</td>
<td>Increases natural ventilation and airflow</td>
<td>Wing walls, top hung windows</td>
</tr>
</tbody>
</table>
7. Conclusion

A close correspondence between architectural features and certain climate zones has been demonstrated. Despite the contrasting physiography, there is a remarkable similarity in the building morphology across the tropical regions. It is evident that this was not only a response to similar climatic challenges, but most importantly the availability of local building materials as can be seen in the use of thatch across the region (see Table 1). The mix of indigenous cultures (which were surprisingly similar in most tropical regions), religion and colonial influences dictated the attention given to various aspects of life and the way they addressed thermal comfort. One of the advantages of traditional building techniques and forms was their flexibility and natural conditioning capacities. To fossilize traditional patterns for contemporary times would be inappropriate, given current housing requirements, as would a disregard for traditional building techniques. Our understanding of tropical architecture through the variety of its morphology, building techniques, materials and settlement types has been greatly limited by the dearth of studies of their performance. Currently there is no well-documented design framework for the tropics, and the best way through which this can be achieved is by an adaptation of the traditional passive mechanism of indoor thermal regulation. It is hoped that the summary provided on (Table 1) will prompt further investigation of how these mechanisms could be adapted.

References


Adaptive behaviours to achieve thermal comfort in low energy dwellings in Australia

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Abstract: Internationally and locally, there is increasing interest in the application of adaptive models of thermal comfort in the assessment of residential thermal environments. Central to these models of thermal comfort is the relationship between occupants’ recent thermal history and their use of adaptive controls such as clothing arrangement, window and fan operation, etc. However, existing adaptive models included within the widely used Standards, ASHRAE 55 (2013) and EN 15251 (2007), are predominantly based on observations from non-residential buildings. The aim of this research is to contribute to an evidence base establishing the suitability (or otherwise) of the use of an adaptive model in residential building performance assessment. A longitudinal thermal comfort vote survey of 40 ‘low energy’ households (20 in a cool temperate climate and 20 in a hot humid climate) reveals a wide range of behavioural strategies used by the occupants to adapt to and modify their thermal environment for comfort. The findings presented in this paper support the development of an adaptive model of thermal comfort for residential building performance assessment in Australia.

Keywords: Thermal comfort; adaptive; residential; occupant behaviour.

1. Introduction

Worldwide, thermal comfort models are used to assess the thermal environments of buildings in both design (predicted/simulated) and operational (measured) phases. The current predominant models are either based on steady-state climate chamber observations (e.g. ISO Standard 7730: 2005) or field study observations from mainly commercial buildings (i.e. adaptive models in ASHRAE Standard 55: 2013 or EN Standard 15251: 2007). The appropriateness of these models for application in residential contexts is yet to be extensively tested, particularly within Australia. There is, however, a general consensus that an adaptive model of thermal comfort is likely to be the most suitable as it has a greater capacity to reflect the wide range of strategies use by people within their own homes to modify the thermal environment.

Traditionally, field studies in residential buildings have been difficult to conduct due to privacy of the householders, expense and power consumption of monitoring equipment, and the influence of socio-cultural and economic factors on occupants’ thermal behaviour, preferences and expectations. Recently,
advances in monitoring equipment have made longitudinal thermal comfort studies more feasible (e.g. Cândido et al., 2016; Daniel et al., 2015b). Combined with growing interest in residential thermal environments, this has contributed to a gradual increase in residential field studies both locally and internationally (Kim et al., 2016).

This paper explores the adaptive behaviours of two cohorts of occupants living in atypical or ‘low energy’ dwellings; 20 in a north-east suburb of Melbourne, Victoria, and 20 in Darwin, the Northern Territory. The results are presented in a similar format to other recent Australian residential field surveys (i.e. Kim et al., 2016 & Saman et al., 2013). The aim of this paper is to begin to establish a dialogue between Australian, and indeed international, researchers to form an evidence base from which a model for thermal comfort specific to Australian residential buildings can be developed. It is expected that such a standard could be used in mandatory building performance assessment, e.g. currently expressed as the Nationwide House Energy Rating Scheme (NatHERS) using the AccuRate simulation software.

2. Methods

A longitudinal thermal comfort field study was conducted in 40 households for a period of about 12 months in 2013 to 2014. Twenty households were located in Nillumbik Shire, a north-eastern suburb of Melbourne, Victoria, and 20 households were located in or close to Darwin, the Northern Territory. The Melbourne households all incorporated earth wall construction, while the Darwin households were operated as partially or solely naturally ventilated. These households have previously been established ‘low energy’ forms of housing (e.g. Daniel et al., 2015a). The comfort study was part of a larger investigation of the thermal expectations, behaviours and preferences of the occupants. Within the broader research project, the methodological approach of ‘extreme case analysis’ was used in order to investigate the extent of thermal performance related behaviour, preferences and expectations within Australian residential buildings.

Occupants of the case study houses (>18 years old) were asked to complete a paper based comfort vote survey on a daily basis. Three widely used subjective measures of thermal comfort were included; thermal sensation (7-point scale), thermal preference vote (3-point scale) and thermal comfort vote (6-point scale). Householders were also asked to report their clothing insulation, activity level, and their operation of windows, fans and heating and/or cooling appliances. Prior to the survey, an interview was conducted with all available members in the household that sought to gather detailed information on various aspects of their operation of the dwelling (e.g. heating and cooling practices).

Indoor environmental conditions were measured using HOBO U12-013 data loggers that recorded temperature, relative humidity and globe temperature measurements at 30 minute intervals. Two were located in each dwelling: one in the main living area and one in either the main bedroom or a secondary living area. External meteorological measurements were recorded every 30 minutes in proximity to the Melbourne households using a HOBO U30 weather station, whilst meteorological measurements for Darwin were obtained from the Bureau of Meteorology (BOM) climate data service for the Darwin Airport weather station (Station number 014015). In general, the data collection met the requirements of a Class II field survey (ASHRAE Standard 55: 2013). The internal and external environmental data were matched to the corresponding thermal comfort vote surveys and analysed using Microsoft Excel and IBM SPSS Statistics 23.
3. Results & Discussion

3.1. Household characteristics

Nineteen of the 20 Melbourne households participated in the semi-structured interview. The single house that did not was located on the same property as another case study dwelling where responses to the interview broadly reflected conditions within the other dwelling. All of the Darwin households participated in the interview.

The average occupancy rate for the Melbourne cohort was 2.3 persons per dwelling (SD 0.8); while for the Darwin cohort it was higher at 2.9 persons per dwelling (SD 1.4). The Melbourne households were mostly older couples and the Darwin households largely made up of families with young children. The average age of the Melbourne dwellings was 32.1 years old (SD 15.4), ranging from eight to 64 years old. Ten of the Darwin houses were pre-cyclone Tracey (1974), while the average age of the other Darwin dwellings was 20.3 years old (SD 12.1), ranging from three to 38 years old. All of the Melbourne participants owned their dwellings. Two of the Darwin households were renting their homes, while the remainder were owned by the participants. The majority of households had lived in their current home for at least three years. For both cohorts the most common setting was suburban with close neighbours, although in many cases the block sizes allowed for significant vegetation surrounding the house. All of the Melbourne dwellings were separate houses, although three had multiple dwellings on the same property that shared electricity/gas and water meters. Eighteen of the 20 Darwin houses were separate houses; one was a unit and one a townhouse. The majority of the Melbourne houses were single storey, while the majority of the Darwin houses were two storey or ‘high-set’ elevated houses. All of the Melbourne houses incorporated some form of earth wall construction; either using traditional puddled mud bricks or pressed earth blocks. Many also incorporated recycled timber as structural elements within the building (e.g. wharf pylons, railway timbers). Almost all of the Melbourne houses had concrete slab-on-ground or masonry floor construction. All of the single story houses in Darwin, except one, incorporated heavyweight construction (i.e. brick or blockwork walls). The two story or high-set houses were predominantly lightweight construction (i.e. stud walls with steel or timber cladding, with some use of heavyweight materials in the construction of the ground floor walls. Floors of the single story houses were predominantly concrete-slab-on-ground, while upper floors often incorporated some form of timber construction.

3.2. Interaction and perspectives of local climate

During the interviews, householder were asked about their perception of the local climate at different times of the day and year (i.e. summer and winter/wet, dry and build-up seasons, and daytime and nighttime). Melbourne’s climate can be broadly classified as a cool temperate with four typical seasons, whilst Darwin has a hot humid climate with distinct dry and wet seasons, and a ‘build-up’ period in between that is characterised by high temperatures and humidity with little to no rainfall. Overall, both cohorts responded positively, the Melbourne cohort giving an average rating of 5.8 (SD 1.6) on a 7-point Likert scale (where 1= “Dislike very much” and 7= “Like very much”) and the Darwin cohort giving an average rating of 6.4 (SD 1.3). Whilst their responses were largely positive, some of the Melbourne households did express concern about the increasing likelihood of hot weather and bushfires (note that the interviews were conducted in March 2013 just after Melbourne had experienced a record breaking 10-day heatwave). The Darwin cohort were also largely positive, however most reported some
discomfort during the build-up. Figure 1 shows the mean monthly minimum and maximum temperatures for the two locations during the monitoring period.

Throughout the interviews it became apparent that the occupants from both cohorts, but particularly the Darwin households, desired a ‘thermal connection’ with the outdoor environment. In fact, 14 of the 20 interviews with Darwin households were conducted outside, clearly demonstrating the occupants’ preference and acceptance of the local climate. The following excerpt from a Darwin participant gives some insight into these attitudes:

90% of the time the tropical design and tropical living provides a pleasant and comfortable way to enjoy the climate. If the house was not ‘tropical’ i.e. built to 'southern energy efficient standards' i.e. close everything up and crank up the AC- not only would it be very expensive and energy inefficient but it would also be impossible to get any enjoyment from the tropical climate. (Darwin participant, 2014)

The way in which this interaction effects the households’ operation of their dwellings is explored in the following sections.

![Figure 1: Outdoor minimum/maximum temperature (monthly average) of Melbourne and Darwin during the monitoring period (data from Australian Bureau of Meteorology)](image)

3.3. Reported adaptive behaviours

This section reports on the cohorts’ heating and cooling practices as discussed during the interviews.

3.3.1. Melbourne cohort’s response to hot & cold conditions

The Melbourne cohort’s response to cold conditions within their homes was primarily to change clothes (15) or to turn a heating appliance on (14). Of the responses to “Other”, two either consumed warm beverages or food, or used their oven for cooking to warm the kitchen, one used a blanket and one suggested that they simply acclimatise to the cool conditions (results not shown due to small number of
variables i.e. adaptive strategies). The entire Melbourne cohort had some kind of space heating in their homes. Gas space heaters (10), slow combustion stoves (10), reverse cycle (7) and open fires (6) were most common, while responses to “Other” include three oil heaters, one hydronic in floor system and one wall furnace heater. Heating was primarily used in the living areas in the afternoons and evenings until bedtime. On average, the households estimated that they use their heaters for 136 days of the year (SD 60.5) and were generally satisfied with the performance of their heating appliances.

When discussing cooling strategies many of the participants repeatedly commented that air-conditioning was only needed when conditions in the house became uncomfortable after prolonged periods of hot weather. Instead, occupants reported that opening windows for ventilation and changing clothes were the primary behavioural means for adapting to warm conditions (see Figure 2). Again, one occupant commented that their response to hot conditions was simply ‘acceptance’. Thirteen of the Melbourne households had either portable fans or ceiling fans for cooling, while 11 had some kind of cooling appliance. Of those that did not have cooling, only two households perceived a future need to install an air-conditioner, citing the increasing likelihood of heatwaves. Air-conditioning was primarily installed in the living areas and in the main bedroom, and used in the afternoons and evenings until bedtime. The average estimation of days per year that air-conditioning was used was 12.9 cooling days per annum (SD 9.7), ranging from just 1 to 30. All of the households with air-conditioning were satisfied with its performance.

![Figure 2: Common responses to hot conditions within the Melbourne households](image)

### 3.3.2. Darwin cohort’s response to hot conditions

The occupants of the Darwin households had many different ways to deal with hot conditions (see Figure 3), including taking a swim (13) and turning on the fans (12). The number of households who nominated “Turning on A/C” (4) was relatively small. The responses to “Other” include; resting in the coolest part of the house (5), wetting clothes or skin (3), leaving the house during hottest conditions (2),
staying hydrated (2), accepting the hot conditions (1), and modifying behaviour so they do not become too hot (1). During the interviews, one of the occupants claimed that, in Darwin, it is necessary to have either an air-conditioning or a swimming pool. Nine of the houses had swimming pools, which were frequently used to lower body temperature during the hottest parts of the day or before bedtime. Almost all (16) of the households reported that opening their windows and doors allowed for sufficient natural ventilation.

All of the Darwin households had either portable fans or ceiling fans within their homes. Additionally, 15 also had some kind of air-conditioning appliance. None of the households without air-conditioning perceived a need to install one; instead some of the occupants cited alternative methods to cool down, with one also stating that their house was not designed for air-conditioning.

Air-conditioning was mostly used in the bedroom(s) in the afternoons and evenings when conditions where uncomfortable, particularly during the build-up season, however, generally the households reported infrequent use. Some households went further and sought to clarify their operation of air-conditioning by specifying a time limit or time frame (6), usage in certain seasons (5), or specific social circumstances e.g. visitors (3), displaying a general reticence towards the operation of air-conditioning. The average estimation of days per year that air-conditioning was used was 81.1 cooling days per annum (SD 88.9), ranging from 2 to 240. All of the households were satisfied with the performance of their air-conditioning appliances.

The behaviours of both the Melbourne and Darwin cohorts in response to warm or hot conditions (Figure 2 and Figure 3) share similarities with those reported by occupants in Adelaide and Sydney houses (see Figures 3.6 & 3.7 in Saman et al, 2013). Many of the strategies are the same (e.g. open windows, change clothes, turn on fans), though the order in which they are prioritised are quite different. This comparison is important because it demonstrates that occupants across various different housing types and climates in Australia are all using adaptive strategies in some manner to modify their thermal environment.
3.4. Observed adaptive behaviours

The following section demonstrates the Melbourne and Darwin cohorts’ use of adaptive strategies through the analysis of the thermal comfort vote survey data (relevant variable response rates summarised in Table 1). Figure 4 demonstrates the range of temperatures experienced within the Melbourne and Darwin homes during the monitoring period. The results presented in this paper report on the behavioural aspects of the thermal comfort vote survey. Note that the analyses below are confined to air temperature, for work concerning the effect of other environmental parameters please refer to Daniel et al, 2015a; 2015b; 2016.

Table 1: Behavioural variables response frequencies for both cohorts

<table>
<thead>
<tr>
<th>Variable</th>
<th>Categories</th>
<th>N Melbourne cohort</th>
<th>N Darwin cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clothing insulation (clo)</td>
<td>Very light (0.04)</td>
<td>0</td>
<td>568</td>
</tr>
<tr>
<td></td>
<td>Light (0.35)</td>
<td>355</td>
<td>1676</td>
</tr>
<tr>
<td></td>
<td>Medium (0.72)</td>
<td>1007</td>
<td>253</td>
</tr>
<tr>
<td></td>
<td>Heavy (1.0)</td>
<td>868</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Very heavy (1.2)</td>
<td>1557</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Missing</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Window &amp; door operation (win)</td>
<td>Open</td>
<td>843</td>
<td>2473</td>
</tr>
<tr>
<td></td>
<td>Closed</td>
<td>2934</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>Missing</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Fan operation (fan)</td>
<td>On</td>
<td>191</td>
<td>1262</td>
</tr>
<tr>
<td></td>
<td>Off</td>
<td>3579</td>
<td>1272</td>
</tr>
<tr>
<td></td>
<td>Missing</td>
<td>19</td>
<td>0</td>
</tr>
<tr>
<td>Heating and/or cooling appliance operation (app)</td>
<td>On</td>
<td>1174</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Off</td>
<td>2601</td>
<td>2503</td>
</tr>
<tr>
<td></td>
<td>Missing</td>
<td>14</td>
<td>12</td>
</tr>
</tbody>
</table>

Figure 4: Distribution of indoor air temperature logged at the time of thermal comfort vote responses
3.4.1. Clothing

The clothing response options were modified for the Melbourne and Darwin cohorts to reflect the type of clothing worn in the two locations; the survey given to the Melbourne households depicted light (0.35 clo), medium (0.72 clo), heavy (1.0 clo) and very heavy (1.2 clo) ensembles, while the survey given to the Darwin households depicted very light (0.04 clo) light (0.35 clo), medium (0.72 clo) and heavy (1.0 clo) ensembles. The Melbourne cohort nominated the very heavy ensemble as the most reflective of their dress in 41% of their votes, while the Darwin cohort most regularly nominated the light clothing ensemble as representative of their dress (66%), (see Table 1). Figure 5 shows the relationship between the clothing worn by the occupants at the time of voting and the indoor temperature (binned in 1K degree intervals).

![Figure 5: Clothing insulation worn by subjects at the time that votes were cast plotted against indoor temperature. Error bars represent 95% confidence intervals.](image)

3.4.2. Window, fan, and heating and/or cooling appliance use

Based on the thermal comfort vote survey data, heating was the primary form of adaptive control used by the Melbourne households in cooler weather (see Table 1), while windows and doors were used for ventilation for 22% of the time in warm conditions. Fan use was minimal, reported in only 6% of the Melbourne cohort’s surveys. In the Darwin households, windows and doors were open almost all of the time (98%). Fans were used for 50% of time, while air-conditioning was very seldom used (1%).

Logistic regression analysis was performed to determine the effect of outdoor air temperature (independent variable) on the operation of windows, fans, and heating and/or cooling appliances (dependent variables). The logistic regression models were statistically significant ($p < 0.005$) in all cases except for the Darwin window operation variable ($p = 0.671$). This is likely because the Darwin dwellings were almost continuously naturally ventilated. Based on the results of the logistic analyses, the probability of the use of windows, fans and heating can be estimated as follows (see also Figure 6):
Adaptive behaviours to achieve thermal comfort in low energy dwellings in Australia

\[
P(\text{melb\_win\_open}) = \frac{100}{1+e^{-(0.1037T-2.888)}} \quad (1)
\]
\[
P(\text{melb\_fan\_on}) = \frac{100}{1+e^{-(0.079T-4.241)}} \quad (2)
\]
\[
P(\text{melb\_app\_heating\_on}) = \frac{100}{1+e^{-(0.222T+2.153)}} \quad (3)
\]
\[
P(\text{darw\_fan\_on}) = \frac{100}{1+e^{-(0.232T-6.523)}} \quad (4)
\]

where \(T\) = outdoor air temperature

Note that the variable for appliance use in the Melbourne cases was disaggregated into assumed ‘heating’ and ‘cooling’ instances. No further analysis was completed for the ‘cooling’ instances due to small sample size (\(n = 26\)). The function for the probability of cooling appliance use in Darwin produced negligible results due to limited use of air-conditioning so is not shown in Figure 6.

Figure 5 and Figure 6 deliberately replicate analyses in (Kim et al, 2016), who presented results from a recent residential field study in Sydney and Wollongong. The climate of Sydney can be broadly described as sitting somewhere between that of Melbourne and Darwin: a moderately humid, warm temperate climate. Comparison between the two studies reflects this. For example, the reported clothing worn by the Melbourne cohort generally indicated a higher clothing insulation level than that of Kim et al’s Sydney study cohort, and that reported by the Darwin cohort a lower level of clothing insulation. Fan use by the Melbourne cohort is slightly less than that of the Sydney cohort, while in Darwin, fan use is significantly higher – this is likely due to greater humidity in Darwin (not reflected in these analyses). Window operation by the Melbourne cohort is much more gradual with increasing outdoor temperature, probably due to the high thermal mass of the specific houses studied. Finally, heater usage decreased in the Melbourne houses at lower temperatures than the Sydney houses – this may reflect acclimatisation of the Melbourne cohort to cooler temperatures (as noted in Daniel et al, 2015).
5. Conclusions

The results presented in this paper demonstrate the need to develop an adaptive model specific to Australian residential buildings. In the context of building performance assessment, the trends in the adaptive strategies used by the two cohorts could be incorporated into the simulation models for the designs of new dwellings of similar constructions for more accurate predictions (i.e. into NatHERS/AccuRate window and fan use routines). Importantly, the comparisons with other recent thermal comfort field studies show the variation in thermoregulatory behaviours between different occupants and climates. Any modification of existing user assumptions within AccuRate should have some capacity to reflect these variations.

It is important to note that, in Australia at least, the scope of thermal comfort fieldwork is often confined to very specific examples of housing from which more pointed understandings can be drawn. However, this specificity means that it is not often appropriate to generalise these results to other forms of construction or other climates. Therefore, it would be of great relevance to survey more ‘typical’ housing across a range of climates. More broadly, continued research within this area and development of a thermal comfort standard for Australian residential buildings will enable designers and architects to better respond to the thermal behaviour, preferences and expectations of the future occupants.

Acknowledgements

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References


Spaces between buildings: comfort and user-behaviour assessment of outdoor restorative and transition spaces

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Abstract: Designing spaces between buildings and streets as spaces have emerged as a key consideration in city urban planning and design. Cities like Melbourne, Australia have experienced urban revitalisation through the transformation of its street precincts, laneways, arcades, promenades and micro open spaces. A feature in the design of these urban outdoor spaces is microclimate. The evaluation of urban microclimates by means of comfort sensation and physiological temperature generally quantify the effects of urban environments with the use of thermal environmental indices. However, these outdoor comfort indices are underpinned by steady state models primarily developed for indoor applications and have been modified for outdoor use to account for outdoor effects such as solar radiation. This paper is a proof of concept study via continuous monitoring of microclimate conditions and usage patterns of an urban outdoor space located at an inner city university campus. Preliminary analysis of results of the pilot study show observations of the usage patterns of the university outdoor space pointing to a pronounced relationship between the thermal sense of people using the space and the environmental elements of thermal radiation, convection, and contact thermal conductivity not considered by the widely used outdoor thermal comfort indices.

Keywords: Urban outdoor spaces, urban microclimates, outdoor thermal comfort assessment

1. Introduction

Designing urban ancillary open spaces (refers to open spaces such as between buildings and streetscapes) as places has emerged as key a consideration in city urban planning and design (Heath et al., 2011). The City of Melbourne, a city of approximately 4 million people located in the South East of Australia, has experienced urban revitalization through the transformation of its street precincts, laneways, arcades, promenades and micro open spaces (Thompson Berrill Landscape Design Pty Ltd and Environment & Land Management Pty Ltd, 2012). Currently under review is an amendment to the Melbourne Planning Scheme on setting a local policy on public open space contributions (City of Melbourne, 2014). These improvements to Melbourne’s public spaces and precincts between buildings where much social interaction take place have profound social, cultural and economic significance (Gehl and Svarre, 2013). A feature in the design of these ancillary open spaces is microclimate. A more complete understanding of microclimate will help designers and planners produce more successful
outdoor spaces with better environments for users and in the same vein will lend to improving aspects of the performance of adjacent buildings (Erell et al., 2011).

Microclimate conditions in open spaces are affected by parameters such as surrounding building form and geometry (Oke, 1988), vegetation and design features (Ali-Toudert and Mayer, 2007), and properties of the surfaces (Takebayashi and Moriyama, 2012). An initial orientation on outdoor thermal comfort literature in relation to microclimate, design of space, interactions thereof showed that more investigations and information are needed to probe into the combined effects of climatic factors (temperature, solar irradiation, wind velocity, turbulence and direction) of urban microclimates and comfort conditions in open spaces. The field investigation of five public locations (railway station, municipal cultural centre, national museum, performance art centre and university campus) in hot and humid Taiwan indicate that increased air movement and the use of sun shading design strategies can increase thermal comfort and utilization rate of spaces (Hwang and Lin, 2007). Similarly, the outdoor comfort fieldwork on three different urban spaces with distinctive microclimates in tropical Dhaka City, suggests that the influence of air flow increased the upper boundary of acceptable relative humidity (Ahmed, 2003). In contrast, the findings of the field experiments in an outdoor urban plaza in Japan and urban park in Tel Aviv, Israel show that relative humidity has a statistically insignificant effect on comfort perception (Givoni et al., 2003). In Hong Kong, however, urban wind speeds ranging from 1-1.5 m/s are required for pedestrian comfort under shade in average summer temperature of 28°C (Ng and Cheng, 2012). The extensive outdoor thermal comfort study conducted in Singapore found that solar radiation had the most significant effect on human thermal sensation in outdoor spaces (Yang et al., 2013). For urban outdoor areas specifically designed for relaxation, a study in Randstad, Netherlands which has generally more windy conditions, investigated pavement cafés and children’s playgrounds and found that comfort depends on the amount of solar radiation and wind speed, for example, if wind velocity is higher than 2.5 m/s, a considerable amount of solar exposure is necessary (>700 W/m²) (Tacken, 1989).

Limited research has been done on thermal comfort in outdoor settings in Australia, particularly for restorative and transition spaces. Spagnolo and De Dear (2003a) conducted field surveys in various locations: railway stations, sidelines of a football field, bus interchange, inner-city urban canyon, commuter ferry terminal and parks in Sydney and findings indicated that comfort temperatures in outdoor and semi-outdoor environments significantly exceed the recommended values for indoor environments. An earlier field survey of four urban spaces in the central business district Sydney found that people expressed being comfortable in a wide range of conditions throughout the year from 15°C to 34°C for average wind speeds less than 1 m/s (Forwood et al., 2000).

2. Methodology: outdoor open space assessment

The principal aim of this outdoor comfort study is to examine the connections between the immediate microclimate and usage patterns of a restorative open space located within a university campus grounds in the inner CBD of Melbourne.

The selected site, University Lawn Precinct (ULP), is a passive lawn courtyard space located within the university grounds surrounded by buildings and remnant historic structures and although sheltered from the city, it is accessible to the public (Figure 1). The space has three main components – a 250m² central lawn, north facing courtyard which connects a café to the central lawn and a perimeter of gardens and linear water feature with an understory provided with tree-shaded area (Peter Elliott Architecture + Urban Design, 2013). The variety of surfaces, ground cover materials, site features and
Spaces between buildings: comfort and user-behaviour assessment of outdoor restorative and transition spaces

vegetation include: bluestone paving, timber deck and timber seating, artificial turf, concrete seating and walls, garden beds with low-scale planting and a strip water feature.

2.2. On-site monitoring: microclimate measurement and space use

Climate measurements of the lawn courtyard are taken by a microclimate monitoring system assembled using Vaisala WXT520 weather sensor coupled to a Campbell Scientific CR800 datalogger. The microclimate instrument is installed at the northern end of the courtyard at a height of 3.50 metres. The WXT520 measures air temperature, relative humidity, wind speed and direction, precipitation and barometric pressure. All outputs are measured by the CR800 datalogger programmed to record at a 1-minute sampling interval and downloaded via secure wireless data transmission. Measurements from this microclimate station have been validated with concurrent meteorological observations from the Bureau of Meteorology Melbourne Olympic Park station (ID 086338, 3 kms south east of the university campus).

Still-image recording is via a Raspberry Pi micro-controller and camera module programmed to capture a still photo at a time interval of 1-minute, daily from 7am to 6pm. The camera set-up is powered by solar PV panels and mounted on the roof ledge of the corner south-east building of the lawn courtyard at a height of 21.0 metres above ground level. The still-images are transmitted and downloaded via a secure wireless network. Both the microclimate monitoring datalogger and time-lapse image recording system are time-synchronised.

2.3 Data analysis method

A key objective of this pilot study is to assess the behaviour of the users of the lawn courtyard and to explore the pioneering anthropological observation methods of William ‘Holly’ Whyte (1980) in conjunction with the conventional methodology for outdoor thermal comfort studies. In 1970, Whyte in
his *Street Life Project*, investigated the curious dynamics of urban spaces and sought to determine why some urban plazas in New York City are successful as public spaces while others were not. Whyte and his team began by looking at New York City’s parks, plazas, and various informal recreational areas like city blocks — a total of 16 plazas, 3 small parks, and “a number of odds and ends” — trying to figure out why some city spaces work for people while others don’t, and what the practical implications might be about living better, more joyful lives in the urban environment (Popova, 2013). Whyte’s findings, collected in *The Social Life of Urban Spaces* (Whyte, 1980), informed the 1975 Zoning Amendments on the Zoning Resolution for Open Spaces in New York City and Residential Plaza (enacted in 1977), where, among others, guidelines on seating, planting and trees, retail frontage, lighting, circulation and access, disability access, food facilities and permitted obstructions were outlined.

Whyte’s analysis of the success and failures of the public spaces in New York City was based on the direct observation of human behavior in urban settings. In studying people’s behavior in public spaces, he adopted the technique of time-lapse filming and using a 10-second interval film recording to construct a chronological chart (akin to a piano roll), where space users were represented by a line on the chart as a function of time. The length of the line represents the time spent on the space. Whyte’s time-lapse/piano roll technique was the inspiration in analyzing the space utilisation of the university lawn courtyard, which is observed to be a popular ‘hang-out’ space within the university grounds. For this pilot study a Java image processing and analysis program, *ImageJ* developed for biological image analysis by the U.S. National Institutes of Health (Schneider *et al.*, 2012) was used to process the still images. The program is able to process a series of still images of various formats that share a single window (stacks) and calculate the area and pixel value statistics of user-defined selections. A plugin – *MTrackJ* was used to facilitate tracking of the users’ movements in the image sequence and the measurement of tracking statistics. *MTrackJ* was developed for cell and particle tracking in time-lapse microscopy images using tracking algorithms compared to manual tracking by human observers (Meijering *et al.*, 2012).

For the pilot autumn season study, the still images recorded for May 2015 were reviewed to identify the days when the lawn courtyard was busy and occupied the most. Based on a cursory analysis of recorded still images, five (5) days were identified as the busiest: 01/05 (Friday), 04/05 (Monday), 18/05 (Monday), 25/05 (Monday) and 28/05 (Thursday) and confined between 11am to 5.30pm. The review of the still images included noting the pattern of use and where the users stay within the lawn courtyard. Of the five sample days, 18 May was selected for a further image processing and space users tracking measurement using *ImageJ* and *MTrackJ*. The key objectives for the analyses were:

- To identify the zones within the university lawn courtyard frequently used and occupied.
- To qualify the key physical features and conditions of the areas within the zones at the time of occupancy
- To observe and generally characterise how long the space users stayed – where they cluster, the behaviour and activity mainly posture – standing, sitting (ledge, ground), reclined, lying down.

### 3. Results and discussion

For this study, the approach adopted was to initially monitor the microclimate conditions of the lawn courtyard and the occupancy rate of the space to identify the days, period of the day in autumn (May 2015) and evaluate the outdoor conditions when the courtyard is busiest. A limitation of this observation is the consideration of the campus setting where population numbers depend on the university activities around the academic calendar. The preliminary results reported in this paper will
Spaces between buildings: comfort and user-behaviour assessment of outdoor restorative and transition spaces

mainly be on the microclimate conditions for the transitional autumn season (May 2015). Patterns of usage (number of users in the space, activity, movement, behaviour – if they stay in the sun or in the shade, posture/position – standing, sitting, reclined) will only be visual observations which are qualitatively correlated with the environmental conditions and site features.

3.1. Monitored simultaneous environmental parameters

The microclimate observations from the on-site station (air temperature and relative humidity) compare well to those observed from the BoM Melbourne Olympic Park Station, with the exception of the wind speed. The average daytime temperature (8am-6pm) and relative humidity observed at the lawn courtyard and BoM station for the autumn month of May were 14.6°C and 63%, and 14.5°C and 66%, respectively.

The close correlation of the observed environmental conditions on-site with those from the closest BoM station was taken as a validation of the on-site measurements. The average daytime wind speed measured in the lawn courtyard was 1.1 ms\(^{-1}\), whereas, the average wind speed at Melbourne Olympic Park was 3.6 ms\(^{-1}\). The difference in the monitored wind speeds maybe due to the installation height of the weather station. World Meteorological Organisation guidelines for surface wind measurements indicate that wind is measured at a standard height of 10m above ground (WMO, 2008). The weather instrumentation at the lawn courtyard is installed at 3.5m above ground level to closely correspond to the air movement experienced by space occupants. Moreover, wind profiles in urban areas typically slow towards ground level. The observed wind speed range of 1.0-1.5 ms\(^{-1}\) (approximately 3.6-5.4 km/h), is characterised as ‘2’ in the Beaufort scale and corresponds to “light air or light breeze”, where wind is felt on face and leaves rustle (WMO, 2008).

The average daytime temperatures (8am to 6pm) for each of the five (5) sample days ranged from 17-18°C (early May) and 13-17°C (late May) with relative humidity of 50-62% (Table 1). With the exception of elevated wind speeds of 1.6-1.8 ms\(^{-1}\) for 04/05, the day time wind speeds were observed to be in the range 1.0-1.2 ms\(^{-1}\).

<table>
<thead>
<tr>
<th>Date</th>
<th>On-site Temperature (T_a) (°C)</th>
<th>On-site Relative Humidity (RH) (%)</th>
<th>On-site Wind Speed (W_s) (ms(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>01 May, Fri</td>
<td>18.0</td>
<td>52.5</td>
<td>1.0</td>
</tr>
<tr>
<td>04 May, Mon</td>
<td>18.4</td>
<td>53.8</td>
<td>2.7</td>
</tr>
<tr>
<td>18 May, Mon</td>
<td>17.5</td>
<td>55.9</td>
<td>1.3</td>
</tr>
<tr>
<td>25 May, Mon</td>
<td>15.8</td>
<td>59.9</td>
<td>4.7</td>
</tr>
<tr>
<td>28 May, Thurs</td>
<td>13.8</td>
<td>57.8</td>
<td>3.3</td>
</tr>
<tr>
<td>BoM station</td>
<td>16.1</td>
<td>59.8</td>
<td>1.1</td>
</tr>
<tr>
<td>BoM station</td>
<td>13.8</td>
<td>58.3</td>
<td>0.90</td>
</tr>
<tr>
<td>BoM station</td>
<td>17.2</td>
<td>61.5</td>
<td>2.7</td>
</tr>
<tr>
<td>BoM station</td>
<td>17.2</td>
<td>60.3</td>
<td>1.2</td>
</tr>
<tr>
<td>BoM station</td>
<td>17.2</td>
<td>62.3</td>
<td>6.2</td>
</tr>
</tbody>
</table>

3.2. Observed patterns of space use

A review and preliminary analysis of the still-images taken during the selected five sample days and from the timeframe of 9am to 6pm show that the university lawn courtyard is busiest between 11am to 4pm. It is interesting to note that these five ‘busy’ days were generally preceded by a run of days with wet conditions and lower temperatures, weather fluctuations (precipitation, temperature and wind chill) typical of Melbourne autumn season.

During the time period of 11am to 4pm, it was observed that the high-density zones within the lawn courtyard, as shown in Figure 2-1, are the artificial turf covered central lawn (Zone A), west timber
perimeter seating (Zone B1), south corner timber seating (Zone B2) and the east corner timber seating (Zone B3). These zones can be typically described as having random areas with available shade (due to trees lining the timber deck at the west perimeter, the wall at the north-east corner of the lawn courtyard and the 3-storey building at the west) and as well as sections with opportunity to have unobstructed solar exposure. The patterns of space use and activity are relatively similar across the five sample days and observed to be typical between 11am to 3.30pm. At mid-day to mid-afternoon (12-3pm), there seems to be the same tendency to stay in and occupy the areas of both unobstructed solar exposure (open) as well as in the shade within the high-density zones (Figure 2-2). These areas would generally be the central lawn (Zone A, ZA) and the west timber deck seating (Zone B1, ZB1) (Figure 3).

Figure 2: Use-pattern zones.

Figure 3: Occupancy distribution (18 May).
Having observed that the space use patterns and activities are similar across the five sample days, 18 May (Monday) was selected for further analysis using Image J/Mtrack J to track space users. Analysing the sequence of images for 18/05, 246 individual tracks (users, \( N_r = 246 \)) occupied the lawn courtyard between 9-6pm. These tracks correspond to a total of 2627 points across 327 sequential still images. As occupancy of the space is tracked according to each image frame, these points would show the number of occupants and the time periods these space users stayed in the open space, i.e. tracked in several sequential frames. Over 60\% (\( N = 151 \)) of the total day occupants were in the lawn courtyard between the busy period of 12-3pm (Figure 3). The length of period of stay (dwell time) for each user can be deduced from the number of images the user was tracked and deriving the length of time using the image time stamp. Binning the dwell time of the space users in 10 minute-intervals between 9-6pm show that over 79\% (\( N = 194 \)) stayed in the lawn courtyard for up to 40 minutes of which 41\% (\( N = 100 \)) used the space for 10 minutes. Analysis further shows that 10 minutes seem to be the time period in which most users would spend on the courtyard suggesting that predominantly short times are spent in the open space. Long term use of the space was arbitrarily defined solely for this preliminary analysis as staying in the courtyard for more than 40 minutes. For this autumn day, approximately only 21\% (\( N = 52 \)) spent more than 40 minutes in the outdoor space.

Figure 4: Pattern of space use – tracking of users (18 May, 11am-2pm).

Further to the evaluation of dwell times, a notable aspect, relative to the pattern of space use, is the observable preference to occupy areas within the very high-density zones, however, staying along the
'edge' hovering between open to sun exposure and under the shade (Figure 4). The combination of available shading opportunities (availability of trees not yet completely bare of leaves, the wall at the north-east corner and the 3-storey building at the west side) and the low altitude of the autumn sun provides quick changing patterns of open and shaded areas.

Furthermore, the behavior and postures of the users were found to vary: users elected to lie down on the artificial turf with half of the body under the shade and under the sun, reclining in the courtyard using the concrete wall as backrest, lying down on the timber deck and timber seating, reclining on the timber deck with the seating as backrest, sitting around in clusters either under the shade offered by the trees and surrounding walls or completely under the sun. The environmental conditions from 12-3pm ranged from steady temperatures of 19.4-19.8°C and relative humidity dropping from 55% to 43%. The wind speeds fluctuated between 1.0-1.4 ms⁻¹. The interplay of these mild autumn environmental conditions and physical features of the lawn courtyard seem to influence the use of space beyond its effect on people’s perception of thermal comfort.

4. Conclusion and direction of further study

Thermal comfort assessment of outdoor spaces is generally modelled from indoor thermal comfort applications. This has been proven to be inappropriate as the conventional theory of indoor thermal comfort cannot be simply generalised to outdoor settings without modifications (Spagnolo and de Dear, 2003a; Nikolopoulou, 2004). Field surveys of thermal comfort are in situ polls of comfort among a given population (for example, users of outdoor courtyards or parks). For outdoor comfort studies, the transverse thermal comfort survey is used widely (Ng and Cheng, 2012) where a whole or substantial proportion of the population will give a small number of comfort assessments during the monitoring period which can range from a whole day to a full week covering different seasons to obtain the perception of comfort in the use of the space. With enough survey participants involved, results are deemed to be representative of the chosen population (Nicol et al., 2012). For this pilot study on an outdoor restorative and transition space, to extend the analysis on the observed patterns of use and activity, the next phase of the study would include a comfort assessment following a transverse survey method.

The observations and analysis of the usage patterns of the lawn courtyard suggest that the physical features of the space and the combined and/or individual effects of the environmental conditions lend much to the preference to use the space and how to stay within the space. This also underpins this study on outdoor comfort, where the interplay of the site features and combined and separate effects of solar access and wind movement in a restorative open space will be investigated. Widely used thermal comfort indices for outdoor comfort such as the physiological equivalent temperature, PET (Höppe, 1999), the outdoor standard effective temperature, OUT_SET* (Spagnolo and De Dear, 2003b) and the universal thermal climate index, UTCI (Jendritzky et al., 2012) are underpinned by steady state models taking into consideration the combined effect of six thermal parameters: air temperature, humidity, air velocity, radiant temperature, metabolic rate and clothing insulation. Although solar radiation is also considered, these indices quantify only the universal effect of the environmental factors on human thermal comfort. These do not express the separate thermal effects of factors such as solar radiation, air velocity and humidity. The combination, for example of wind amplification and shading effects seems to generate thermally comfortable (or acceptable) outdoor conditions. Furthermore, with the relatively short times spent in outdoor spaces, thermal steady state is hardly reached by the users (Höppe, 2002).
The preliminary observations and analysis of the usage patterns of the university outdoor space point to a relationship between the thermal sense of people using the space and the environmental elements of thermal radiation, convection, contact thermal conductivity and humidity level not considered by the widely used outdoor thermal comfort indices. In a recent study by Nagano and Horikoshi (2011), a new thermal index, universal effective temperature (ETU) was proposed for outdoor and non-uniform environments with heat conduction. ETU can also express the universal effect of the environment as well as the separate thermal effects of air velocity, longwave and shortwave radiation and humidity. To date, only three studies have been published using this new model: thermal comfort in open-air footbaths in Japan, thermal performance of traditional pine hedges and the evaluation of building and pergola shades (Watanabe et al., 2014). Results of these limited studies show that the ETU model can provide a more detailed understanding of the various parameters affecting thermal comfort in outdoor spaces.

As part of the further analysis of this study and to adopt the ETU model, additional parameters will be measured such as sky obstruction by way of measuring the openness of the sky (sky view factor) in winter (no leaves) and in summer (with leaves); and the solar radiation (shortwave and longwave) with the installation of pyranometer and pyrgeometer on site. With the observed behaviour and postures of the space users in the lawn courtyard, the surface temperatures of the diverse surfaces in the open space will also be monitored. The visual observations and analysis of the still images will also inform the design of the comfort assessment survey for the next stage of the pilot study where a comfort perception survey and monitoring will be conducted.

Acknowledgements

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References


Predicting environmental conditions at building site for natural ventilation design: Correlation of meteorological data to air speed at building openings

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Abstract: For the design of naturally ventilated buildings, information of air speed at the openings of a building is important. However, the only data set usually available to designers is meteorological data, such as wind speed and direction measured at weather stations. This paper explores the ratio of air speed at building openings to the wind speed measured at weather stations. Meteorological data from three weather stations as well as air velocity that was obtained through full-scale physical measurements were used in this study. The results showed that air speed at building openings was about half of the wind speed recorded at the closest station to the case study. This ratio reduced to approximately 30% when comparing to the weather stations located in greater distance and more open areas. Given that air speed at the openings has a direct relation to the ventilation rate, employing these ratios to the available weather data when designing for natural ventilation, can provide more realistic picture of natural ventilation performance.

Keywords: Natural ventilation; Air speed at openings; Meteorological data; Full-scale experiment

1. Introduction

Due to the oil and energy crises, energy efficiency policies have experienced a rapid growth in many countries around the globe over the last four decades (e.g. Europe, Japan, the United States, Australia, etc.) (Geller et al., 2006). This includes building energy regulations and standards (Recast, 2010; IECC, 2012). Buildings, as one the main energy consumers, have a great potential to contribute to energy savings by adopting passive and low cost strategies. However, passive strategies and design based on climate are often disregarded in rapidly growing high-rise buildings which makes them highly energy intensive (Cheung et al., 2005; Kennedy et al., 2015).

Appropriate design of natural ventilation as a passive cooling strategy can provide thermal comfort for the building’s occupants (Liddament et al., 2006) which can result in reduced use of air-conditioners and hence, save energy (Luo et al., 2007). Implication of natural ventilation is even more
feasible in cooling-dominant climates. Furthermore, natural ventilation can improve the Indoor Air Quality (IAQ) by replacing the stale air with the fresh air from the outside (Liddament, 1996).

Natural ventilation mainly relies on outside wind and the resultant pressure difference for conditioning the space. Since wind is intermittent in nature and the process involved is rather complex, it is difficult to predict natural ventilation performance (Allocca et al., 2003). A major problem for building designers is that accurately predicting environmental conditions inside and around a proposed building is difficult. Having said that, understanding the potential air speed at the openings as a representor of ventilation rate can be a step toward an accurate natural ventilation prediction and a successful design.

To investigate the potential air velocity at building openings in relation to meteorological data, wind speed data at openings of an apartment in a high-rise residential unit in Brisbane, Australia were collected. In addition, weather data from three different weather stations were obtained. The chosen weather stations are situated in locations with different terrain roughness and various distances from the case study, which allows further comparison considering urban context.

2. Background

The ventilation rate has a direct relation with the air speed at the buildings openings. In its simplest form can be expressed as:

\[ Q = VA \]  \hspace{1cm} (1)

Where Q is ventilation rate (m\(^3\)/s), A is the area of opening (m\(^2\)) and V is the air velocity through the openings (m\(^2\)/s). Hence, the air velocity at the buildings openings can be used as a good indication of ventilation rate.

The main data source available to architects and building designers is meteorological data from the weather station nearest to the location of interest. Weather stations are mostly located in open areas and the meteorological data from them are likely to be different from the expected wind at dense urban settings (Truong, 2012). Furthermore, wind magnitude changes with height and meteorological data are usually measured at the height of 10 m while building openings can be above or below that height.

Wind speed at different heights in relation to the wind speed at a reference height can be expressed by power law equation (Feustel, 1999):

\[ V_z = V_{ref} \left( \frac{z}{z_{ref}} \right)^{\alpha} \]  \hspace{1cm} (2)

Where \( V_z \) is wind speed at height \( z \) (m/s), \( V_{ref} \) is wind speed at the reference height of \( z_{ref} \) (m/s) and the \( \alpha \) exponent represents the terrain roughness and varies from 0.15 to 0.35. A greater values indicates a rougher terrain (Awbi, 2003). However, wind speed at building façade and openings is always lower than the \( V_z \) value obtained from equation (2). That is due to the positive and negative pressure built up as a result of wind hitting an obstacle (e.g. building). In order to use meteorological data for natural ventilation design, knowing the relation between the reference wind speed and the wind speed at the openings is an important factor which can help in a more realistic prediction of natural ventilation. The lack of such a relation in the literature was motivation of the current study.
Predicting environmental conditions at building site for natural ventilation design: Correlation of meteorological data to air speed at building openings

3. Methodology

In order to investigate the correlation of weather data and air velocity at building openings, full-scale physical measurement of air velocity at openings of a residential apartment was carried out. Analysis of the collected data in addition to the available weather data helps to reveal any possible connections. Full-scale measurement was chosen as it can yield more reliable information compared to the other available methods (e.g. small-scale experiments, simulation software, etc.) (Chen et al., 2010). Selected weather stations and the case study used for the full-scale measurements are described in the following sections.

3.1. Case study

A 36-storey building located at Brisbane, Australia (latitude: -27.46, longitude: 153.03) was chosen as the case study for this research. This building is located near the Brisbane Central Business District (CBD) in a relatively dense urban layout. However, there are no major obstructions in the case study’s immediate surroundings. The building is oriented 35° from North toward West and is next to the Brisbane River on one side and adjacent to a street approximately 25 meters wide on the other side. Figure 1 shows the location of the case study in relation to its surroundings. A residential unit located on the western side of the building at the fifth floor, was used for the data collection. This 2-bedroom apartment features two balconies at two opposite sides of the living area and is situated about 18 m above the ground level of the adjacent street. The case study unit was vacant when measurements were conducted and no mechanical or fan-assisted ventilation was operating.

![Figure 1: Case study’s site plan.](image)

The instruments employed to measure wind velocity at the case study’s openings were a Windmaster 3-axis ultrasonic anemometer (3D) and a 2D WindSonic anemometer (2D), commercially produced by Gill Instruments. The sensors allow accurate measurement of wind speed and direction at resolution of 0.01 m/s. Wind speed accuracy is 1.5% for 3D and 2% for 2D. The 3D sensor was attached to the exterior of the southern balcony’s parapet wall and the 2D anemometer was placed inside the northern balcony. The parapet walls of balconies are 1.2m high thus, the sensors were installed at a height of 1.3 m from the unit’s balcony floor. Wind velocity was measured for 30 hours at sampling rate...
of 1Hz starting at 1:00 pm and ending 7:00 pm the day after. The authors believe that due to fluctuating nature of wind and the frequent sampling rate of data logging adopted in this study, 30 hours of air velocity data is enough to represent various wind speed ranges. All the doors and openings -except for balcony doors- were kept closed for the duration of the data collection. The sensors were placed close to the openings which provides information on external airflow near the openings. Plan and placement of the sensors is presented at Figure 2.

Figure 2: Case study’s plan (right) and photos of sensors (left).

3.2. Weather stations

Meteorological data for this study was obtained from three weather stations: Brisbane station, Brisbane Airport and Archerfield stations which are located approximately 2 km, 9 km and, 12 km from the case study building respectively (Figure 3). The weather stations’ information is presented in Table 1.

<table>
<thead>
<tr>
<th>Weather station</th>
<th>Distance to case study</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Station height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brisbane Station</td>
<td>~2 km</td>
<td>-27.4808</td>
<td>153.0389</td>
<td>8.13 m</td>
</tr>
<tr>
<td>Brisbane Airport</td>
<td>~9 km</td>
<td>-27.39</td>
<td>153.13</td>
<td>4.51 m</td>
</tr>
<tr>
<td>Archerfield</td>
<td>~12 km</td>
<td>-27.5717</td>
<td>153.0078</td>
<td>12.5 m</td>
</tr>
</tbody>
</table>

The wind speed and direction 30-minute data for the duration of the experiment was downloaded from Australian Government Bureau of Meteorology website (http://www.bom.gov.au/, 2016). Wind speed data are averaged over 10 minutes and are rounded values with no decimal places, and wind direction data are presented in 16-compass point.

Wind speed and direction data acquired from the installed anemometers together with weather station data were analysed to investigate objectives of this study.
4. Results and discussion

This section presents and discusses the analysis of weather stations data along with the measurement results from the installed sensors.

4.1. Weather stations

Figure 4 represents wind speed (Figure 4-left), and wind directions (Figure 4-right) captured at the three weather stations: Brisbane, Brisbane Airport, and Archerfield stations, for the duration of the experiment. Both graphs show that despite the long distance between the stations and the different urban layouts and contexts, wind speed changes and the prevailing wind direction are very consistent at all three stations, and wind is predominantly blows from NNE to ENE. The graph at the top shows the lower wind speed recorded at Brisbane station compared to Brisbane airport and Archerfield stations. Since Brisbane weather station is located close to the Brisbane CBD in a predominantly residential suburb with higher density urban layout compared to Brisbane Airport and Archerfield, the recorded wind speed is lower due to the adjacent obstructions (as would be expected). Whereas Brisbane Airport and Archerfield are both located in open terrain, and thus present a similar range of wind speed changes and about twice that of the Brisbane station. In addition, as Brisbane Airport is close to a large body of water (ocean), wind magnitude recorded at this station can be affected. This may explain the higher mean wind speed captured by this station compared to Archerfield station, despite the higher elevation of Archerfield station.

Figure 5 represents wind speed at Archerfield and Brisbane Airport stations in relation to Brisbane station’s wind speed. Regression lines confirm a linear relation between air speed changes at these weather stations. Again, it also confirms that Brisbane station had the lowest readings of wind speed.
with values of about 56% and 65% of wind speed at Brisbane Airport and Archerfield stations respectively.

Figure 4: Wind speed change (left) percentage of different wind directions (right) at Brisbane, Brisbane Airport and Archerfield weather stations.

Figure 5: Regression lines between wind speeds recorded at Brisbane station expressed according to Brisbane Airport and Archerfield stations wind speed.

The relations between the three weather stations are expressed in Table 2 where $V_{Br}$, $V_{Ar}$, and $V_{Ai}$ refer to Brisbane station, Archerfield and Brisbane Airport stations wind speed respectively.
Predicting environmental conditions at building site for natural ventilation design: Correlation of meteorological data to air speed at building openings

In view of confidence in the regression equations, the fact that the available wind data is averaged over 10 minutes and is presented in rounded values without decimal places might have introduced some marginal errors. To this end, the acquired regression lines are considered reasonably valid.

Table 2: linear regression equations of Brisbane station wind speed ($V_{Br}$) on wind speed for Brisbane Airport ($V_{Ai}$) and Archerfield ($V_{Ar}$) stations.

<table>
<thead>
<tr>
<th>Weather stations</th>
<th>Regression equation</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brisbane and Brisbane Airport stations</td>
<td>$V_{Br} = 0.5596V_{Ai} - 0.356$</td>
<td>0.71</td>
</tr>
<tr>
<td>Brisbane and Archerfield stations</td>
<td>$V_{Br} = 0.6474V_{Ar} - 0.5796$</td>
<td>0.76</td>
</tr>
</tbody>
</table>

To summarize, data analysis of the weather stations exhibit consistency in wind direction collected at different stations located in areas with different terrain roughness and urban context over 10 km apart. This consistency in the recorded wind direction can be mainly due to the unobstructed immediate surroundings of the weather stations with the minimum distance of 30 meters even in the case with the highest density setting (Brisbane station). In addition, the effect of urban density was clear in the recorded wind speeds, and as expected, Brisbane station represented the lowest speed range among the three stations. Most importantly, the linear relation between the air speed values at different stations shows that wind speed changes with relatively the same pattern in different locations. Therefore, in the following section, results will be presented and discussed using Brisbane station data only. The selection was made as Brisbane station is located in a similar urban context and is the closest station to the case study building.

4.2. Wind speed at building’s openings

To explore the potential wind speed outside of the case study’s openings in relation to the meteorological data, the collected data by the installed anemometers was averaged over 10 minute intervals to allow comparison with Brisbane station’s data. Wind speed changes during the measurement period recorded by Brisbane weather station, 2D and 3D sensors are presented in Figure 6.

![Figure 6: Wind speed changes of Brisbane station, 2D and 3D for duration of the data collection.](image)
The intermittent line representing air speed changes at the 3D sensor is due to some glitches in the logging system, which resulted in loss of some of data. As can be seen 2D and 3D change trends are similar to the Brisbane station at a lower speed.

To investigate the correlation of this trend, data recorded by 2D and 3D sensors were plotted in relation to Brisbane station wind speed data (Figure 7). It is evident that a decrease in Brisbane station wind speed results in wind speed decrease at both measurement points (2D and 3D). The obtained R-squared values which are equal to 0.7 for 2D and 0.78 for 3D versus Brisbane station, confirm that the acquired regression lines are acceptably valid. It also demonstrates that the air speeds captured by the sensors are very similar in values and are roughly half the values recorded at Brisbane station.

Figure 7: Variation of wind speed recorded at measurement points (2D and 3D) versus Brisbane station wind speed.

In summary, comparing wind speed outside of the case study’s openings with Brisbane station wind speed, the same variation pattern was observed at a much slower speed range (about 50%). This percentage is obviously smaller when compared to the Brisbane Airport and Archerfield weather stations (nearly 30%). This slower speed range was expected, as building acts as a large obstruction on the airflow path and as a result, the positive pressure built on the windward side results in a lower air speed. In addition, air speed values were very similar at both the inlet and outlet of the case study which is not surprising since openings were the same size. This can be explained by conservation of mass.

It needs to be considered that the case study was located at fifth floor (nearly 18 m above the ground), and there were no major obstructions in the immediate surroundings of it. Application of the acquired results to a broader context needs to be further investigated. The measured values are expected to be lower in the case of buildings at lower floors in contrast to the higher floors, which would be expected to be higher. In addition, that having openings at two opposite sides might have accelerated the air speed compared to a case with openings at only one side.

Air flow rate in cross ventilation is higher than that of the single-sided ventilation (Jiang et al., 2003). Therefore, the resultant air speed is expected to be much lower in a building with openings only at one side (single-sided ventilation).
5. Conclusion

Natural ventilation rate directly correlates to air velocity at building openings. Understanding the potential values of wind speed at the openings can result in better estimation of ventilation rate. Considering meteorological data is the main data source available to the building designers, this study explored possible air velocity at building openings in relation to the available meteorological data. To this end, air speed at openings of a high-rise residential unit was measured using 2D and 3D anemometers. Furthermore, wind speed data from three weather stations situated in locations with varying terrain roughness and different distances from the case study was also obtained.

Firstly, wind speed and direction from three different weather stations situated in different urban context were compared. The results showed consistency in the captured directions by all three stations. Also, wind speed analysis showed similar wind speed fluctuation pattern. Scatter plots of wind speed at the weather stations confirmed this relation. As expected, the lowest wind speed range was from the station located in the denser urban layout.

Air speed measurement data for the unit was then compared to the meteorological data from the closest weather station to the case study. Once more, a similar change trend was evident between weather data and the measured values at the case study. Interestingly, regression lines revealed that the wind speed through the openings was approximately half of the wind speed measured at the weather station. The reference weather station was in a similar urban setting as the case study and closest to it (about 2km). Unsurprisingly, this ratio reduced to nearly 30% when compared to the two other meteorological stations located in low rough terrains further way from the case study building.

In conclusion, when using the meteorological data to design for natural ventilation, similarity of urban context of the closest weather station to the site of interest is an important parameter which can yield values close to those that can be expected at building openings. Even in that case, the potential air velocity at building openings may not exceed half of the wind speed at the reference weather station. However, in a case that design site is in a dense urban setting, chances of existing any weather station in similar urban context is very low as meteorological station are usually located in open areas with minimum obstructions. If it was the case, lower ratio of wind speed of the reference station should be expected at the openings (roughly 30%). Findings of this study can help in better use of meteorological data in natural ventilation design.

6. Future work

The current study provided building designer with ratios of potential air velocity at building openings to the meteorological data, considering urban context and distance to the building of interest. However, when using results of this research, the following factors needs to be taken into consideration. Firstly, the measurements were conducted in a cross-ventilated unit with two openings at two opposite sides. Airflow produced by cross ventilation can be much higher than the airflow produced by single-sided ventilation. Even in such an instance, wind speed at inlet is far less than that of at the same height in the free atmosphere. Hence, lower values of air velocity should be expected at the openings of a building utilising single-sided ventilation. Having said that, more studies are needed to investigate the amount of airflow at openings in the case of single-sided ventilation. Secondly, the measurements of this study were done at a case study located at fifth floor. As wind magnitude increases with height, higher ratios at upper levels and lower rations at lower levels should be expected.

In future research, it would be desirable to validate the applicability of the results of this research to a broader context and different heights.
References


Truong, P.H. (2012) Recommendations for the analysis and design of naturally ventilated buildings in urban areas, Massachusetts Institute of Technology.
Thermal experiences of older people during hot conditions in Adelaide

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Abstract: This study examined the thermal experiences of older people during extreme heat and summer more broadly. A longitudinal field study of thermal comfort and thermal acceptability of conditions during summer 2015-16 was conducted as part of a larger project into the overall thermal comfort of older people in Adelaide, South Australia. The experiences and preferences of the participants were arranged into 3 categories: acceptable thermal sensation votes, warm and hot thermal sensation votes and votes recorded on extreme heat days when the maximum outdoor temperature was 35\degree Celsius or above during the study period. In each category, participants reported sensations of ‘warm’ and ‘hot’ within the acceptable range of operative temperature and humidity suggested by ASHRAE Standard 55. Participants also expressed a desire to feel cooler within this acceptable range, and described conditions within this range as ‘thermally unacceptable’. These results show that older people may be experiencing thermal conditions differently to younger people. Specifically, it appears that these participants have a desire for cooler temperatures than predicted by ASHRAE Standard 55. The study poses a series of challenges for future research to ensure comfortable and healthy homes for ageing Australians.

Keywords: thermal comfort, ageing, heat waves, Australia.

1. Introduction
Adelaide, South Australia has a temperate climate with a Köppen classification of Csa (McBoyle, 1971). It has warm summers, but frequently experiences periods of extreme heat. The frequency, length and intensity of these heat waves is likely to increase in the future (Meehl and Tebaldi, 2004). In Adelaide these extreme heat events are associated with increases in mortality, hospital admissions and ambulance call outs in the general population and these pose specific concern for more vulnerable groups, including older people (Bi et al., 2011). As older people have a tendency to spend more time inside, it is important that internal conditions remain comfortable and safe during periods of extreme heat.

Whilst the earliest thermal comfort work suggested there was no difference in the conditions preferred by older people and younger adults (Rohles and Johnson, 1972; Fanger and Langkilde, 1975), more recent research has indicated that this may not be the case (Collins and Hoinville, 1980; Schellen et al., 2010). Changes to physiology and perception amongst older people means they experience thermal
conditions differently to younger people. As such, it is important to ensure they experience their surroundings in such a way that is not detrimental to their health.

This research examines the thermal comfort of a cohort of people aged 65 and over in Adelaide during summer 2015-16, including data from a number of extreme heat days which occurred between October and January. It investigates comfort, acceptability of the thermal environment and the thermal preferences of the occupants during warm weather. All of these variables are considered rather than the more traditional approach of simply making the assumption that the central category votes on a 7-point thermal sensation scale means conditions are acceptable and that no change for warmer or cooler conditions is preferred. The study was done to obtain a very specific picture of the actual experiences of the participants.

2. Methods

2.1 Participants

Participants were recruited from an earlier survey of housing and health in which they could volunteer for the more in-depth longitudinal study (Bills & Soebarto 2015). Participants were recruited through invitations distributed by local councils and church groups. Some participants were also recruited through the University of the Third Age. This paper focuses on the results from 15 households with a total of 17 participants (8 Female, 9 male). Data were from October 2015 to January 2016. Despite only December and January typically considered to be “summer”, Adelaide experienced several extreme heat days in October and November 2015 and for this reason data from these months was also included in the study.

2.2 Protocol

Unobtrusive data loggers were installed in the bedrooms and living rooms of all participants. These recorded air temperature, humidity and globe temperature (as proxy of mean radiant temperature) every 15 minutes. Participants were asked to regularly complete short comfort vote surveys which included a vote on the ASHRAE 7-point thermal sensation scale (TSV) (ASHRAE, 2013) and the McIntyre 3-point thermal preference scale (TPS) (McIntyre, 1980). The comfort vote survey also asked participants to indicate their current level of clothing and their level of activity for the previous 30 minutes. Participants were also asked about ventilation via doors and windows, and whether ceiling fans or heating or cooling were in use.

2.3 Analytical techniques

The air temperature and humidity data at the times of the votes were analysed using the Graphic Comfort Zone Method of ASHRAE 55 (ASHRAE 2013) as the houses were air-conditioned at times. The comfort zone shown on the following charts includes clothing levels in the range 0.5-1.0 clo and a metabolic rate in the range 1.0 to 1.3 met. The thermal sensation votes (TSVs) were filtered to remove responses given when higher levels of clothing were being worn, or when higher levels of activity had been completed in the last 15 minutes before completing the survey. The comfort zone indicated by this method assumes an air-speed of less than 0.2m/s and a radiant temperature close to the recorded air temperature. In this study, globe temperature was on average within 0.04° of the measured air temperature and therefore no shifting of the comfort zone was required to accommodate for this. Whilst air speed was not measured in the houses in this study, it is the experience of the authors that air movement in houses in Adelaide rarely
exceeds 0.2m/s, even with windows open. Whilst some of the buildings were fitted with ceiling fans, which could increase air speeds above 0.2m/s, their use was recorded only about 10% of the time. Typically, thermal comfort studies present the ‘acceptable’ range of TSVs (-1, 0, or +1 on the 7 point ASHRAE comfort scale); however, in this paper TSVs of ‘warm’ and ‘hot’ (+2 and +3 on the ASHRAE comfort scale) have also been analysed in order to demonstrate experiences during extremes in temperature.

3. Results

In all cases, there was a large overlap of instances where the TSVs indicated that conditions were acceptable or unacceptable, and conditions where a preference for change was recorded versus no preference for change. There is no clear threshold where conditions suddenly become acceptable, or where participants felt ‘hot’ rather than ‘slightly warm’. A total of 400 votes were cast during December 2015 and January 2016.

3.1 Thermal comfort in December 2015 and January 2016

3.1.1 Acceptable thermal sensation votes

Upon initial examination of the 305 ‘acceptable’ votes during December and January, it appears that they largely aligned with the range of conditions indicated by the acceptable range of operative temperature and humidity based on the Graphic Comfort Zone Method of ASHRAE 55 (figure 1). Upon closer examination, around 20% (60/305) of the ‘acceptable’ votes fell outside the comfort zone.

Figure 1: Operative temperature and humidity at times when acceptable Thermal Sensation Votes (-1, 0, or +1 on the ASHRAE thermal sensation scale) were recorded. TSV of -1 = blue, 0 = green and +1 – yellow. Source: Adapted from ASHRAE 55-2013, Figure 5.3.1
Out of the 245 ‘acceptable’ votes that fell within the comfort zone, 9.4% (24/245) noted a preference for cooler conditions than they were currently experiencing (Figure 2). Whereas, out of the 305 ‘acceptable’ votes, a preference for cooler conditions was indicated 36 times (11.8%). In other words, of the 36 votes cast indicating a preference for cooler conditions, 66% of the time (24 votes) the conditions fell within the comfort zone. Analysing this data using a two-dimensional Kolmogorov-Smirnov two sample test this finding is significant (d=0.37, p<0.01).

Figure 2: Operative temperature and humidity at times when participants recorded either a) a preference to be cooler (red), or b) no preference for change (green).

3.1.2 Warm and hot sensation votes

Out of the 400 votes, 55 indicated ‘warm’ and ‘hot’. Interestingly, of these ‘warm’ and ‘hot’ votes cast during the summer months, 35 (64%) were cast during the conditions that were within the comfort zone specified by ASHRAE 55 (figure 3). Out of these 55 votes, 48 votes (87%) also preferred for cooler conditions regardless of the votes and 63% of these (30/48) occurred when the operative temperatures and humidity were within the comfort zone (figure 4). These indicate that older people may be experiencing discomfort in conditions that would normally be considered comfortable.
Figure 3: Operative temperature and humidity at times ‘warm’ (orange) or ‘hot’ (red) thermal sensation votes (+2 and +3 on the ASHRAE thermal sensation scale) were recorded during December and January.

Figure 4: Operative temperature and humidity at times when ‘warm’ or ‘hot’ thermal sensation votes were cast, sorted by whether participants would prefer to be cooler (red) or had no preference for change (green)
3.2 Thermal Comfort on Extreme Heat Days

During extreme heat days (days when the maximum daily temperature was more than 35°C) a total of 209 votes were cast, with 27% (56/209) of the votes cast during conditions that were outside the comfort zone. Out of the 209 votes, 24% (51/209) voted ‘warm’ and ‘hot’ (TSV of +2 and +3), and interestingly, 63% of these (32/51) were cast when the indoor conditions were within the comfort zone (figure 5). Further, 77 of the total votes during extreme heat days (37%) indicated a preference to be cooler (regardless of the votes), and 49 of these instances (64%) were cast during conditions that fell within the comfort zone.

![Figure 5: All thermal sensation votes cast on extreme heat days, where green = neutral (TSV=0), yellow = slightly warm (+1), orange = warm (+2) and red = hot (+3)](image)

4. Discussion

These results show that whilst older people experience some thermal sensations similarly to their younger counterparts, there is a worrying trend of experiencing conditions usually considered ‘comfortable’ as unacceptably warm. There is often a preference for a change to cooler conditions than those suggested by ASHRAE as ‘comfortable’; that is, falling within the acceptable range of operative temperatures suggested by psychrometric graphing.

The trend toward older people experiencing conditions that would normally be considered comfortable as unacceptable, and expressing a desire to be cooler when conditions are within the comfort zone is both interesting and confusing. Other researchers in the area of thermal comfort amongst older people have almost universally found the opposite; that older people in general need a warmer environment than younger people to achieve thermal comfort (van Hoof and Hensen, 2006; DeGroot and
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Kenney, 2007; Schellen et al., 2010). Previously this has been attributed largely to the slowing of metabolism that comes with age, requiring higher ambient temperatures to maintain heat balance. Further explanations have cited clothing levels and other behavioural mechanisms.

There is a significant body of evidence within the field of physiology that shows changes to a range of thermoregulatory functions, such as reduced sweating (Foster et al., 1976; Dufour and Candas, 2007), and altered reactions of blood vessels in older people (Yochihara et al., 1993; Schellen et al., 2010) which ultimately leads to changes in the ability to control core temperature (DeGroot and Kenney, 2007). Thermal sensitivity has also shown to be decreased in older people (Natsume et al., 1992; Taylor et al., 1995). These physiological responses tend to give evidence to the general preference for warmer rather than cooler conditions; any physiological measurements were outside the scope of the current study.

In examining age-related differences concerning the ability to regulate room temperature, Taylor et al. (1995) posit that “it is possible that thermal discomfort reflects an integration of previous thermal experiences, with the elderly possibly having a greater history of exposure to such stresses, and perhaps being more accepting of the resultant sensations”. This acknowledgement of the importance of an individual’s thermal history is important when examining the results in this study. It is possible that living in Australia, widely regarded as having a hot climate, had led to an almost constant desire or preference for cool conditions. This includes in the winter, as previously indicated by earlier results from this longitudinal study where colder conditions than expected were deemed both acceptable and ‘neutral’ according to the thermal comfort votes during the winter months (Bills and Soebarto, 2015; Bills, 2016). So, whilst the results of this study are different from those of studies overseas, the experience of conditions as warm within what is usually considered a neutral zone is at least consistent within the Adelaide context. Much of the earliest thermal comfort work was conducted in Europe and America, where not only the climate but also the trends in heating and cooling usage differ greatly from Australia. It is perhaps then not surprising then that expectations of coolness outside of the standards derived from this early research exist in a place so very different in culture and environment.

Ultimately, it is a physiologist’s job to determine the physiological responses of older people to warmer conditions, and a psychologist’s job to analyse the behavioural and psychological responses. The role of the designer and building scientist is to use all the information available to them, and create living spaces which provide comfortable conditions for their occupants whilst nurturing good health. It is thus important that thermal comfort field work continue in varied contexts around the world to provide a greater understanding of how comfort expectations and preferences may change with cultural and environmental milieu. It may well be that for the Adelaide context, designing houses that stay cooler than standards normally suggest is important as people age in place. This would be best accomplished where possible through passive design principles so as to have minimal impact on household energy consumption.

5. Conclusion

In this study, older people showed a preference for conditions cooler than those predicted by existing thermal comfort standards. Whilst a majority of the acceptable votes cast did fall within the standards, of concern is the trend for sensations of ‘warm’ and ‘hot’ to also fall within these standards. When conditions were deemed ‘unacceptable’ and participants expressed a desire to be cooler, these instances again largely occurred at times where conditions met the current standards. This contradicts the current body of research which suggests older people generally prefer warmer conditions to their younger counterparts. Further research across a broad range of climatic and cultural situations should be
considered to examine the effect these may have on perception, acceptability and preferences in regards to thermal comfort.

References


Thermal comfort evaluation of natural ventilation mode: case study of a high-rise residential building

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Abstract: Natural ventilation can be used as a low-cost alternative to mechanical ventilation. Bearing in mind that ventilation mode plays an important role in natural ventilation performance, the current study investigates the effectiveness of two major natural ventilation modes (i.e. single-sided and cross ventilation) in providing thermal comfort for occupants of high-rise residential buildings in cooling dominant climates. Measurements of air velocity, temperature and relative humidity were carried out in a unit located in a high-rise residential building in Brisbane, Australia. Both single-sided and cross ventilation settings were examined in two consecutive days in summer. The extended Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfaction (PPD) were calculated and results showed a considerably better performance of cross ventilation over single-sided ventilation. Cross ventilation could provide thermal comfort in a typical hot summer day for most of the day (greater than 70% of the time), while, for single-sided ventilation the thermal conditions of internal spaces was comfortable for only 1% of the time.

Keywords: Natural ventilation; ventilation mode; thermal comfort; high-rise residential.

1. Introduction

In cooling dominant climates, weather conditions mostly lie outside the comfort range, especially during summer. Therefore, air-conditioners are widely used for space cooling and providing a thermally comfortable environment. Air-conditioners are energy intensive and consume a large portion of the energy delivered to buildings (Pérez-Lombard et al., 2008). Natural ventilation as a passive cooling strategy, on the other hand, is a low-cost alternative to air conditioners. Natural ventilation not only contributes to thermal comfort but also can improve indoor air quality.

There are a number of parameters that affect natural ventilation performance and can be addressed through building design such as building orientation, shape and size of openings, and ventilation mode. Among these design related parameters, ventilation mode has the most impact on ventilation performance (Fung and Lee, 2014).
There are two major ventilation modes namely: single-sided ventilation and cross ventilation (Jiang and Chen, 2001). In single-sided ventilation, air enters and exits from openings at one side of the space while in cross ventilation, air flow enters and leaves through separate openings at different sides of the space (Liddament, 1996). Air movement in single-sided ventilation is mainly due to temperature difference between inside and outside and the consequent buoyancy forces and pressure difference (Linden, 1999). In cross ventilated spaces, on the other hand, the pressure difference produced by the wind at inlet and outlet is the main driving force (Liddament, 1996). As far as pressure difference goes, wind produces a much larger force compared to buoyancy and temperature difference. Therefore, a space with cross ventilation normally experiences a higher airspeed and ventilation rate (Evola and Popov, 2006).

Although cross ventilation performs better than single-sided ventilation, it is not always possible to design buildings with cross ventilation. Sometimes site restrictions dictate single-sided ventilation as the only possible option especially in high-rise buildings in dense urban areas. Despite the importance of this subject matter, effectiveness of ventilation modes in providing a thermally comfortable environment is yet to be thoroughly investigated.

The current study investigates the effectiveness of the two major ventilation modes (single-sided and cross ventilation) in providing thermal comfort for a high-rise residential building in a cooling dominant climate. Air velocity, temperature and Relative Humidity (RH) data were collected for two hot summer days in a residential apartment in a high-rise building located in Brisbane, Australia. The collected data were used in calculating a thermal comfort index applicable to naturally ventilated buildings. Finally, thermal conditions inside the case study for both cases of cross ventilation and single-sided ventilation were evaluated and compared.

1.1. Climate condition of Brisbane

Brisbane is located in 27.4° S latitude and 153° E longitude. Brisbane’s climate is subtropical with warm and humid summers and mild to cool winters. Monthly mean temperature ranges from 10°C in July to 30°C in January and mean relative humidity is relatively high most of the time, laying in the range of 50% to 70% on average. The annual mean wind speed is 3.6 m/s and is predominantly blowing from south and south-west in the mornings and from east and north-east in the afternoons (Australian Government Bureau of Meteorology, 2016). The graph below shows mean monthly temperature and wind speed in Brisbane.
2. Methodology

This study investigates the effectiveness of single-sided and cross ventilation in proving thermal comfort for building occupants using full-scale on-site measurements. Air velocity, temperature and RH were measured in a high-rise residential apartment for both single-sided and cross ventilation. The collected data was used for thermal comfort evaluation by adopting extended PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfaction) as criteria.

2.1. Full-scale measurements

Data collection for the current study was carried out in a residential unit located at level five of a 36-storey residential building situated in Brisbane, Australia. The case study’s layout with two balconies at two opposite sides of the living area allowed measurements for both single-sided and cross ventilation. Both balcony doors were kept fully open (1.16m*2.5m=2.9 m² operable area each) for the cross ventilation setting. For the single-sided ventilation setting, the northern balcony door was shut and the southern door was kept fully open for the duration of the experiment. Figure 2 represents the location of the case study within the whole building (left) and the measurement point on the case study’s plan (right). As can be seen, the case study is a two bedroom apartment; however, all the measurements were only carried out in the living area. Therefore, doors and windows to the bedrooms were kept closed for the duration of the data collection.

The data collection was conducted in summer (January 13th and 14th) to examine the possible worst case scenario. In Brisbane, January is the hottest month of year (Figure 1) and the most critical time in terms of cooling energy requirements. Therefore, if a naturally conditioned building is thermally comfortable in the hottest time of year, it may not need mechanical cooling for the rest of the year.
Temperature, RH and air velocity were measured inside the living area of the case study (Figure 2) for single-sided and cross ventilation during 24 hours for each setting. Considering the fluctuating nature of wind, temperature change and solar radiation pattern, 24 hours might be long enough to cover typical weather condition variations. Measurements were carried out on days with clear sky when no precipitation occurred.

Instrumentations that were used in the data collection included a velocity transducer (8475 series, TSI), and temperature and RH sensors (iButton, Maxim integrated). The velocity transducer logged air speed at a sampling rate of 5 Hz, temperature and RH data were recorded at one-minute intervals. All the sensors were installed at a height of 1.2 m which represents the head level of a sitting occupant.

Figure 2: Case study location within the building (left) and plan and measurement point (right)

2.2. Evaluation criteria

One of the main purposes of natural ventilation is to provide occupants with a thermally comfortable environment. To this end, thermal comfort was chosen as the criteria for assessment of ventilation modes. Hence, an appropriate comfort model needed to be adopted for this study. In the last few decades, a number of comfort models have been developed with the aim of predicting an environment’s thermal condition for its occupants.

One of the first comfort models was the PMV developed by Fanger (Fanger, 1970). PMV is an index for human body thermal sensation and ranges from -3 to +3 where -3 refers to cold, 0 shows neutrality and +3 indicates hot sensation of the environment. ASHRAE standard (ASHRAE, 2013) considers an environment therma lly comfortable when at least 80% of its occupants are satisfied with the thermal condition of their environment which can be translated to -0.5<PMV>0.5. Parameters such as air temperature, radiant temperature, air velocity, RH, metabolic rate and clothing are taken into consideration in PMV calculations. PPD can also be calculated based on PMV. The PMV model is proven to underestimate thermal comfort for naturally ventilated buildings (Croome et al., 1993). De Dear and Brager (1998) explain this shortcoming with regards to the steady-state assumption of thermal comfort in the PMV model, as well as neglecting physiological (acclimatisation), psychological and, behavioral...
Thermal comfort evaluation of natural ventilation mode: case study of a high-rise residential building

Effects. The adaptive comfort model, therefore, was developed by De Dear and Brager (1998) based on an extensive field study to predict thermal comfort in naturally ventilated buildings. The adaptive model represents the acceptable limits of indoor operative temperature as a function of mean outdoor temperature. Although considered in the model development process, there is no direct input for air velocity in the adaptive comfort model. Therefore, it was not a suitable model for the current study.

Subsequently, Fanger and Toftum (2002) introduced the extended PMV model by adding two correction factors to the traditional PMV model. One is expectancy factor (e) which should be multiplied by the traditional PMV. The expectancy factor considers thermal expectation of occupants based on their experience and varies between 0.5 and 1. The other parameter considered in the extended PMV model is the activity level. People tend to reduce their activity level unconsciously when feeling warm. This reduction is 6.7% by every scale unit increase in PMV index above the neutral point. Therefore, for PMV values above zero, a new metabolic rate needs to be obtained and considered in recalculation of the traditional PMV. Accordingly, PPD can be calculated based on the obtained extended PMV value. The extended PMV model could predict thermal sensation votes for free-running buildings in warm climates reasonably well (Fanger and Toftum, 2002). The extended PMV model, therefore, was chosen for thermal comfort evaluation in the current study.

The source code of the CBE thermal comfort tool (Hoyt et al., 2013) provided by the developers were used for calculating PMV using the R statistical software (Team, 2014). The expectancy factor and adjusted activity level were then applied to the obtained PMV values and extended PMV was calculated.

To assess thermal comfort performance of single-sided and cross ventilation using the extended PMV model some assumptions needed to be made. Occupants were assumed to be involved in sedentary activities. Metabolic rate therefore, was set to 1.2 met. Considering measurements were carried out in summer, typical light clothing insulation value equal to 0.5 clo was taken for PMV calculations. The expectancy factor for Brisbane was set to 0.9 based on Fanger and Toftum’s (2002) suggestion. Activity level reduction was also taken into consideration.

3. Results and discussion

3.1 Cross ventilation

The experimental measurements for cross ventilation setting were carried out on January 13th for 24 hours. A summary of external weather conditions and measured values are presented in Table 1. A narrower temperature range is evident inside the case study compared to the external weather temperature while the internal average temperature is slightly higher yet very close to the external weather mean temperature ($\Delta T_{\text{mean}}=0.6$).

<p>| Table 1: weather condition and measured values summary for the cross ventilation setting |
|-----------------------------------------------|-----------------------------------------------|</p>
<table>
<thead>
<tr>
<th>External weather condition</th>
<th>Internal measured values</th>
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<tbody>
<tr>
<td>Temperature (°C)</td>
<td>Mean</td>
</tr>
<tr>
<td>26.25</td>
<td>31</td>
</tr>
<tr>
<td>RH (%)</td>
<td>65.8</td>
</tr>
<tr>
<td>Wind speed (m/s)</td>
<td>1.8</td>
</tr>
</tbody>
</table>
The extended PMV values and corresponding PPD for the experiment duration are plotted against
the time of day in Figure 3. The lowest and highest values for PMV are -0.64 and 0.98 respectively.
Average PMV and PPD are 0.23 and 8.9% correspondingly demonstrating a predominantly comfortable
environment for the cross ventilation setting. PMV exceeds ASHRAE upper limit (0.5) for 28% of the
experiment time and it is mainly from around 11:30 am to 4 pm when the outside temperature is high.

![Figure 3: extended PMV and PPD results for the cross ventilation setting](image-url)

### 3.2. Single-sided ventilation

Physical measurements were conducted on January 14\textsuperscript{th} in the same case study building with single-sided ventilation setting. All the opening conditions were kept the same as cross ventilation setting except that the northern balcony door was fully closed during the measurements. Outside weather and internal conditions presented in Table 2 show higher temperatures inside the case study with average value difference of about 2 °C (\(\Delta T_{\text{mean}}=2.02\)). In addition, internal temperature changes in a relatively limited range compared to the outside temperature variations.

<table>
<thead>
<tr>
<th>External weather condition</th>
<th>Internal measured values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>26.28</td>
</tr>
<tr>
<td>RH (%)</td>
<td>66</td>
</tr>
<tr>
<td>Wind speed (m/s)</td>
<td>2.14</td>
</tr>
</tbody>
</table>

PMV and PPD were calculated and rendered in Figure 4. Average PMV of 1 and average PPD of 28%
highlight a dominant warm internal thermal condition. PMV results also confirm an uncomfortable
Thermal comfort evaluation of natural ventilation mode: case study of a high-rise residential building

Internal condition for the single-sided ventilation setting as PMV exceeds the 0.5 limit for 99% of the time. PMV reaches its highest range (1.2-1.6) from around 11 am to 4:30 pm which can be due to high external temperature and solar radiation.

Figure 4: extended PMV and PPD results for the single-sided ventilation setting

3.3. Discussion

The experimental measurements for single-sided and cross ventilation cases were carried out on two consecutive days in summer under relatively similar weather conditions to allow fair comparison of ventilation mode performance and its effect on thermal comfort in a hot summer day when cooling is needed most. All the influential and controllable variables such as size of the openings, sensors height and location were kept the same in both measurement settings. Results reported in section 3.1 and 3.2 revealed a significant difference between single-sided and cross ventilation performance in terms of thermal comfort. PMV values from both settings are also displayed in Figure 5 for better interpretation and comparison between the two cases.

Single-sided ventilation failed to provide thermal comfort in a hot summer day since PMV value was within the comfort zone for only 1% of the time. On the other hand, cross ventilation could provide a comfortable thermal environment for more than 70% of the time. Average PMV values for single-sided ventilation was more than four times higher than that of the cross ventilated case. The difference between these two ventilation modes becomes even more apparent when considering that in the cross ventilation setting, the PMV values were under the lower limit of thermal comfort (-0.5) representing cool thermal sensation for about 1% of time which happened around midnight. Given that occupants have control on the openings, the cool sensation that would result from high airspeed can be eliminated by the occupants in such instances.

Looking at Figure 5, both cases have experienced their highest PMV range from around noon to 4:30 pm which should be related to temperature rise as a result of solar radiation. In addition, both graphs follow a consistent trend while more fluctuations of PMV values are evident in the cross ventilation...
graph. This can be explained by the fluctuating nature of wind and the fact that the cross ventilation case has experienced higher indoor airspeeds.

![Extended PMV Results for the Single-Sided Ventilation Setting](image)

In summary, cross ventilation performed considerably better than single-sided ventilation in terms of thermal comfort as could be expected. However, the major result is the significant difference which puts the two ventilation modes almost at two ends of the spectrum. While single-sided ventilation totally failed in providing thermal comfort, cross ventilation offered desirable thermal conditions for more than 70% of time. Considering all the influential parameters except for ventilation mode were similar in both cases, this extreme difference can be explained by natural ventilation driving forces in each case.

The potential reduction in air conditioning equipment cost versus the possible increased cost of designing for cross ventilation needs to be studied.

4. Conclusion

This study evaluated the performance of two major ventilation modes, namely single-sided and cross ventilation, in providing thermal comfort for occupants of a high-rise residential building situated in Brisbane, Australia. Full-scale measurements of airspeed, temperature and RH were carried out in a residential unit of the building. Measurements were conducted in summer to allow assessment for the expected worst case scenarios. Two experimental arrangements of single-sided and cross ventilation were examined during two consecutive days in the same case study unit. Extended PMV and PPD were adopted as thermal comfort assessment criteria. It was found that cross ventilation could provide thermal comfort for more than 70% of the day while in the case with single-sided ventilation thermal comfort was achieved for only 1% of time. This suggests that in case of applying cross ventilation the need for air conditioning for space cooling can be reduced significantly.

It needs to be noted that this study was conducted at a case study unit at fifth floor. Considering that wind magnitude increases with the increase in height, higher airspeeds can be expected at upper floors
and vice versa. Therefore, higher floors could potentially experience acceptable thermal conditions for longer periods compared to the tested case study. Finally, regardless of building’s height, natural cross ventilation is a much more effective solution than single-sided ventilation in providing thermal comfort.

References


Bridging the gap between environmental sustainability and heritage preservation: towards a certified sustainable conservation, adaptation and retrofitting of historic buildings

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Abstract: In front of the increasing importance of greenhouse gas emissions reduction required by European Directives and international agreements, historic buildings performance upgrade plays an important role in mitigating climate change. However, historic buildings are still excluded from deep renovation activities and a balance between historic values and environmental sustainability is yet to be found. If environmental certification represents a key strategy for promoting and improving energy efficiency, environmental quality, rational use of resources, and design innovation, the definition of methodologies and tools for orienting the conservation and adaptation process towards high performance levels can allow heritage buildings to play a relevant role in global reduction of energy use and CO₂ emission, while maintaining their unique features. To this regard, the paper presents GBC Historic Building®, a new assessment method developed by the Green Building Council of Italy and derived from the widely adopted standard Leadership in Energy and Environmental Design (LEED®). The new rating system evaluates the sustainability level of conservation-related activities on pre-industrial buildings subject to major renovation through a holistic and transparent approach.

Keywords: Historic Building; Environmental Sustainability; Rating System; LEED®.

1. Introduction

The combination between the preservation of heritage values and the overall performance upgrading of historic buildings still represent a critical issue and a challenging activity in Europe. The target of a widespread deep renovation of the existing building stock, i.e. beyond minimum energy performance requirements (European Parliament and Council, 2012), necessarily entails the definition of effective methodologies for addressing also the historic heritage, which represents an important asset in Europe. To this regard, environmental certification is a key issue for improving energy efficiency, environmental quality, rational use of resources and design innovation, allowing transparency during all the process’ phases and the environmental management in buildings, while preserving the buildings’ cultural identity. To tackle this issue, the Green Building Council of Italy has worked for the promotion of a dialogue
between the sustainability criteria and the knowledge of the conservation world, developing a new tool called *GBC Historic Building®* for the voluntary certification of the sustainability level of conservation, rehabilitation and adaptation of historic buildings (Green Building Council Italia, 2014). The tool is developed on *LEED® 2009 Italia Nuove Costruzioni e Ristrutturazioni* (Green Building Council Italia, U.S. Green Building Council, 2011), a local version of one LEED® rating system, which, although potentially applicable to historic buildings, does not consider the valorisation of heritage values through a design activity compliant with the preservation principles.

### 2. When to use *GBC Historic Building®*

In the new rating system, a ‘historic building’ is a construction which represents a “material witness having the force of civilisation” (Franceschini *et al.*, 1967) characterised by a pre-industrial building process (in terms of phases, tasks and operators), pre-industrial materials and construction techniques (spontaneous and local) and pre-industrial technical elements. The threshold between a pre-industrial and an industrialised process in Europe is, conventionally, 1945, the year when the massive and widespread post-war reconstruction activity begun, leading to the deep transformation of the building sector in terms of materials, technologies and techniques. Therefore, the existing building aiming at the certification must have been built before 1945 for at least 50% of the existing technical elements. In order to assess whether the building fits the scope of the rating system’s field of application, a new information form has been developed, namely the ‘Historic Building Identity Card’ (Boarin, Guglielmino, & Zuppiroli, 2014). In case the building was built after 1945 but demonstrates the above-mentioned pre-industrial features and has recognised cultural heritage value, the rating system is applicable. If the building was built before 1945 for a portion of less than 50% of the existing technical elements, the already existing rating systems of the LEED® or GBC® family can be adopted.

The protocol can be used for projects seeking a range of intervention degrees, from conservation to renovation (according to the definitions provided in Douglas, 2006). Demolition and reconstruction of copies of existing or former structures are out of the scope of the protocol as they are, by all means, a new construction. In all cases, the main goal of the process must be the major renovation, defined as action that involves significant elements of HVAC systems and the renewal or functional reorganization of interior spaces, considering a building envelope’s performance improvement consistent with the preservation of the heritage, architectural, and construction features.

Further to the criteria above and similarly to the LEED® process, the project must demonstrate compliance with a list of Minimum Project Requirements (MPRs), i.e. minimum characteristics that a project must possess in order to be eligible for certification (Green Building Council Italia, 2016).

### 3. Methodology

The development of the new rating system started in 2012 when the Green Building Council (GBC) of Italy highlighted that the gap in the application of the European Directive 2012/27/EU (European Parliament and Council, 2012) to traditional and heritage buildings could actually become an important opportunity for the building sector in Italy, where the building conservation represents a significant asset. In order to combine the theoretical knowledge and the professional practice together, the GBC of Italy activated a Technical Advisory Group (TAG) formed by representatives of the Italian Universities and the building sector, who worked in co-ordination with the technical and certification groups of the Italian association. The activities were developed through the following phases:
Phase 1: analysis of GBC of Italy’s already existing rating system for major renovations, i.e. LEED® 2009 Italia Nuove Costruzioni e Ristrutturazioni;

Phase 2: analysis, during the public ballot period, of the new version of the LEED® protocols for major renovations released by the U.S. Green Building Council (LEED® v4), in order to evaluate the possible integration of new credits or new approaches into GBC Historic Building®;

Phase 3: assessment of preliminary case studies with the existing LEED® NC 2009 Italia and definition of applicable (also with modifications and/or integrations) and non-applicable credits;

Phase 4: research and development of new prerequisites and credits; in parallel, implementation and/or modification of existing credits;

Phase 5: credit weighting of the new protocol, based on the priorities highlighted during the gap analysis process (phase 3); publication of the rating system’s short version;

Phase 6: development of the new supporting tools and information forms for demonstrating the project compliance to the rating system and development of the certification process; publication of the rating system’s long version; application for case studies is open;

Phase 7: publication of the rating system’s long version with errata and addenda; application for full certification is open; preparation of educational activities for accredited professionals and accredited inspectors.

During the gap analysis (phase 3), LEED® NC 2009 Italia has been used for the complete assessment of three preliminary case studies that were considered representative of the new targeted field of application from the historical, architectural, technological and environmental point of view. This evaluation has defined strengths, weaknesses, opportunities and threats of the existing tool, in terms of relevance and applicability of the existing prerequisites and credits, on one side, and related to the existing certification process, on the other side, including the accredited professionals and inspectors to be trained and the integrative documentation to be prepared. During the gap analysis, the evaluation of a preliminary possible convergence towards the v4 version released at the time by the U.S. Green Building Council was also done. Another relevant result of this phase was the definition of credits that are not applicable to heritage buildings (and therefore to be deleted), mainly because they are related to the construction of new buildings and their connections with the surrounding environment.

As result, the TAG highlighted that principle, objectives and procedures for delivering a sustainable conservation process for the historic heritage were not completely addressed by the existing tool and that, in many cases, an adjustment and/or implementation of the existing credits was needed. The development of a brand new category (namely ‘Historic Value’) resulted from this review, aiming at collecting all the requirements related to the fulfilment of conservation principles within the building process, with particular attention to the acknowledgement of heritage values as sustainability criteria. This approach conveys the interpretation of the conservation activity as “methodological moment in which a work of art is appreciated in its material form and its historical and aesthetic duality for its transmission to the future” (Brandi, 1963), thus becoming a sustainable ‘action’ itself and therefore assessable through tools and methods pertaining to the sustainability context (such as LEED®).

4. Credit weightings

All the LEED® protocols are structured on the basis of a maximum achievable score of 110 points (100 points as sum of the scores assigned to the credit of thematic areas Historic Value, Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources and Indoor Environmental Quality, to which further 10 points allocated to areas thematic Innovation in Design and Regional Priority are added).
In order to allocate new points to the ‘Historic Value’ category, a revision of the scores assigned to each existing credit has been done, according to the results of the assessment conducted during the gap analysis. All aspects of the historic building that could be evaluated through existing credits, even in case of their partial applicability, were integrated through additions or modifications, in order to preserve the existing structure and language as much as possible. The new credits allocated in the ‘Historic Value’ category used the 9 points coming from those non-applicable existing credits in LEED® NC 2009 Italia. Besides, since the relevance of this new credits for the promotion of a sustainable conservation process and for the field of application, it was decided to give the area a high impact within the overall certification, i.e. the 20% (equal to 20 points) of the total points available, excluding the topic Innovation in Design and Regional Priority (therefore, 18.2% considering the whole rating system). Further to the first allocation of points, all existing credits were proportionally decreased and rounded in order to achieve the targeted number of points for the new category. The comparison between the allocation of points and distribution of weightings in the reference tool and in GBC Historic Building® is shown in Table 1.

Table 1: Comparison between the allocation of points and weightings for each topic in LEED® NC 2009 Italia and in GBC Historic Building®.

<table>
<thead>
<tr>
<th>Topic</th>
<th>LEED® NC 2009 Italia</th>
<th>GBC Historic Building®</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Points per topic</td>
<td>Topic Weightings [%]</td>
</tr>
<tr>
<td>Historic Value (HV)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Sustainable Sites (SS)</td>
<td>26</td>
<td>23.6</td>
</tr>
<tr>
<td>Water Efficiency (WE)</td>
<td>10</td>
<td>9.1</td>
</tr>
<tr>
<td>Energy and Atmosphere (EA)</td>
<td>35</td>
<td>31.8</td>
</tr>
<tr>
<td>Materials and Resources (MR)</td>
<td>14</td>
<td>12.7</td>
</tr>
<tr>
<td>Indoor Environmental Quality (IEQ)</td>
<td>15</td>
<td>13.6</td>
</tr>
<tr>
<td>Innovation in Design (ID)</td>
<td>6</td>
<td>5.5</td>
</tr>
<tr>
<td>Regional Priority (RP)</td>
<td>4</td>
<td>3.6</td>
</tr>
<tr>
<td>Total</td>
<td>110</td>
<td>100%</td>
</tr>
</tbody>
</table>

5. Structure of the rating system and topics

The following paragraphs introduce the structure and contents of all the categories of the new rating system, showing the allocation of points, the eligibility of the credits for one extra point for Exemplary Performance (EP) and highlighting the type of activity on the existing LEED® NC 2009 Italia rating tool, i.e.:

- development of new prerequisites/credits;
- revision (major or minor) of existing prerequisites/credits;
- confirmation of existing prerequisites/credits.

5.1 Topic ‘Historic Value’ (HV)

‘Historic Value’ (HV) is the main innovation in GBC Historic Building® and the prerequisite and all credits are brand new (Table 2).

The prerequisite’s aim is to acknowledge and identify the historic building’s heritage value through the analysis of its features and its transformations across the time. In particular, it requires evidences regarding the multiple construction phases and different uses, structures, materials, construction techniques, on-going deterioration processes and both historic and non-historic comfort systems.
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The group of credits related to the advanced analyses are oriented towards the in-depth assessment of the building’s state-of-the-art from the energy, materials, degradation and structural point of view. Reversibility and compatibility, two milestones of preservation together with minimum intervention, represent an important aspect of this topic. Particularly, the compatibility principle is addressed in its intangible and tangible connotations: the first, in terms of compatibility of the new use and positive effects on the community provided by the access to the building; the second, in terms of compatibility of the new integrated mortars and structural improvement.

The topic HV also includes one credit related to the sustainable management of the building site, aiming at reducing the negative impacts that could potentially affect the different environmental components and surrounding communities, also improving the awareness and communication on the site’s heritage value. Furthermore, the inclusion of one credit regarding the future maintenance plan contributes to the reduction of costs on a long-term period, helping the improved performances and quality achieved to be maintained.

The last credit awards the collaboration of a Specialist in the preservation of buildings and sites, a professional figure with accreditation and/or expertise in the field, who can help the design team in the definition of strategies that are as much sustainable and compatible as possible with the historic building.

Table 2: List of prerequisite and credits of the topic ‘Historic Value’.  

<table>
<thead>
<tr>
<th>Prerequisite/Credit</th>
<th>Points</th>
<th>Eligibility for EP</th>
<th>Type of credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prerequisite 1 – Preliminary analysis</td>
<td>Mandatory</td>
<td>Not eligible</td>
<td>New</td>
</tr>
<tr>
<td>Credit 1.1 – Advanced analysis: energy audit</td>
<td>1-3 points</td>
<td>Not eligible</td>
<td>New</td>
</tr>
<tr>
<td>Credit 1.2 – Advanced analysis: diagnostic tests on materials and deterioration</td>
<td>2 points</td>
<td>Not eligible</td>
<td>New</td>
</tr>
<tr>
<td>Credit 1.3 – Advanced analysis: diagnostic tests on structures and structural monitoring</td>
<td>2-3 points</td>
<td>Not eligible</td>
<td>New</td>
</tr>
<tr>
<td>Credit 2 – Project reversibility</td>
<td>1-2 points</td>
<td>Eligible</td>
<td>New</td>
</tr>
<tr>
<td>Credit 3.1 – Compatibility of the new use and open community</td>
<td>1-2 points</td>
<td>Eligible</td>
<td>New</td>
</tr>
<tr>
<td>Credit 3.2 – Chemical and physical compatibility of mortars</td>
<td>1-2 points</td>
<td>Not eligible</td>
<td>New</td>
</tr>
<tr>
<td>Credit 3.3 – Structural compatibility</td>
<td>2 points</td>
<td>Not eligible</td>
<td>New</td>
</tr>
<tr>
<td>Credit 4 – Sustainable building site</td>
<td>1 point</td>
<td>Eligible</td>
<td>New</td>
</tr>
<tr>
<td>Credit 5 – Scheduled maintenance plan</td>
<td>2 points</td>
<td>Not eligible</td>
<td>New</td>
</tr>
<tr>
<td>Credit 6 – Specialist in preservation of buildings and sites</td>
<td>1 point</td>
<td>Not eligible</td>
<td>New</td>
</tr>
</tbody>
</table>

Maximum total points allocated to the topic 20 points

5.2. Topic ‘Sustainable Sites’ (SS)

This topic addresses the environmental aspects related to the place where the historic building is located, with a focus on the environmental concerns related to building landscape, hardscape and exterior building issues. The prerequisite is aimed at the reduction of pollution from construction activities in order to guarantee health and comfort for the people inhabiting the building or the vicinity during all the construction phases. The removal of pollution and hazardous materials from the building site are important activities addressed within the credits, as well as the recovering of open spaces, previously saturated or paved, and altered historic gardens. The group of credits related to alternative transportation encourage multimodal transportation choices or otherwise reduced motor vehicle use, thereby reducing greenhouse gases, air pollution, and other environmental and public health harms associated with motor
vehicle use. The integration of effective strategies to control, reduce and treat stormwater runoff and the minimization of heat islands effects are other important intents, together with the reduction of light pollution. Table 3 shows the list of prerequisite and credits.

Table 3: List of prerequisite and credits of the topic ‘Sustainable Sites’.

<table>
<thead>
<tr>
<th>Prerequisite/Credit</th>
<th>Points</th>
<th>Eligibility for EP</th>
<th>Type of credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prerequisite 1 – Construction activity pollution prevention</td>
<td></td>
<td>Mandatory</td>
<td>Confirmed</td>
</tr>
<tr>
<td>Credit 1 – Brownfield redevelopment</td>
<td>2 points</td>
<td>Not eligible</td>
<td>Major revision</td>
</tr>
<tr>
<td>Credit 2.1 – Alternative transportation: public transportation access</td>
<td>1 point</td>
<td>Eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Credit 2.2 – Alternative transportation: bicycle storage and changing rooms</td>
<td>1 point</td>
<td>Eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Credit 2.3 – Alternative transportation: low-emitting and fuel-efficient vehicles</td>
<td>1 point</td>
<td>Eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Credit 2.4 – Alternative transportation: parking capacity</td>
<td>1 point</td>
<td>Eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Credit 3 – Site development: open spaces recovery</td>
<td>2 points</td>
<td>Eligible</td>
<td>Major revision</td>
</tr>
<tr>
<td>Credit 4 – Stormwater design: quantity and quality control</td>
<td>2 points</td>
<td>Not eligible</td>
<td>Major revision</td>
</tr>
<tr>
<td>Credit 5 – Heat island effect: non-roof and roof</td>
<td>2 point</td>
<td>Eligible</td>
<td>Major revision</td>
</tr>
<tr>
<td>Credit 6 – Light pollution reduction</td>
<td>1 point</td>
<td>Not eligible</td>
<td>Confirmed</td>
</tr>
</tbody>
</table>

Maximum total points allocated to the topic 13 points

5.3. Topic ‘Water Efficiency’ (WE)

Through this topic, in addition to the reduction of water consumption, it is possible to enhance the contribution of pre-industrial devices for stormwater collection and management, through their conservation or renovation, as well as to improve the efficiency of fountains and other water amenities in outdoor spaces. A brand new credit on water metering (U.S. Green Building Council, 2013) was included, supporting water management and identifying opportunities for additional water savings by tracking water consumption. Table 4 shows the list of prerequisite and credits.

Table 4: List of prerequisite and credits of the topic ‘Water Efficiency’.

<table>
<thead>
<tr>
<th>Prerequisite/Credit</th>
<th>Points</th>
<th>Eligibility for EP</th>
<th>Type of credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prerequisite 1 – Water use reduction</td>
<td></td>
<td>Mandatory</td>
<td>Confirmed</td>
</tr>
<tr>
<td>Credit 1 – Water efficient landscaping</td>
<td>1-3 points</td>
<td>Not eligible</td>
<td>Confirmed</td>
</tr>
<tr>
<td>Credit 2 – Water use reduction</td>
<td>1-3 points</td>
<td>Eligible</td>
<td>New</td>
</tr>
<tr>
<td>Credit 3 – Water metering</td>
<td>1-2 points</td>
<td>Eligible</td>
<td>New</td>
</tr>
</tbody>
</table>

Maximum total points allocated to the topic 8 points

5.4. Topic ‘Energy and Atmosphere’ (EA)

One of the innovative aspects of GBC Historic Building® is the consideration that energy efficiency and retrofit process represent a form of protection of the historical building (Carbonara, 2015) and not a change in the building’s original material consistency. This category is based on the principle of building performance improvement compared to a reference condition, rather than an adaption to pre-defined and fixed performance levels. In fact, any improvement is an important step towards the energy consumption and greenhouse gases emissions reduction and towards the improvement of comfort
Bridging the gap between environmental sustainability and heritage preservation: towards a certified sustainable conservation, adaptation and retrofitting of historic buildings

conditions. This approach allows greater opportunities in terms of range of intervention on the historic building. Commissioning is another important awarded measure to meet the owner’s project requirements for energy, water, indoor environmental quality and durability, with further opportunities for the commissioning of the building envelope. The category also promotes the integration of renewable energy sources produced on-site or resulting from certified off-site green energy production. Moreover, measurements and verification of the consumption during operation and refrigerant management are also awarded. Table 5 shows the list of prerequisite and credits.

Table 5: List of prerequisite and credits of the topic ‘Energy and Atmosphere’.

<table>
<thead>
<tr>
<th>Prerequisite/Credit</th>
<th>Points</th>
<th>Eligibility for EP</th>
<th>Type of credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prerequisite 1 - Fundamental commissioning of building energy systems</td>
<td>Mandatory</td>
<td>Not eligible</td>
<td>Confirmed</td>
</tr>
<tr>
<td>Prerequisite 2 – Minimum energy performance</td>
<td>Mandatory</td>
<td>Not eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Prerequisite 3 – Fundamental refrigerant management</td>
<td>Mandatory</td>
<td>Not eligible</td>
<td>Confirmed</td>
</tr>
<tr>
<td>Credit 1 – Optimize energy performance</td>
<td>1-17 points</td>
<td>Eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Credit 2 – Renewable energies</td>
<td>1-6 point</td>
<td>Eligible</td>
<td>New</td>
</tr>
<tr>
<td>Credit 3 – Enhanced commissioning</td>
<td>2 points</td>
<td>Eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Credit 4 – Enhanced refrigerant management</td>
<td>1 point</td>
<td>Not eligible</td>
<td>Confirmed</td>
</tr>
<tr>
<td>Credit 5 – Measurement and verification</td>
<td>3 points</td>
<td>Not eligible</td>
<td>Confirmed</td>
</tr>
</tbody>
</table>

Maximum total points allocated to the topic 29 points

5.5. Topic ‘Materials and Resources’ (MR)

This credit category focuses on minimizing the embodied energy and other impacts associated with the extraction, processing, transport, maintenance and disposal of building materials, while enhancing the building’s original features. The requirements are designed to support a life-cycle approach that improves performance and promotes resource efficiency both for the retrofitted building and its improvements or new volumes, when relevant. The prerequisite on the collection and storage of recyclable is new, but it is founded on pre-existing GBC-related rating system. The prerequisite and credit regarding the building reuse derive from the previous credits, but their structure has been changed and it is now based on the ‘Historic Building Identity Card’ form (Boarin et al., 2014). The brand new credit on building product environmental optimisation is based on the Environmental Product Declaration (EPD) or on the Life Cycle Assessment approach and it has been added to promote a positive market transformation in the production of materials used for conservation purposes. Table 6 shows the list of prerequisite and credits.

Table 6: List of prerequisite and credits of the topic ‘Materials and Resources’.

<table>
<thead>
<tr>
<th>Prerequisite/Credit</th>
<th>Points</th>
<th>Eligibility for EP</th>
<th>Type of credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prerequisite 1 – Storage and collection of recyclables</td>
<td>Mandatory</td>
<td>Not eligible</td>
<td>Confirmed</td>
</tr>
<tr>
<td>Prerequisite 2 – Demolition and construction waste management</td>
<td>Mandatory</td>
<td>Not eligible</td>
<td>New</td>
</tr>
<tr>
<td>Prerequisite 3 – Building reuse</td>
<td>Mandatory</td>
<td>Not eligible</td>
<td>New</td>
</tr>
<tr>
<td>Credit 1 – Building reuse: maintaining existing technical element and finishing</td>
<td>3 points</td>
<td>Not eligible</td>
<td>Major revision</td>
</tr>
<tr>
<td>Credit 2 – Demolition and construction waste management</td>
<td>1-2 points</td>
<td>Not eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Credit 3 – Materials reuse</td>
<td>1-2 points</td>
<td>Eligible</td>
<td>Minor revision</td>
</tr>
</tbody>
</table>
Credit 4 – Building product environmental optimization 1-5 points Eligible New
Credit 5 – Regional materials 1-2 points Eligible Minor revision
Maximum total points allocated to the topic 14 points - -

5.6. Topic ‘Indoor Environmental Quality’ (IEQ)

The achievement of high indoor comfort levels can sometimes be very complex for historic buildings, due to the presence of decorated surfaces or high artistic and heritage values that do not allow any substantial interventions on the technical elements. For this reason, the compliance with the requirements can be achieved through a dual approach: the first allows a higher degree of preservation and is more suitable for buildings with higher heritage values or special character; the second is oriented towards the achievement of high levels of comfort and is more suitable for buildings with a higher potential in terms of renovation. The improvement of indoor air quality through ventilation, the management of indoor air contaminants, the use of low-emitting materials and products and the occupants’ possibility to control comfort conditions are the fundamentals of this credit category and can be pursued through the dual approach mentioned above. Table 7 shows the list of prerequisite and credits.

Table 7: List of prerequisite and credits of the topic ‘Indoor Environmental Quality’.

<table>
<thead>
<tr>
<th>Prerequisite/Credit</th>
<th>Points</th>
<th>Eligibility for EP</th>
<th>Type of credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prerequisite 1 – Minimum indoor air quality performance (IAQ)</td>
<td></td>
<td>Mandatory</td>
<td>Not eligible</td>
</tr>
<tr>
<td>Prerequisite 1 – Environmental Tobacco Smoke (ETS) control</td>
<td></td>
<td>Mandatory</td>
<td>Not eligible</td>
</tr>
<tr>
<td>Credit 1 – Indoor air monitoring</td>
<td>2 points</td>
<td>Not eligible</td>
<td>Major revision</td>
</tr>
<tr>
<td>Credit 2 – Minimum outdoor air delivery assessment</td>
<td>2 points</td>
<td>Not eligible</td>
<td>Major revision</td>
</tr>
<tr>
<td>Credit 3.1 – Construction indoor air quality management plan: during construction</td>
<td>1 point</td>
<td>Not eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Credit 3.2 – Construction indoor air quality management plan: before occupancy</td>
<td>1 point</td>
<td>Not eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Credit 4.1 – Low-emitting materials: adhesives and sealants, cement-based materials and timber finishes</td>
<td>1 point</td>
<td>Not eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Credit 4.2 – Low-emitting materials: paints and coatings</td>
<td>1 point</td>
<td>Not eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Credit 4.3 – Low-emitting materials: flooring systems</td>
<td>1 point</td>
<td>Not eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Credit 4.4 – Low-emitting materials: composite wood and agrifiber products</td>
<td>1 point</td>
<td>Not eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Credit 5 – Indoor chemical and pollutant source control</td>
<td>1 point</td>
<td>Not eligible</td>
<td>Major revision</td>
</tr>
<tr>
<td>Credit 6.1 – Controllability of systems: lighting</td>
<td>1 point</td>
<td>Not eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Credit 6.2 – Controllability of systems: thermal comfort</td>
<td>1 point</td>
<td>Not eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Credit 7.1 – Thermal comfort: design</td>
<td>1 point</td>
<td>Not eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Credit 7.2 – Thermal comfort: verification</td>
<td>2 points</td>
<td>Not eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td>Maximum total points allocated to the topic</td>
<td>16 points</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.7. Topic ‘Innovation in Design’ (ID)

The objective of this category is to recognize projects for innovative building features, sustainable building practices and strategies during the conservation process, also rewarding excellence in case of performance that greatly exceeds those required by the credits within the other categories. Table 8 shows the list of prerequisite and credits.
Bridging the gap between environmental sustainability and heritage preservation: towards a certified sustainable conservation, adaptation and retrofitting of historic buildings

Table 8: List of prerequisite and credits of the topic ‘Innovation in Design’.

<table>
<thead>
<tr>
<th>Prerequisite/Credit</th>
<th>Points</th>
<th>Eligibility for EP</th>
<th>Type of credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Credit 1 – Innovation in design</td>
<td>1-5 points</td>
<td>Not eligible</td>
<td>Confirmed</td>
</tr>
<tr>
<td>Credit 2 – GBC Historic Building Accredited Professional</td>
<td>1 point</td>
<td>Not eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td><strong>Maximum total points allocated to the topic</strong></td>
<td><strong>6 points</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.8. Topic ‘Regional Priority’ (RP)

To encourage design teams to focus on regionalism, GBC Italia has identified some credits of the rating system for each of the three climate zones groups of the Italian territory. If achieved, these credits are rewarded extra points because of their importance for reducing environmental impacts at the local level. As example, EA Credit 1 – *Optimize energy performance* is eligible to one extra point Regional Priority for cold zones. Table 9 shows the list of prerequisite and credits.

Table 9: List of prerequisite and credits of the topic ‘Regional Priority’.

<table>
<thead>
<tr>
<th>Prerequisite/Credit</th>
<th>Points</th>
<th>Eligibility for EP</th>
<th>Type of credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Credit 1 – Regional priority</td>
<td>1-4 points</td>
<td>Not eligible</td>
<td>Minor revision</td>
</tr>
<tr>
<td><strong>Maximum total points allocated to the topic</strong></td>
<td><strong>4 points</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Certification process

The certification process is based on the verification of conformity by an accredited third-party organisation. Each prerequisite and credit has a dedicated form to be used to describe and demonstrate the compliance of both the design and construction activities with the rating tool’s requirements. All forms are to be completed by the design and construction team and contain a list of the information required by the accredited third-party organisation, in order to complete the verification on the design project and on the building site. The certification path includes the following phases:

- registration of the project and certification contract between the GBC of Italy and the applicant;
- design compliance verification by the accredited third-party organisation through qualified inspectors;
- construction compliance verification, including site inspection by the accredited third-party organisation through qualified inspectors;
- final review by the GBC of Italy;
- assessment of the certification level and release of the certification by the GBC of Italy.

At the end of the certification path, if all prerequisites and a minimum number of credits are achieved, the certification is reached. The sum of the achieved points defines the level of certification attainable, according to the following scale: “Certified”, 40 to 49 points earned; “Silver”, 50 to 59 points earned; “Gold”, 60 to 79 points earned; “Platinum”, above 80 points earned.

7. Conclusions and future research

*GBC Historic Building®* is a new Italian assessment tool that responds to the gap of legislation related to the improvement of environmental performances of heritage architecture. The holistic approach, typical of the LEED® and LEED®-based systems, allows the achievement of a balance between the different
requirements related to energy efficiency, environmental sustainability, indoor comfort and historic values. To this regard, the benefit of a clearly defined new category that collects the conservation-related prerequisite and credits lays in its flexibility, as it could be potentially adopted for other rating tools aiming at the environmental sustainability assessment of heritage buildings, but with a different field of application. It is the case of the future adaptation of another existing tool within the GBC ‘family’, i.e. GBC Home® that will be implemented and merged together with the current version of GBC Historic Building® in order to have a complete reference guide.

GBC Historic Building® is now available for the Italian market only, but future activities will evaluate its applicability out of the Italian boundaries, at a European level (regional) and at an international level (global). A possible approach to be investigated for the international adaptation could be the Alternative Compliance Paths (ACPs), i.e. additional options or approaches to the credits that address unique project needs, making the tool more flexible and applicable for projects outside Italy. The ACP approach is currently used by USGBC for projects outside US.

GBC Historic Building® is currently collecting the feedback from the first two registered case studies (a rural house in the countryside of the Province of Cuneo and a palazzo in the city centre of Turin, both in the North of Italy), which will help the validation process, and has seen the registration of the first pilot project willing to achieve full certification, targeting the ‘Gold’ level. The pilot project is the MEIS, the National Museum of the Italian Jewish Culture and of the Shoah, to be placed in a former prison in the historic centre of the UNESCO city of Ferrara, Northern Italy. The building, built in 1912 and abandoned in 1992, will host an exhibition space, a library and educational spaces and will be funded by the Italian Ministry of Cultural Heritage and Activities and Tourism.

References

Experimental construction in a timber house

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Abstract: This paper describes work undertaken in order to examine structural innovations in the New Zealand construction system, in order to test the efficiency of standard solutions vs newer methods of construction. The systems used are described and evaluated as possible scenarios for alternative construction methods, and the drawbacks and plaudits are discussed. It examines whether the standard methods of construction still hold validity, or if there are alternative systems worth further exploration. Can a system which utilises thin strips of engineered plywood woven into a stressed skin matrix, be the structural equivalent of standardised units of large timber sizes arrayed in a regular orthogonal grid? The weight, amount, and cost of the systems are compared and findings are discussed.

Keywords: plywood; click-raft; experimental; housing.

1. Introduction

New Zealand Standard 3604 (NZS 3604) is the formally recognised, standard means of construction for the vast majority of New Zealand residential building projects. It is an extremely prescriptive, pre-engineered solution for timber-framed housing up to 3 stories tall. It removes the need for a structural engineer to be involved in the design of a house if the house is fully compliant with the limited scope of NZS 3604. Functionally however, NZS3604 merely formalizes the traditional form of timber framing prevalent in New Zealand since colonization and features few (if any) innovative improvements over the more traditional balloon framing. This paper examines a building construction project (completed September 2016) which utilizes an alternative to traditional, NZS3604 methods of timber framed construction.

The volume and weight of timber being utilised in the building project concerned forced a rethink part way through the project, to trial using plywood as a series of woven strips to form a stressed-skin structural matrix. The system may compete with a more traditional timber structure in terms of strength and cost, thereby offering more value to the owners as well as speeding up the building process. The ensuing research question tackled in this paper is therefore “can a plywood based woven lattice system compete with a timber frame system for similar load conditions?”

While the construction project visually conforms on the exterior primarily to images of stereotypical New Zealand construction, internally, the building houses an innovative response to the environment.
2. Background

The prescriptive-based NZS 3604 has to work alongside the New Zealand Building Code (NZBC), which by contrast is a performance-based code for construction. The NZBC contains 17 Clauses, which range from B1 (Structure), through E2 (External Moisture), to H1 (Energy). These clauses, while on the surface still being very performance based, have over the last 15 years been serially revised and are now much more prescriptive as to what are deemed to be “Acceptable Solutions”.

New Zealand has many houses that have lasted well over 100 years with good quality building solutions, but more recently the house building industry has had a chequered history, involving several billion dollars worth of building envelope failures and even some structural collapse within 10 years, due to systemic bad building issues. Murphy has written extensively on the history of the “Leaky Building Crisis” in papers presented at ANZASCA (Murphy, 2010 and 2011) and Alexander et al have written a history of the Leaky Building Crisis (Alexander, 2011).

A dichotomy arises in the case of constructing a home in NZ. Clauses B1 and E2 set out standard details of construction, while NZS 3604 describes the route to achieving the pre-determined details. Typically these are details for a 1-2 storied timber framed building with aluminium windows and an external facade comprising timber weatherboard, profiled metal, brick veneer or externally insulated facade systems (EIFS). Building solutions that are not in strict accordance with B1 and E2 then become, typically, an “Alternative Solution” for which justification is needed and / or prior precedence is often requested by Building Consent Officers (BCO).

Some of these Alternative Solutions are reasonably common and easily accepted by BCOs (such as proposing timber windows instead of aluminium windows), while other Alternative Solutions have to be justified on paper, often at considerable expense to the architect or owner. For those reasons, most NZ houses are strictly dull iterations of regurgitated B1, E2, and NZS 3604 details, in order to circumvent having to apply for Building Consent for an Alternative Solution.

Buckminster Fuller would frequently ask architects “how much does your building weigh?” (Braham, 2009), when extolling the benefits of his lightweight aluminium Dymaxion house, a phrase which has even made it into a feature length documentary in the film “How much does your building weigh, Mr Foster?” (Carcas, Amado and Sudjic, 2010). While the Dymaxion house was, in the end, not a financial or physical success, Fuller makes the point strongly that the use of limited natural resources going into construction projects needs to be considered. The approach of NZS 3604 does not take into account such esoteric concerns as building weight, only building strength using ‘traditional’ materials.

3. Project

This search for alternative construction systems is an ongoing project. Most standard residential buildings in NZ utilise timber framing studs sized at 100mm x 50mm nominal (90x45 actual), historically based around the imperial 4”x2” timber frame. Services such as electrical and plumbing are typically routed through a series of drilled holes in the timber frame, which further reduces strength (minimally) and flexibility for services route changes (retrospectively). This 90mm depth restricts the width of internal insulation to a maximum of 90mm, which in turn both impedes achieving a high R-value of insulation and also creates cold thermal bridges at regular intervals.

As requirements for R-values increase, insulation is now often being installed on the external face of the building, comprising polystyrene sheets screw-fixed externally directly over the framework, and often plastered as the final finish. Alexander notes that this EIFS construction system is one of the
primary contributors to Leaky Building Syndrome and the industry has largely moved to avoid building systems of this type by installing drained and ventilated cavities to the external face of the building, alongside (hopefully) better building practices (Alexander, 2011). Services, however, still are routed within walls.

On this particular project, due to the location in an ‘Extra High’ wind zone and height of the building, a minimum depth of 140 stud walls was required, which facilitated an increased depth of insulation within the timber wall-framing cavity. This puts the cost of timber up by 50%, but also has the follow-on effect of drastically increasing the volume and weight of the timber utilised, by a corresponding 50% also. Strength is also commensurately higher, and there is more room for services, but is the increased strength worth the extra cost and ensuing extra volume of timber? The physical strain of handling large and heavy lengths of timber during construction spurred a desire to seek methods of building substantially lighter from a stronger and yet more lightweight material: plywood.

The Extra High wind zone also required the building to have both a drained and ventilated cavity, as well as a rigid air barrier (RAB) to the inner face of the external cavity, so the opportunity was taken to utilize the North American system of completely sheathing the external face of the building (walls and roof) with a layer of structural 12mm structural bracing plywood to assist in both weathertightness and structural rigidity. This is an unusual solution in NZ, where walls and roof are normally sheathed only in lightweight fabric membrane ‘building wrap’ or, at most, a 4.5mm thick RAB to the walls only.

4. Click-Raft

The first part of this exploration was to exchange an area designed with timber floor beams, with a plywood lattice solution. One part of the house is two storied and contains an exposed underside of the upper floor. Originally, the floor was designed as a traditional timber frame, but during construction, a building amendment was lodged to change one part of the system to a plywood lattice, allowing a side-by-side comparison. This exposed underside is a structural solution, but does not follow standard means of fabrication, assembly or construction. Instead of the standard, fully NZS 3604-compliant solution of timber floor joists at 400mm centres, composed of regulated 190x45 lengths of machine-stress-graded (MSG-10) pinus radiata timber spanning across the room below, the building utilises the strength of 12mm thick plywood in order to create a woven grid of plywood beams to form a lightweight floor structure (refer figure 1).

The construction used is the Click-Raft system, developed by Christopher Moller and until now, used primarily in small out-buildings (Moller, 2016). Originally conceived of as a children’s construction toy but since developed into a system of prefabricated wall and floor components, Moller has now constructed a few of these Click-Raft buildings, including a small studio at his own house, where the Click-Raft system is used for walls, floors and roof structures, with a completely separate outer skin comprising the envelope. This allows the needs of the enclosing envelope (waterproofing, insulation etc) to be completely separated from the needs of the structural system (strength, longevity, rigidity etc).

Moller’s woven plywood system uses a series of “Click-Leaves” and “Click-Beams” cut from a plywood sheet using a CNC cutting head, with the final product being assembled on site on a flat surface, and then lifted by hand into place. The system has therefore undergone field testing in a number of locations in Europe and New Zealand and has had fairly rigorous engineering explorations over the last decade of developing the Click-Raft system. Engineering calculations were submitted to the Building Consent Authority as justification.
Figure 1: The Click-Raft floor as installed. (source: author, 2016)

A comparison of the two systems (traditional and plywood Click-Raft) is evaluated in table 1. The Click-Raft system, although highly innovative in terms of NZS 3604 and NZBC clause B1, nonetheless passed through the Building Consent amendment process without any fuss.
Table 1: Comparison of timber framing and plywood Click-Raft system for flooring.

<table>
<thead>
<tr>
<th>Element measurement</th>
<th>NZS 3604 compliant</th>
<th>Click Raft plywood</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam length</td>
<td>2400mm</td>
<td>2400mm</td>
<td>Plywood more fragile</td>
</tr>
<tr>
<td>Beam width</td>
<td>45mm</td>
<td>12mm</td>
<td>Plywood more flexible</td>
</tr>
<tr>
<td>Beam depth</td>
<td>190mm</td>
<td>190mm</td>
<td>Plywood strength same in vertical axis</td>
</tr>
<tr>
<td>Volume (m3 per m)</td>
<td>0.00855 m³/1.0m and 0.02052 m³/2.4m</td>
<td>0.00228 m³/1.0m and 0.005472 m³/2.4m</td>
<td>Ply volume less</td>
</tr>
<tr>
<td>Number of beams</td>
<td>10</td>
<td>20</td>
<td>Ply beam numbers doubled, but arranged as sinusoidal curves</td>
</tr>
<tr>
<td>Weight - material general</td>
<td>400kg/m³</td>
<td>600kg/m³</td>
<td>Ply weight 50% heavier than timber by volume</td>
</tr>
<tr>
<td>Weight of beam per meter (volume/m in brackets)</td>
<td>4kg/m (0.01m³)</td>
<td>1.5kg/m (0.0024m³)</td>
<td>Ply weight 2.5 times less than timber, due to reduced volume</td>
</tr>
<tr>
<td>Weight - per beam</td>
<td>9.6kg</td>
<td>3.6kg</td>
<td>Ply beam approx 1/3 weight for equiv length</td>
</tr>
<tr>
<td>Weight - actual usage</td>
<td>96kg</td>
<td>72kg</td>
<td>Ply system 75% of weight</td>
</tr>
<tr>
<td>Fixings</td>
<td>90mm power-driven nails, skew nailed 3 each side at ends and at blocking joists</td>
<td>No fixings to majority, as plywood interlocks, but screwed to centre beam</td>
<td>Less fixings to ply, but more fiddly to install.</td>
</tr>
<tr>
<td>Cost - unit (excluding GST)</td>
<td>$8.50 per lineal metre</td>
<td>$79 per sheet (2.44m²)</td>
<td></td>
</tr>
<tr>
<td>Cost - beam</td>
<td>$20.40</td>
<td>$13.20</td>
<td>Ply beam 65% of cost of timber beam</td>
</tr>
<tr>
<td>Cost - actually usage</td>
<td>$204</td>
<td>$264</td>
<td>Twice the number of beams, so ClickRaft system ends up 30% more expensive, not including design time and cutting time.</td>
</tr>
</tbody>
</table>

Note 1: Nogging not allowed for, but will be similar results.
1 row of blocking joists would be needed at mid span, between joists
4 rows of blocking required, CNC cut to interlock over the beams
Overall, blocking costs likely to be greater with ply system.

Note 2: Labour costs not allowed for in calculations.
Carpenter: 2 hours construction time estimated
Machine cutting time: 1 hour plus skilled operator. Unskilled assembly team of 2 at 15 minutes each.
Click-Raft notably swifter in assembly, but overall, excluding Design phase, labour costs are likely to be broadly similar.

Note 3: Material costs are wholesale, exclude GST, and retail costs may be 50% higher (or more). Table data sourced from NZTE (2011) and 2016 trade prices received by author.
Flooring over is 18mm ply, cost not included.
Screw fixed through flooring ply down into floor joists.
Flooring over is the same for both systems.
4.1 Summary of Click-Raft system.

A summary of figures from table 1 shows that the Click-Raft system utilizes plywood beams that are significantly less volumetric (about one quarter of the volume) and also lighter (40% of the weight) of a more traditional timber floor, but because the actual number of beams is doubled, the resultant weight saving is only 75% of the more traditional method. Costs are higher (30% more) for material, but would achieve significant savings in labour if adopted on a larger scale, as well as achieving better quality through more accurate dimensions. On the whole therefore, if just material cost is taken into account, the Click-Raft system is more expensive, but when potential labour savings and aesthetic appearance are taken on board, then the finished result would indicate that the system is a worthwhile investment.

In the building project explored here, a large beam was inserted down the centre of the room, and one Click-Raft system was installed to each side of the beam. The two Click-Raft systems were then stitched together with a plywood floor diaphragm reaching from side to side and screwed securely to both the central beam and the perimeter joists. The cost and weight of the central beam was not included in the calculations, as it would be necessary for either system. An alternative solution with no central beam, but instead relying on oversized timber floor joists / extra large plywood beams was briefly explored but it was not feasible on any front: neither cost, volume, or aesthetics, although there are many recognized means of linking together plywood sheets to form larger structural systems as shown by the Super-Slob projects (Tubby et al, 2012).

There seems no doubt that a plywood latticework system such as the Click-Raft can provide a significantly lighter building, assembled in a much more speedy fashion, at least in parts of a typical building. Further tests will have to be made to see if a plywood lattice can equal a more typical solution, particularly in strength and longevity - and like any new building prototype, there will be success and there may be failures. The Click-Raft system puts the plywood under stress to create tension and compression in both planes, and utilises the sinusoidal curve’s tension to create the strength in the waffle slab. As a result the floor, when loaded, becomes extremely rigid and creates a rigid platform / wall plane for building on, but the sinusoidal curve does create issues with the more rectilinear forms of traditional building materials such as plywood. Fixings between rectangular systems and sinusoidal edge strips of plywood can be especially awkward.

Moller continues to explore the uses of Click-Raft, including on larger building projects following the success of this residential test project, and his Mt Pleasant Community Centre building (also completed in September 2016) will utilise several new innovative structural solutions including folded plane CLT wall and roof panels anchored to a concrete slab floor, but any such system innovation is still going to be an Alternative Solution, rather than an Acceptable Solution (Moller, 2016).

However, one key aspect of the Click-Raft system unaccounted for by the need to reach and comply with the NZBC is it’s looks: Click-Raft has a grace and beauty inherent in the gentle sinusoidal curves of the Click-Leaves and, dependent on the angle viewed (and the viewer), looks like waves, or leaves, or surfboards. This is not the usual description of the underside of a wooden floor by a work-hardened carpenter. In reality, the construction system has an elegance often attained in the Gothic tradition by fan-vaulting ceilings, where the ribbed tracery of the ceiling is a direct outcome of the structural system used for construction. Perhaps Click-Raft is, in effect, a modern, pre-fabricated form of Gothic.

Moller’s use of Click-Raft solely as structure (with ornamentation as a pleasant side effect), allowing the separation of the external building envelope into a solely external system has its advantages, but it is potentially difficult to integrate into a large scale building. The traditional timber frame is normally
Experimental construction in a timber house utilized as the place to hide services, with electrical wiring and plumbing pipes ‘hidden’ within. In exposing the Click-Raft system such as Moller does (fully) or has been done here (exposed, but partially integrated into the walls), there is no convenient route for concealment of services. While in Moller’s buildings the Click-Raft structure is fully separated from the external cladding, permitting the use of the system as ‘free’ internal shelving, in this case the decision was made – independently – to line the walls with plywood. The plywood of the Click-Raft ceiling integrates visually well with the flat aesthetic look of the ply walls, integrating the system totally into the building and providing a harmonious experience.

4.2 Compressed Laminated Timber system.

As a comparison with these two systems, a third system was also examined for inclusion at design stage, but did not proceed due to issues of getting materials on site (the site concerned has no street access, so therefore no crane access is possible). This third system is the increasingly popular use of cross-laminated timber (CLT) as a structural and aesthetic system, well annotated in the construction of the Warrander Studio in Christchurch (Marriage and Sutherland, 2014). It rapidly became extremely obvious that while the Warrander Studio was highly innovative in New Zealand, the volume and weight of the building would be prohibitive on a site where everything had to be lifted in by hand.

CLT by weight is approx 40kg for a 100mm thick wall in a metre by metre panel, so a building nearly 6m high could weigh 240kg per metre of wall, and with wall panels typically 3m wide, each panel could weigh nearly 3/4 of a tonne. In terms of Buckminster Fuller's previous question therefore of “How much does your building weigh?” the answer to CLT is simply “way too much (without a crane)”. 5. Plywood Lego

The second part of the trail was to be another exploration of a plywood lattice system, set out on a more typical orthogonal grid, i.e. doing without the curving sinusoidal Click-Beams. In an effort to integrate more fully with a standard plywood sheet 2.4m long, an orthogonal plywood interlocking system was proposed for part of the house project. Plywood structural ‘studs’ were planned to intersect with plywood ‘nogs/dwangs’ and the whole was to be ‘stitched’ together with plywood walls connected by small CNC-cut interlocking teeth.

Numerous examples of interlocking plywood furniture exist, as well as entire fabrication systems such as the WikiHouse, where beams of plywood are interlocked with tight-fitting joints to create large spans. This is a fairly standard method of rigidly fixing two sheets of plywood together, and with CNC technology allowing tight friction-fit jointing, it allows plywood sheets to lock together without the need for screw fixings (Tubby et al, 2012). The Click-Raft system is largely screw-free as well: the CNC-cut slots rigidly define where every joint must occur. The Sutherland system used by Makers Of Architecture in the Warrander Studio utilises a completely screw-free gravity hanging system for the installation of external cassette panels on the outside face of the CLT base structure.
On this occasion however, the project did not get as far as the Building Consent Authority, and was stopped in its tracks by the structural engineer. As the wall concerned was a bracing wall, the engineer insisted on a perimeter structure of solid timber frame to each plywood bracing sheet (the building is completely externally clad with plywood to achieve high bracing results to combat the Extremely High wind zone). While for a while the design team was keen to accommodate the engineer’s requirements and attempted to change the system to a hybrid timber and plywood system, the resulting space left over for a solely plywood wall element was minimal, and the decision was made to delete this hybrid and just continue with a standard timber frame in order to permit the construction of the house to proceed according to program.
6. Conclusion

More time is required to fully test out whether the Click-Raft system is a worthy alternative to the more ‘tried and tested’ systems such as NZS 3604 timber framing, although if the Click-Raft system does require replacing at some stage in the future (hopefully never), then the house would require substantial rework to extricate the plywood from within the house. Faith is put in the calculations of the engineers that the strength of the system is up to the task of remaining vertical in an Extra-High wind zone. Further testing of the system could be undertaken on a separate test rig, i.e. testing compression and tension of the plywood lattice to destruction, as well as tests run on assessing thermal performance of a plywood system versus a traditional NZS 3604 system, but these aspects were not tested on the current project. The author hopes to be able to continue to use the project as a test bed for future building innovations.

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References

Prefabricated Passive House construction: Case study in Jinan, China

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Abstract: Passive House, promoted mostly in Germany, requires a high level of airtightness and high-quality construction, which can slow down the building process and so lead to difficulty in popularization. On the contrary, prefabricated building systems provide installation efficiency and protection of the site environment. By combining Passive House with prefabricated structures, a building project may not only achieve the standards for Passive House, but also be constructed within a short time. The two primary problems in designing and building prefabricated Passive Houses are cracks caused by the on-site assembly of components, and thermal bridges due to the steel structure. Taking a building in Jinan, China as a case study, this paper introduces a prefabricated, thermal bridge-free insulation system. The sandwich-shaped exterior wall system has four layers: a 100 mm PC inner wallboard, two 75 mm staggered high-density polyurethane insulation layers, and a 50 mm PC outer wallboard. By improving the structure of the key nodes, namely the slab joints of the exterior wallboards, foundation, roofs, and exterior window openings, the compound heat-transfer coefficient of this building envelope is 0.146 W/(m²·k), while the air change rate under 50 Pa differential pressure is 0.56/h.

Keywords: Passive House; prefabricated building; nearly zero energy consumption; architectural science.

1. Introduction

A number of developing countries, such as China, are in the process of rapid urbanization, which requires large amounts of new construction every year (Xu, 2014). Therefore, in a sense, there is a conflict or mismatch between the two aspects of building performance and speed of construction. Based on this contradiction, this research has been conducted to study methods of upgrading building energy-conservation levels in China, and to explore strategies for raising the construction efficiency of the Passive House (PH).

On the one hand, it is imperative to reduce the dependence of buildings on traditional fossil-fuel energy by cutting building energy consumption, as well as utilizing renewable energies. In recent years, China has made efforts to promote the construction of high-performance projects (Li, 2013), by
promulgating incentive policies for Green Building, issuing new building energy-saving standards (Yu, 2013), and constructing Green Ecological Urban Area. Under this trend, in 2009, propagated by the German Energy Agency (DENA), the concept of PH began to be popularized among Chinese architectural scientists (Lan, 2016). According to German standards, the heating demand of a PH should be less than 15kWh/(m²·a), which is far lower than the current Chinese code. It is estimated that if all new Chinese residential buildings with provision for heating were constructed in accordance with the PH standard, 3.2 billion tons of coal equivalent (Btce) could be saved by 2050. And if all existing residential buildings in Chinese cities and towns were retrofitted as PHs, the heating demand could be substantially reduced from 20 million tons of coal equivalent (Mtce) to 1.8 Mtce by 2050 (Zhang, 2014).

On the other hand, the implementation of PH faces numerous problems. Among these, the high technological requirements and the low construction speed are the two most significant issues. Compared with traditional work, a prefabricated building can save 70% of construction time and can do less harm to the surroundings (Wan, 2013; Liu, 2014). However, PHs should have superior airtightness performance such that the air change rate under 50 Pa differential pressure does not exceed 0.6/h. That is to say, the sealing condition of the building envelope has to reach a fairly high level. Whereas, it is inevitable that a prefabricated building has a number of cracks because of its assembly method. Although these cracks are acceptable in conventional buildings, they should be considered more carefully when designing PH. Additionally, a prefabricated structure is normally a steel system (Liu, 2012), which may cause obvious thermal bridges (Zhang, 2014). Although there is previous research about reducing thermal bridges in steel components, there is no research that discusses prefabricated steel structures for PH. Thus, the main technical problems of the prefabricated Passive House (PPH) are cracks caused by component assembly and thermal bridges caused by the steel structure (Figure 1).

Figure 1: Research gap.

In recent years, China, mostly in the northern region, has accumulated some experience in PH construction systems. Although the heat-transfer coefficients (K) of these Chinese-constructed PHs are relatively low, research in PPH has just begun. The selected case study, the Experimental House at Shandong Jianzhu University, Jinan, is the only constructed PPH in China. The two-storey steel structure is a precedent-setting experimental practice for the university’s Complex Building. Within an area of 157 m², this small PPH tests the key technologies for the larger building, which has an area of 9696 m² (Figure 2). The primary feature of this Experimental House is that it uses a sandwich-shaped exterior wall system. Key performance indicators of the house are listed in Table 1.
2. Wallboard design

In a PPH project, the design of the wallboard has two main aspects: the type of board and the connection of the board layers (Chen, 2012; Chen, 2014). In this case, the PPH used one sandwich-shaped wallboard linked by basalt fibre reinforced plastics (BFRP).

2.1. Sandwich-shaped insulation wallboard

Normally, a sandwich-shaped insulation wallboard is a composite of three layers: inner wallboard, insulation board(s), and outer wallboard (Tang, 2013). In order to protect the insulation boards during transportation and construction, as well as to enhance the mechanical property of the building structure, the PPH project in Jinan adapted this sandwich-shaped insulation system. The thickness of a wallboard was determined by the K-value needed and the thermal transmissivity of the material (λ).

On the one hand, λ values of the roof, exterior wall, ground floor, and ceiling of a non-airconditioned basement should not exceed 0.15 W/(m²·K), referring to the first Chinese PH code, Design Standard for Energy-efficiency of Passive Low-energy Residential Buildings (DB 13 J/T 177-2015).

On the other hand, it was proposed to utilize high-density polyurethane (HDPU), a vapour-impermeable material, as the Experimental House’s main insulation. Because this project is located in the Cold Area of China, the air temperature difference between indoors and outdoors in winter is very large, often more than 30 °C. If the exterior wall was permeable, vapour would get into the insulation layers, which would lead to degradation of the thermal performance. But, in summer, Jinan is dry and
hot. Therefore, the requirement for space heating in winter was more important than mould-proofing in summer. Calculated according to the basic formula for heat transformation, the required thickness of the HDPU layer was 143 mm. Allowing for convenient of production, a thickness of 150 mm was adopted. Considering the high insulation requirement of PH window frames, it is a usual way to split one insulation layer into two layers to eliminate thermal bridges. Therefore, the insulation of this PPH was composed of two layers of 75 mm HDPU boards (Figure 3).

Figure 3: Exterior wallboard’s basic formation.

Moreover, in relation to wallboard assembly, there are three widely used patterns (Zhang, 2014; Zhang 2014): the flat joint, rebate joint, and staggered joint (Figure 4). The flat joint is the most frequently-used pattern because of its capacity to maintain the integrality of the components; however, this kind of joint can lead to severe heat loss even after sealing, owing to its straight joint. The rebate joint has a better airtightness performance than the flat joint, but the manufacturing process of rebate joint board is complex and the board ends are easily broken during transportation; thus, usually this kind of joint’s heat transmission performance after construction is not satisfactory. Although the form and transport of the staggered joint are more complex than for a flat joint, they are simpler than for a rebate joint. As a result, this PPH adapted staggered joint wallboards.

Figure 4: Wallboard assembly methods.
2.2. Connection of wallboard layers

Although the sandwich-shaped wallboard had insulation boards in the centre, mechanical fixings between the layers were still needed. There are two types of anchorage parts on the Chinese market, metal and non-metal. Commonly, the λ-values of metal fixings are higher [i.e. the λ-value of stainless steel is 16.2 W/(m·K)], but their connection performance is better. On the contrary, non-metal materials have lower λ-values but worse linking capability. In addition, the cost of non-metal fixings is relatively high, so they are not building materials broadly promoted in China, a developing country.

Therefore, this project utilized a less expensive connection material that has both a low λ-value and good linking behaviour: BFRP (Xu, 2013). As a new type of glass-fibre composite reinforced material, BFRP combines the merits of composite material and steel bar, and has outstanding resistance to corrosion and bearing strength. To test the λ-value of the BFRP used in this project, seven experiments were conducted. The results show the mean λ-value was 0.28 W/(m·K). Although this value is higher than that of HDPU, it is far lower than that of traditional steel ties. In relation to economy, the market price of 8 mm BFRP was only AU$1.24/m and this diameter was sufficient to fasten 0.5 m² of wallboard by calculation. That is, the cost of BFRP was AU$2.48/m². While the price of widely used metal connections that meet the PH standard was AU$21.49/m². Thus, the adoption of BFRP lowered the building cost by a large margin.

3. Insulation and airtightness

Insulation and airtightness are not only two related parts of a prefabricated building, but are also two key issues in a PH. As a consequence, this project focused on the localized structures of the PPH’s slab joints of exterior wallboards (Zhou, 2012), foundation, roofs, and exterior window openings.

**Slab joints of exterior wallboards:** As previously stated, the prefabricated wallboards had staggered joints. The indented distance between two connected wallboards was 100 mm, and the design width of the gap was 20 mm (Figure 5). The sealing of the slab joints contained three key nodes: the outer joint, the middle joint, and the inner joint. Three measures were conducted to seal an outer joint. First, a piece of expanded polystyrene (EPS) or HDPU board, or some foam PU, was stuffed or poured into the gap between the insulation boards. Second, 8-13 mm preloading expansion sealing tapes (PEST) were pasted to both left and right sides of the close-to-insulation layer part of the outer wallboard. This gap sealed up after the tapes expanded. Third, sealant was poured into the gap. The middle joint was the connection location of the staggered insulation boards. Four pieces of 6-10 mm PEST were pasted to the four sides of this location. There were also three measures to seal an inner joint. The first and second steps were similar to those for an outer joint, while the third step was to paste a 200 mm vapour-and water-proof sealing tape on the inner surface of the wallboard joint. These three layers of insulation effectively guaranteed the airtightness, water-proofing, and thermal performance of the wallboards.
Foundation: Similarly to the wallboards, the insulation layer of the house’s foundation included two layers of 110 mm staggered extruded polystyrene (XPS) board (Figure 6). Because the indoor ground level was higher than the outdoor ground level, an L-shaped XPS board was also fixed to the bottom of the ground insulation. The two wings of this XPS board were both 820 mm in length, which was sufficient for Jinan’s depth of frozen ground, 440 mm.

Figure 6: Foundation. Note: ①=10 mm floor tile; ②=20 mm 1:3 harsh cement mortar; ③=40 mm C20 fine aggregate concrete; ④=2×110 mm XPS boards; ⑤=20mm 1:3 cement mortar; ⑥=120 mm C15 concrete; ⑦=150 mm 3:7 lime soil; ⑧=packed soil.
**Roofs:** The insulation of the roofs was the same as for the foundation, namely, using two layers of 110 mm staggered XPS board (Figure 7). In order to ensure the safety of the roof entrances, stainless steel boards were paved onto the steps, and close-grained foam PU was poured into the gaps between the boards and the steps. Furthermore, the parapet walls were wrapped in one layer of 150 mm HDPU board or two layers of 75 mm HDPU board (Figure 8). The copings of the parapets were also covered by 100 mm XPS boards. In addition, the roofs of this Experimental House perform the functions of thermal pressure ventilation and rainwater collection.

![Figure 7: Roof](image1)

Figure 7: Roof. Note: ①=40 mm C20 fine aggregate concrete; ②=4 mm SBS modified asphalt waterproof roll; ③=30 mm C20 fine aggregate concrete; ④=2×110 mm XPS boards; ⑤=20 mm 1:2.5 cement mortar; ⑥=1:6 (weight ratio) 2 % moisture proof expanded perlite; ⑦=3 mm SBS modified asphalt waterproof roll; ⑧=PC floor panel.

![Figure 8: Localized structure of the parapet walls.](image2)
**Exterior window openings**: To fulfill the requirement of PH windows’ K-value, this house used a type of energy-saving window that has three glass layers, one vacuum layer, and one argon layer (Zhong, 2014). There was only an inner wallboard around an exterior window frame at a circumference of 300 mm (Figure 9). On each side of the opening, eight anticorrosive wood bricks were fixed on the inner wallboard by angle irons to secure the window. After window installation, a layer of 300 mm vapour- and water-proof film was installed along the outer windowsills to ensure airtightness.

![Diagram of exterior window opening](image)

**Figure 9: Exterior wall opening.**

4. **House performance verification**

In order to ensure that the insulation, energy consumption, and airtightness performances would meet the requirements of the DENA standards after construction, this research conducted heat-transfer calculations, energy-consumption simulations, and airtightness measurements for the PPH. Although the data relating to indoor comfort, namely indoor air temperature, relative humidity, and CO₂ concentration, are significant to PH certification, they are not included in this paper. The focus of this paper is the prefabricated method and the building’s thermal performance.

**Heat-transfer calculation**: According to DB 13 J/T 177-2015, the K-value should be the mean value of those for the different elements of the opaque building envelope (Formula 1). By calculation, the $K_m$ in this case is $0.146 W/(m^2\cdot K)$, which achieves the PH standard.
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\[
K_m = \frac{K_1F_1 + K_2F_2 + \ldots + K_nF_n}{F_1 + F_2 + \ldots + F_n}
\]

Where:

- \(K_m\) = mean heat-transfer coefficient of building envelope;
- \(K_1, K_2, \ldots, K_n\) = heat-transfer coefficient of different components;
- \(F_1, F_2, \ldots, F_n\) = area of different components.

Energy-consumption simulation: The DENA standard rules that heating demand for a unit area \(q_H\) should be no more than 15 kWh/(m² · a), apart from solar heat gain and indoor heat gain. This paper utilized an energy-saving design tool, PKPM, to simulate the energy consumption of the PPH. By simulation, the value of \(q_H\) was 15.22 kWh/(m² · a). Although this value is significantly lower than that of the reference building [63.40 kWh/(m² · a)], it is still slightly above the German standard. There are two main reasons for this. Firstly, the Experimental House has a large shape coefficient (0.74). Because it was designed to show as many key nodes of PPH as possible, the house has relatively many architectural alternations. Secondly, the heat-recovery system of the house is not efficient enough. These two problems will be solved in the Complex Building under construction such that its energy-consumption will meet the DENA standard.

Airtightness measurement: The blower door test is the most commonly used method to measure building airtightness around the world. The test result showed that the air infiltration \((Q)\) under 50 Pa differential pressure was 320 m³/h. As the volume within this house’s envelope \((V)\) is 575 m³, in dividing \(Q\) by \(V\) the air change rate \(n_{50}\) is 0.56. In other words, the airtightness of this Experimental House is lower than 0.6 and so it meets the requirement of the German standard.

5. Conclusion

Developing countries, as represented by China, are in the process of rapid urbanization, which requires large quantities of new construction. The building performance and the speed of construction are two conflicted yet indispensable parts of these projects. The requirements of a German Passive House are relatively high, while their construction speed is slow. On the contrary, the construction speed of a prefabricated building is rapid, whereas the insulation and airtightness performances are comparatively low. When these two types of buildings are combined, the construction speed can be ensured while the building performance can be raised.

This paper takes the Experimental House in Jinan, China as a case study, which introduced a PH system that is appropriate for a prefabricated building. By adopting sandwich-shaped insulation wallboards, this PPH achieved both high performance and fast construction speed. The compound heat-transfer coefficient of the building envelope is 0.146 W/(m²·k), while the air change rate under 50 Pa differential pressure is 0.56/h.

However, there are some limitations of this case study. Firstly, the shape coefficient of the Experimental House is large, which causes high energy consumption. Secondly, although the construction rate of the prefabricated building was obviously better than for conventional buildings, the exact construction time of this house was not properly recorded; this was because particular experiments were conducted during the building process. Lastly, this research is limited to a certain type of prefabricated insulation wallboard system.
In the near future, further research will be conducted to study PPH. The construction of the Complex Building at Shandong Jianzhu University will be completed by the end of 2016. The building indicators such as shape coefficient and air-conditioning efficiency are expected to be better than those of the Experimental House. Then, more types of prefabricated components will be designed and be put into service in the following years, which will diversify the architectural schemes suited to PPH.

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Legislation revisited: New hope for the earthquake prone “home shop”?

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Abstract: A review of current earthquake-prone building policy undertaken by the New Zealand Ministry of Building, Innovation and Enterprise (MBIE) following the Christchurch earthquake, resulted in the Government introducing legislation to strengthen structural requirements for all earthquake-prone building to a minimum of 35% of the New Building Standard and within a time period of 15 years, and irrespective of a building location’s seismic risk zone. The outcry against the original legislation led Parliament’s Local Government and Environment Committee to change aspects of the Bill and call for re-submissions from the public on their appropriateness. This paper will scrutinize these re-submissions and outline the significant changes subsequently made to The Building (Earthquake-prone Buildings) Amendment Bill as a result of this “community feedback.” It will compare the resultant legislation with those countries of similar earthquake risk, specifically Japan and parts of the USA (California), and investigate the effect this new and revised legislation will have in the continued life of the small earthquake prone “home shop” unreinforced masonry buildings that make up a significant proportion of the urban fabric in the many small towns and suburban communities within New Zealand.

Keywords: Construction technology; earthquake-prone buildings; unreinforced brick masonry

1. Introduction

The aim of this research is to access the effect the 2015 public re-submissions made to the select committee hearings on The Building (Earthquake-prone Buildings) Amendment Bill have had on the final legislation. It will outline the significant changes subsequently made to the Bill as a result of this “community feedback” and compare the resultant legislation with two other countries of similar earthquake risk and economic status, specifically Japan and parts of the USA (California).

Seismic retrofitting of existing buildings remains a complex and often politically difficult area for governmental authorities. Issues of heritage, construction complexity, social upheaval and financial considerations including loss of rental income, can put the building owner to considerable disadvantage and threaten the commercial viability of any retrofit project. This disruption has to be balanced against the advantages of building stock more resistant to earthquake damage, and hence a safer social environment for citizens. Fardis (1998) acknowledges the major threat to human life comes from existing (older) buildings, however he asserts the emphasis of earthquake engineering research and of code writing efforts has been, and still is, on new
The reason: the redesign of an existing structure is a much more complex and technically demanding task than earthquake resistant design of a new structure. Issues of history and culture, building activity and heritage influence legislation. Adding to these factors is the issue of cost, which inevitably means, “..the vast majority of the building inventory in seismic regions worldwide is [and remains] by and large substandard and seismically deficient in the light of our current knowledge”. Upgrading within a jurisdiction remains a fine balancing act between a desirable outcome and the unintended consequences of too severe an imposed timeframe (Fardis, 1998).

A 2006 OECD report suggests poor seismic retrofit outcomes can also originate from a lack of shared responsibility between national and local government, or governments and citizens, combined with weak incentives to undertake the work (OECD, 2006 p.27). Spence (2004) suggests a lack of financial incentive is a consideration. Given that the cost of seismic retrofit varies from 5-50% of the total rebuilding cost and with the return period of major earthquakes one hundred years or more, there is “…small incentive for the building owner to make the investment worthwhile” (Spence, 2004, p.223). Wilkinson et al (2011) suggest building owners also lack trust in the ability of seismic strengthening techniques to perform under earthquake load. This lack of trust in the ability of design solutions to solve earthquake issues makes them reluctant to retrofit and strengthen. Within this challenging social context, the New Zealand Government has embarked on the process of reform to its earthquake legislation, prompted by the events in the city of Christchurch, New Zealand’s second most populated city. Here, on September 4th 2010, an earthquake of magnitude 7.1 struck the city. This was followed by another, some 6 months later on February 11th 2011, this time of magnitude 6.3. The February earthquake caused extensive damage across the city and was responsible for the deaths of some 185 people, mostly as a result of building collapse. The deliberations of The Canterbury Earthquake Royal Commission, assembled to examine the reasons for these collapsed buildings, concluded with recommendations designed to improve the response of the nation to another future earthquake. These recommendations led to the introduction to the New Zealand Parliament of The Building (Earthquake-prone Buildings) Amendment Bill 2013, an amendment to the Building Act 2004, with the aim of improving methods of managing New Zealand’s stock of earthquake-prone buildings.

2. Background: Current earthquake policy

The seismic performance of existing buildings in New Zealand is managed through the Building Act, first and foremost the original Act of 1991, and latterly its successor, the Building Act 2004. The New Zealand Building Code, which contains the regulations under the Act, is a Performance Based Code, and marks a move away from the prescriptive standards based building codes common to New Zealand in the past. The performance-based regulation “establishes mandatory goals rather than enforcing prescriptive standards” and potentially offers the opportunity of achieving health, safety and environmental outcomes while at the same time promoting innovation and reducing regulatory cost (Mumford, 2010). The path to an effective functioning performance-based system is not necessarily straightforward, as the New Zealand system has aptly demonstrated. The period of greatest building failure (in the form of leaking buildings) took place subsequent to the introduction of the 1991 Act, with the long road to remedial action beginning with the replacement 2004 Building Act, a more conservative and document (Murphy, 2011). That aside, the move to performance-based regulations is still expected in the long term to “alleviate the existence of requirements that are too complex and prescriptive, and a system unresponsive to technological change and innovation” (BIA, 1990).
Prior to the 1991 Building Act, the only national requirement for existing buildings was an Act of Parliament that required existing buildings unable to resist ½ of the forces of the 1965 Code to be strengthened. These forces were evidently very low and hence resulted in very few seismic refits. A voluntary program in the capital city Wellington (a high risk earthquake zone) resulted in the 1970s of retrofit or demolition of about 60% of the older building stock. The current regulatory system prior to the advent of this new legislation devolved much of the decision making to local authorities, with central government having a limited role in oversight and monitoring. Up until the Christchurch earthquake this process resulted in very few retrofits. The Christchurch earthquake of 2011 and the damage to existing buildings (including several “modern” buildings) that resulted from it provided the impetus for a review in earthquake policy.

As noted, giving emphasis to the need for a review was The Canterbury Earthquake Royal Commission’s report on the Christchurch earthquake. The main recommendations for change included the creation of additional legislation to empower local authorities to ensure “timely improvements” in the strengthening of existing earthquake-prone URM buildings within their area of jurisdiction, and “...that the maximum time permitted to complete the evaluation and strengthening of existing buildings should be set nationally.” TA problem with this was that the TAs lacked any comprehensive catalogue of earthquake buildings. The MBIE suggested in its Consultative Document that some 15000-25000 buildings would fall into the earthquake-prone category. This figure was as a very broad estimate, as only a few local authorities “can provide good data” (MBIE, 2012, p.6).

Of the 66 local authorities, only 23 were able to provide any information on the number of earthquake-prone buildings in their districts, and much of the information received was incomplete (MBIE, 2012, p.12).

The Commission also recommended structural engineer skills in this area be improved and that a grading system be developed, capable of being understood by the general public, that adequately described the seismic performance of a building. Other recommendations of a more detailed nature gave advice on the degree of strengthening required. In general terms, to protect life safety, the Commission suggested the “shaking level” for these existing buildings be set at no less than “one third of the requirements for a new building. Where however elements of URM posed a particular threat to health and safety, that is, elements such as parapets, ornaments and external walls, that a higher level of protection would be warranted. The Commission acknowledged some URM buildings were of historical importance but was of the view that if considered dangerous, and that demolition the only feasible option to making the building safe, then the building’s status within the Historic Places Act should not prevent this demolition from being carried out (Canterbury Earthquake Royal Commission, 2012, p7).

3. The Earthquake-Prone Buildings Amendment Bill

3.1. 2013 Legislation

The Government response to the Commission’s recommendations was to hold an internal ministerial policy review. It then combined its own ministry recommendations with those of The Commission and published a consultation document “Building Seismic Performance: Proposals to improve the New Zealand earthquake-prone building system: Consultation document”. This document outlined the proposal options to improve the system for managing earthquake-prone buildings within New Zealand. It was released in December 2012, with submissions required on
the proposals from the public by 8th March 2013. The submissions were themselves analyzed in a subsequent report: “Building Seismic Performance: Proposals to improve the New Zealand earthquake-prone building system: Summary of Submissions” (9 MBIE, 2013).

The review and the introduction of the Earthquake legislation in the form of the Building (Earthquake-prone Buildings) Amendment Bill 2013 is a move away from passive strengthening policies to active policies requiring strengthening upgrades to specified standards and within specified nationally imposed timeframes.

The legislation as initially drafted required Territorial Authorities to:
• Complete a seismic assessment of all non-residential, and multi-unit, multi-storey residential buildings in their areas “within 5 years of the legislation taking effect”
• Enter the results of these assessments into a central register of earthquake-prone buildings
• Ensure the buildings on this register are either strengthened or demolished within the 15 year specified timeframe.
• Require certain strategically placed and/or important buildings to be strengthened earlier than the national time frame.

The MBIE document acknowledged initial proposals in the legislation that specified a uniform timeframe to upgrade, regardless of the risk zone, met considerable resistance from submitters. Concerns were expressed about the “one-size fits all approach” inherent in the legislation, particularly the nationwide timeframe of 15 years for strengthening, regardless of risk.

“Whilst we agree with the retention of the current standard, the proposed timeframes and accountabilities appear too hard-hitting for our communities to absorb in any cost effective way” (MBIE, 2013, p.11).

Whilst regional variation introduces complexity into legislation, submissions nevertheless suggested it was important any approach took into account such factors as seismicity, economic profile (high value, high rent versus low value and low rent), local heritage issues and the likely impact of the legislation on the local community.

3.2. The (Re)-Submission Process

3.2.1. Proposed Changes

To its credit, the Government’s response to the obvious deficiencies was to make changes and invite the initial respondents to make additional submissions on the altered bill. The changes included:
• Reducing the scope of buildings covered by the bill, excluding now such structures as farm buildings, retaining walls, fences, monuments, wharves, bridges tunnels and the like.
• Lengthening the time frames for identification and remediation by categorizing New Zealand into three areas of high, medium and low seismic risk (by reference to the seismic hazard factor (Z factor).
• Requiring TAs to identify and assess only potentially earthquake-prone buildings within their jurisdiction (not all buildings as per the previous drafted legislation). This was required within a selected timeframes of up to 15 years, again depending upon seismic risk. Building thus identified would require registering on an earthquake-prone buildings register.
• Linking the remediation times for building strengthening to three seismic risk areas: High=15years; Medium 25years; Low= 35years –as against the sole time of 15 years, regardless of seismic area, operative with the previously drafted legislation.
• Defining priority buildings such as hospitals, school buildings, emergency service facilities such as fire stations, police stations and corridor buildings (building close to strategic access ways). Remediation for such buildings was to be half the timeframe of the seismic zone. Provisions of the bill that were to remain largely unchanged include
  • Exemption to remediate when the risk is assessed as very low.
  • An extra 10 years to remediate for Category 1 listed historic places that are earthquake-prone.
  • Authority for a TA (on a case by case basis) to grant building consent for an upgrade without requiring upgrades to the means of escape from fire and access and facilities for persons with disabilities.

3.2.2. 2015 Re-submissions –Research Methodology

A Total of 121 submissions were received, with 48 late submissions (23 July 2015) specifically commenting on the proposed changes put forward by Cabinet. The stakeholder ratios are as per Table 1. Each submission was examined to identify the thrust of the advice/objection/comment. These were numerically categorized via a spreadsheet into the headings as outlined below. Where possible numerical or percentages were used to identify commonality of purpose.

3.2.3. Timespans

A sizable minority (44%) specifically supported the general thrust of the changes, in particular remediation time extensions relative to seismic risk, even though they may have had reservations about other parts of the Bill.

“The proposed approach would be proportionate to risk and recognizes that for low risk zones, buildings would likely be replaced or significantly renovated during the next 35 years regardless of earthquake requirements, meaning property owners would save money” (Property council, 2015).

3.2.4. Priority buildings

The original Bill proposed faster time frames for “priority buildings” regardless of seismic zone. The amendments proposed these priority buildings be limited to hospital and school buildings, emergency service facilities (eg police stations) and corridor buildings and restricted to areas of high and medium seismic risk.

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual</td>
<td>42%</td>
</tr>
<tr>
<td>Building Owners</td>
<td>18%</td>
</tr>
<tr>
<td>Local Government</td>
<td>10%</td>
</tr>
<tr>
<td>Architects and Engineers</td>
<td>10%</td>
</tr>
<tr>
<td>Others</td>
<td>20%</td>
</tr>
</tbody>
</table>

A number of submitters (33) suggested shortening the timeframes for the strengthening of certain parts of unreinforced masonry buildings (such protrusions as verandas or parapets) due to the hazard such protrusions posed. The submission by Ann Brower, a sole survivor within a bus destroyed by falling building work in the Christchurch earthquake, seem to find particular favour with officials, with her suggested changes incorporated into the final Bill.
“Government should create a separate category for non-structural unreinforced masonry-parapets, gables, and chimneys- because: a. They are the cheapest to fix; b. They are the first to fall; c. They are the deadliest when they do fall...

Fixing parapets, gables, and chimneys first would make the Bill more equitable for towns at lower earthquake risk. Fixing the most dangerous and least expensive bits first might render unnecessary the full building strengthening.” (Ann Brower, 2015)

3.2.5. Definition of earthquake-prone

Most Territorial Authorities supported the definition of earthquake-prone as being a percentage less than 35% of the New Building Standard. A range of Engineering organizations, including GNS Science, and individuals (10) took exception to the definition and asserted any definition realistically had to be linked to seismic risk and occupancy.

“Consideration must be taken for the occupancy rate of each specific building when determining its rating since it is clearly stated that the objective of the Bill is to protect people from injury or death from building failure during a future earthquake” (GNS Science, 2015).

Ian Harrison’s submission reiterated the belief outlined in his original submissions that the definition threshold is overly conservative and that it should be more closely defined in relation to a buildings potential for collapse, which in turn links it to seismic risk. A building in Auckland (low risk) is hence likely to be overly strengthened as against an equivalent building in Wellington, given the difference in risk levels between the two centres.

3.2.6. Low risk exemptions

This section did not arouse much comment, although GNS Science thought the now exemptions for such structures as farm buildings, bridges, retaining walls and tunnels, included in the original legislation, was a backward step. Most were realistic in their assessment however that such structure presented little risk to the public in the event of an earthquake.

3.2.7. Heritage Issues

Category 1 building so registered under the Historic Places Act 1993 can apply to the territorial authority for extensions of time for remediation of up to 10 years. 18 submitters (including eight territorial authorities) suggested the definition of heritage be widened. This would have had implications for the typical “home shop” building, typically of URM and the focus of this paper. Such buildings remain particularly vulnerable should this legislation be enacted, as the vast majority were not, with few exceptions, of Category 1 heritage status.

3.2.8. Upgrade requirements

The Bill amends the Building Act 2004 and enables Territorial Authorities to allow dispensation in certain situations from the overall requirement to upgrade fire and egress requirements, and access and facilities for persons with disabilities when altering or upgrading the building to comply with earthquake strengthening requirements. As could be expected, the discretion caused much comment. Thirty submitters supported the provision with 37 opposed. Supporters included organisations such as the Property Council, Local Government NZ and Historic Places Aotearoa. Dissenters included disability groups, and Human Rights Commission and several individual submitters.

“Article 9 of Convention of the Rights of People with Disabilities...requires States to take appropriate measures to ensure that disabled people have access, on an equal basis with others...” (Human Rights Commission, 2015)
3.2.9. Financial incentives

A number of late submissions continued to call for financial incentives to lessen the burden on building owners required to remediate their buildings, even though this was not addressed in the changes to the Bill. This issue is particularly relevant for the small town low value and low rent “home shop” URM building where the loan-to-value ratios would all but rule out bank finance. Auckland Council suggested “...Government grants for the upgrade of structures of significance, such as those of particular heritage value” and or that the “cost of a seismic retrofit to be deemed ‘repairs and maintenance’ rather than ‘capital expenditure’ for tax purposes (Auckland Council, 2015). Where territorial authority or other government support is not forthcoming, and the owner unable or unwilling to remediate, then demolition of the building, with subsequent loss of streetscape heritage, remains the only viable alternative.

4. International seismic retrofit policies

New Zealand’s attempt to instigate a more active national policy for Earthquake-prone buildings can be compared to other earthquake sensitive jurisdictions of a similar OECD economic status that lie along the pacific rim, viz. Japan and parts of the United States, notably California.

4.1 Japan

In Japan the increased cost of natural disasters, in particular the destruction caused by the Kobe earthquake has led to a revision of the building code to performance-based regulations, a measure similar to the introduction in New Zealand of the national performance based building code in 1991 (Ghobarah, 2001, p.878). The expectation is that the introduction of these performance-based requirements in Japan will assist with more flexibility in the area of local authority control and leave more room for innovation in design and material use. (Otani) Prior to the Kobe earthquake, seismic retrofit was given low priority Japan with a recent OECD report indicating an estimated 30% of the total building stock remain constructed according to outdated codes and standards (OECD, p.270). Whilst it is a leader in seismic hazard mitigation technology for new buildings, the national building code does not provide for existing buildings, except when structural members are changed or there are additions to the building. Unlike California et al, there is also no code requirement for strengthening where a change of use is proposed, and unlike the legislation currently proposed for New Zealand, no mandatory requirements to strengthen or mitigate the specific earthquake hazards in URM building, with the decision to upgrade left to the owner, who may determine the seismic force level for which the retrofit is to be designed (Kikuchi, 1992).

The introduction of the “Law Concerning the promotion of the Improvement of Earthquake-Resistant Construction” after the Kobe earthquake has also come, unlike New Zealand’s legislation, with supporting financial aid for seismic retrofit of buildings such as apartment houses, offices and schools and later in 2002, houses (Yamomoto, 2005). The financial aid is modest, estimated between the range 13-16 percent, but combined with other incentives such as reduced housing loans taxation and reduced interest rates from the Housing Loan Corporation, presents a monetary incentive for an owner to upgrade, an incentive currently missing from the New Zealand legislation (OECD, p.28).

4.2 California

The Uniform Building Code (UBC) operating in California contains only one passive “trigger” and no clear active triggers for the seismic upgrade of existing buildings. The passive trigger is a change of use in the building, with discretion given to the building official to determine that the change of
use is to a more hazardous occupancy. Most cities within the area have instigated additional regulations however that reflect the communities concern over safety issues associated with existing buildings, especially those constructed in URM. In this sense suggests Hoover, California continues “...to be a leader within the USA in the field of seismic mitigation.” (California Seismic Safety Commission (CSSC), 2001, p.1). The active “triggers” require seismic retrofitting for certain building types, with the state mandating that the seismic hazards of unreinforced masonry buildings (URMs) in particular must be mitigated in a proactive manner, particularly in the area of parapet hazards, where the parapet upstand has often deteriorated and is not well secured to the structure. All regional building codes offer a standard for the seismic strengthening of URM buildings –viz. the Uniform Code for Building Conservation. The policy hence has similarities to the just passed legislation for URM buildings in New Zealand. Unlike New Zealand however, which is implementing a national policy with specific timeframes and retrofit requirements, there is within California a wide variation in the standards utilized within the different cities making up the Zone 4 earthquake area (the zone of highest risk). This is an unfortunate situation says Hoover, resulting in “...an uneven level of life safety between jurisdictions, unfair requirements of building owners, and inequitable economic competition between jurisdictions.” [CSSC, 2001, p.2). There is a strong need, suggests Hoover (1992), for “uniform life safety standards for the assessment and retrofitting of existing buildings.” The New Zealand nation-wide policy of seismic retrofitting regulations for earthquake-prone buildings would hence be seen by Hoover as a desirable outcome in the task of providing minimum life safety for building users in California.

The issue of compulsory retrofit within a specific timeframe remains a challenge in California, where for example, the issue of hospital seismic safety with a specified timeframe, imposed by a Senate Bill in 1994, comes up against the social consequences of demolition and closure for non-complying buildings not capable, through lack of funds, of meeting the requirement to “survive earthquakes without collapsing or posing a threat of significant loss of life.” (CSSC, p.2). In these more urgent cases the recommendation is for public funding for genuine hardship, but with a recommendation “to encourage new construction over retrofitting.” (CSSC, p.5).

4.3. Other earthquake jurisdictions within the USA

Most other states adopt the Uniform Building Code (UBC) as the core state code, with many adding additional and different requirements beyond the sole UBC “change of use” trigger for seismically retrofitting existing buildings. Utah for example, home to the Wasatch fault has, within the city of Odgen, an ordinance requiring braces and wall anchorage for URM parapets, was well as snow load analysis, whenever a URM building is reroofed (Reaveley, 1992). Other jurisdictions have equally unique variations. Washington, whilst it adopts the UBC as its state code, requires a structural retrofit if there is extensive structural repair, a major re-modeling to extend the life of the building, a change in occupancy to a more hazardous use or has been vacant for more than a year (Hoover, 1992, p.72).

5. Conclusion

Changes to the Bill have eased the burden for the small home shop and its owner. Time frames for earthquake prone buildings have been extended, especially for buildings in medium or low risk seismic zones. The TAs role is less onerous, with only potentially earthquake-prone buildings requiring identification and classification, and with more time to achieve this classification. Priority buildings still have a shortened time frame to remediate (half that of the seismic zone), but there is no blanket “one off” nationwide time span now required. A greater number of low risk buildings have been excluded from the provisions of the legislation, lessening the burden on farmers, owners of non-occupied
Legislation revisited: New hope for the earthquake prone “home shop”?  

structures (such as monuments) and civil support structures such as bridges. Moderate alterations to the building will still trigger the need for a seismic upgrade, but accessibility and fire egress requirements can be dispensed with (to the annoyance of some submitters) if the TA can be persuaded to agree with the view that such compliance is unreasonable.

Appendages such as the veranda and parapet require now require strengthening as a “priority” and within the priority time frame, but only if the building is on a high use pedestrian corridor. The legislation still insists on the full strengthening retrofit to be achieved by the particular timespan. Here the New Zealand legislation differs from other jurisdictions. The element of compulsion for strengthening to the 34% NBS still remains, albeit to extended timeframes that better reflect the zone and hence level of risk. Table 2 compares the differing legislative requirements.

<table>
<thead>
<tr>
<th>Feature</th>
<th>New Zealand</th>
<th>Japan</th>
<th>California</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upgrade compulsory?</td>
<td>Yes – to 34% NBS within 15-35 yr. time period.</td>
<td>No -</td>
<td>Yes – but certain URM building types only.</td>
</tr>
<tr>
<td>Upgrade required – change of use.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes – but only if to a more hazardous use.</td>
</tr>
<tr>
<td>Upgrade required – structural alterations.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Financial incentive?</td>
<td>No</td>
<td>Yes 13-16%</td>
<td>Public funding for certain building types and if personal hardship.</td>
</tr>
</tbody>
</table>

No financial support has been offered to the building owner, another OECD recommendation; yet there are considerable penalties for failure to complete remediation by the deadline and a fine of up same amount, imposed by the TA, for failing to comply with safety requirements. Such an approach is contrary to Japanese policies and OECD recommendations and is likely to cause wholesale demolition of the small URM buildings in provincial areas, where values are relatively low and financial and insurance costs outweigh rental benefit likely from any strengthening. Retrofit policy, suggests the OECD, needs to be carefully evaluated for its effectiveness. Passive policies may result in little change. More actively focused policies, such as currently before the New Zealand Parliament, may result in the wholesale demolition of buildings that are meeting quite satisfactorily the requirements of the local community, with subsequent loss of streetscape heritage and cultural value. That scenario should be avoided at all costs.

References


Recent increases in the occurrence of condensation and mould within new Tasmanian housing

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Abstract: Tasmania, located in southern Australia, is a cool-temperate climate. For several months, the external environment is cooler than the desired minimum temperature for thermal comfort. However, this same climate has many days in the hotter months where the external temperatures are above those desired for thermal comfort. This creates a scenario where heating is used extensively, and during the warmer months, houses are also increasingly cooled. Combined with enhanced thermal performance regulations three distinctly different, yet interlinked consequences have evolved. Firstly, the newer homes are much warmer in winter, providing thermal comfort and human health benefits. The increase in envelope performance has enabled and created greater differences in vapour pressure between the conditioned and unconditioned interior spaces and the external environment. Finally, the better performing envelope has led to an increase in thermal comfort expectations, where reverse-cycle air-conditioning is often operated 24 hours a day, 7 days a week. These factors have led to a significant increase of internal surface and interstitial condensation within many new homes. This paper discusses recent condensation problems encountered within Tasmania, which has established significant knowledge and practise deficiencies within the design and construction professions in relation to climate based vapour pressure management within buildings.

Keywords: Interstitial condensation, mould, human health, housing

1. Introduction

Tasmania, located in southern Australia, is classed as cool and temperate climate. For the majority of the year, the external environment is cooler than the desired minimum temperature for thermal comfort. However, this same climate has many days in the hotter months where a house provides shelter from excessive solar radiation and temperatures above those desired for thermal comfort. This creates a scenario where heating is used within houses for most of the year and cooling is increasingly more commonplace during the warmer months. This pattern of built environment intermittent heating and cooling creates an outward vapour pressure when heating and the converse in when cooling. Enhancements to the National Construction Code (NCC), since 2004, have included a focus on the reduction of greenhouse gas emissions which result from heating and cooling energy (ABCB, 2004; 2007; COAG, 2009; ABCB, 2010; COAG, 2015). The amount of heating and or cooling energy likely to be used is...
intrinsically linked to the maintenance of thermal comfort within habitable rooms within housing. These regulations have created three distinctly different, yet interlinked consequences. Firstly, compared to pre 2004 housing, the newer homes are much warmer in winter, providing thermal comfort and human health benefits (Ambrose et al., 2013). The increase in envelope thermal performance has created thermally tighter housing but in most cases, there has been no consideration of vapour pressure management. Finally, the better performing envelope has led to an increase in thermal comfort expectations, occasionally termed ‘comfort creep’, where reverse-cycle air-conditioning is often operated 24 hours a day, 7 days a week (Strengers, 2008). The combination of the built fabric improvements, occupant thermal comfort expectations and no consideration of vapour pressure, has led to a significant increase of internal surface and interstitial condensation within new homes in Tasmania (Dewsbury et al., 2016).

This paper discusses specific surface and interstitial condensation problems encountered within Tasmania, and similar industry collaborator advised problems in Victoria, NSW, ACT, North Queensland and the Northern Territory. This research has found significant knowledge and practice deficiencies within the design (draftsperson, building designer & architect), building surveyor, engineering, environmental health and construction trades professions in relation to climate based vapour pressure management within buildings. Additionally, the discussion highlights that at present there is no national regulation in Australian for vapour pressure management, condensation or mould in housing.

2. Condensation and mould in new housing

At a governmental level, condensation and mould in Australian housing has been discussed and reported on, but little has been published within the architectural science field. Figures 1 to 3 below, show three examples of problems in new houses, that were occupied for less than three months. Figure 1 shows timber reveals around a window expanded due to excess moisture within a wall. Figure 2 shows mould growth on the inside surface of external walls, which is a common tell-tale that there may be a problem with moisture retention in external walls. Figure 3 shows excessive moisture and mould growth within a roof space. Whereas, the expanded window reveals and mould on walls will be very evident to house occupants, many owners of new homes rarely inspect roof spaces.

Outside of the architectural and construction industries, the medical and human health field is very aware of the ‘wet buildings’ problem in Australia. Most states have a medical research group within immunology and allergy, that treats persons who are suffering from condensation and mould related conditions. Mould has been increasingly recognised as a threat to human health (The Institute of
Recent increases in the occurrence of condensation and mould within new Tasmanian housing Medicine, 2004; Brandt et al., 2006; Kercsmar and et al, 2006; Bok et al., 2009; WHO, 2009; Mendell et al., 2011). The medical researchers are seeing human health impacts from occupants of warehouses, retail spaces, enclosed factory spaces, office spaces, schools and housing. Until 2016, the Australian NCC for residential buildings (ABCB, 2016), included a non-regulatory objective to:

(a) safeguard occupants from illness or injury and protect the building from damage caused by—

....... (iii) the accumulation of internal moisture in a building;

A similar phrase existed within the non-residential regulations. This non-regulatory, eight-word phrase, is the only mention of the matter within the entire NCC building regulation. Throughout both volumes of the NCC, there is extensive guidance on façade system design and the detailed construction of wet rooms to eliminate water entering the built fabric. There is some limited ‘comment’ that cooling systems and pipes may cause condensation. Otherwise, there is no guidance on the issues of surface condensation, interstitial condensation, mould growth and vapour pressure management within the design and construction of internal and external built fabric systems.

3. Methodology

In response to new home-owner concerns, the Director of Building Control, Tasmanian Department of Justice, initiated a study to explore the regular occurrence of condensation in new homes. The University of Tasmania was engaged to respond and assess home-owner concerns. The prevalence of the problem was manifest when the Building Control office and the University received many calls each day, and at the time of writing this paper, regular enquiries are still occurring. The telephone enquiries were and still are principally from new home-owners, builders, and building surveyors. This paper focuses on the three case study houses, however many other buildings were inspected.

3.1. Case study houses

The research task funding was established to enable the detailed built fabric assessment of new homes, where excessive occurrence of condensation and mould was observed. The task was to include subfloor, interior and roof space examples. Quite quickly, three case study houses were identified, namely:

- Case Study 1 - Excessive subfloor moisture, excessive humidity levels within the home, wet and mouldy roof space, dripping soffit lining, dripping door and window heads.
- Case Study 2 – Dripping down-lights, dripping window heads, sodden roof space
- Case Study 3 – Condensation forming on floor, sodden and expanding internal trims and reveals, sodden wall batts and timber framing, dripping window heads, mould growth on carpet, skirting, walls and ceiling, sodden roof space.

For each of these houses a detailed analysis of the built envelope and documentation was completed, namely: environmental measurement, zone pressurisation testing, a review of approved architectural documentation for construction and construction practises. After an initial analysis was completed, remediation actions were suggested.

3.2. Environmental measurement

Each of the houses presented significant challenges in understanding the built systems, and occupation, heating and ventilation patterns. To better understand the likely causes of interstitial condensation, an
environmental measurement array was installed in each of the case study houses. This was to gain a better understanding of the temperature and relative humidity values in different and at times adjoining zones. This data was used to analyse vapour pressure drivers and dew point temperatures. In each house data was collected from the interior and exterior environments. Generally, the interior environment (temperature and relative humidity) included the subfloor, living and roof space zones. The exterior data collection included site air temperature and relative humidity. Due to the remote location of the houses, traditional data logging systems were not suitable due to the need to retrieve data. Instead, a cloud-based data logging system using mobile data developed by Shinbone Networks was employed. The kit of sensors included temperature, relative humidity, current transducers and surveillance cameras. Sensor type and their locations are shown in Table 1. The positioning of sensors within each zone was carefully considered to ensure the data was suitable. Within each case study house, sensors were occasionally added and/or moved to gain additional data. A significant challenge for the research became the accurate measurement of relative humidity in very moist locations, even though the sensors 90%-95% RH capability. For locations where condensation occurred regularly, like the roof sarking, a proxy mid-roof humidity ratio was interpolated from the measured sarking temperature. The high levels of moisture led to occasional data logging outages within the full data set.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Temperature</th>
<th>Relative Humidity</th>
<th>Surveillance Camera</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type</td>
<td>Type</td>
<td>Camera</td>
</tr>
<tr>
<td>Mid subfloor zone</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Living/kitchen zone</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Mid roof space zone</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes – various locations</td>
</tr>
<tr>
<td>Sarking interior surface</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Site</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1: Environmental Measurement Profile.**

3.3. Building pressurisation testing

To gain a deeper understanding of airflow, infiltration and exfiltration within each case study house, building pressurisation testing was completed. This type of testing is commonly used to provide data on the air-tightness of the building or zone within the building. To understand the quality of the built fabric the entire building or zone was pressurised and depressurised. The zone pressurisation tests that were completed in each house are shown below in Table 2.

<table>
<thead>
<tr>
<th>Case study house 1</th>
<th>Case study house 2</th>
<th>Case study house 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subfloor zone</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>House zone</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Roof space zone</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Table 2: Environmental Measurement Profile.**

3.4. Approved for construction architectural documentation

In most of the houses that the research team visited, one of the first comments from the builder was ‘we built it to the plans’. Approved architectural construction documentation was obtained from Builder
and Building Surveyor. The Building Regulator requires site plans, floor plans, external elevations and sections of the building to enable adequate information to construct the building. Often, an engineer provides additional drawings for footings, lintels, bracing and tie down. For this task, the drawings were examined within the context of notes, annotations and drawn information that documented consideration the NCC Vol 2 (ABCB, 2014b), which was in effect when the house plans were approved.

4. Results

This section focuses on the results of the environmental measurement, air pressurisation tests, approved architectural documentation and construction practises. The research team completed several site visits to each of the three case study houses. Some site visits were at the request of the home occupants, whilst others were due to data acquisition stoppages. Some stoppages were due to power failure, whilst others were due to equipment failure caused by the very wet environments.

4.1. Temperature, relative humidity and moisture

In this research the principle forms of data collected were temperature and relative humidity. Two forms of analysis were used, namely psychrometric charts and water activity graphs. By plotting the measured air temperature and relative humidity values, times when saturation temperature and condensation would likely occur were identified. Figure 4, below, shows the psychometric chart for the subfloor zone of case study house 1. The data in the graph is from three locations in the subfloor; Subfloor North Wall – Blue, Subfloor Middle – red, and Subfloor South Wall – green. The data in the chart shows that the air on the north side of the subfloor zone varies from saturation point to no condensation risk, which is likely resulting from the sun striking the external face of the clay brick subfloor wall. The data from the mid subfloor shows a closely clustered data set that is not warmed by the northern subfloor wall but remains below 80% relative humidity and does not pose any significant moisture threats. However, the data set for the southern edge of the subfloor zone shows a very large amount of data that is above 95% relative humidity and documents the regular occurrence of condensation. Subject to individual material properties, this may cause significant long-term damage. Figure 5, below, shows the measured data from case study house 2, plotted within a psychometric chart. The graphed data includes; Level 2 Living Room – orange/yellow, Site Conditions – green, Level 2 Mid Roof Space – red, Near Sarking Level 2 Roof Space – blue. Some key patterns are identifiable from this data like, the temperature within the level 2 living room is always considerably warmer than the site air temperature. The close grouping of air temperature data in the living room appears to result from the home-owner thermal comfort expectations and has been achieved by the continuous 24 hour use of a reverse-cycle air-conditioner. This has created a very significant and constant vapour pressure driver from the level 2 rooms to the external walls and roof space. The flow of vapour into the roof space is additionally supported by the number of holes in the ceiling fabric caused by the use of down lights, cavity sliding doors and the bathroom ventilator. It is clearly evident that the environmental condition on the interior surface of the roof system sarking is nearly always at saturation, causing the constant presence of significant condensation on the sarking material. Furthermore, this data is from before and after the installation of roof space ventilation. This indicates that the addition of roof space ventilation may not remediate the problem of excessive roof space moisture in all situations.
To better understand the occasional differences between psychometric activity and condensation differences that were observed, water activity calculations were completed. Water activity is a common method used to establish an environments’ potential for mould growth (Kowalski, 2005). Water activity is derived from air temperature, relative humidity and material sample temperature (interpolated). Figure 6, above, is a graph of water activity within the roof space zone of case study house 1. The upper most line is the calculation of roof space temperature and relative humidity that is cooled to the sarking surface air temperature. The middle and darkest line is the calculation from the roof space temperature and relative humidity that is cooled to the southern gable end wall surface air temperature. The lowest line is the temperature and relative humidity data from the living room. In this graph any data that goes above the value of 1.0 identifies when condensation occurs. This method of graphing the measured data further confirms the regular occurrence of condensation on the inside surface of the sarking system and on the inside surface of the roof space gable wall. Furthermore, any values above 0.7 provide potential climates for the growth of mould.

4.2. Mould analysis

Due to the presence of mould on many surfaces, mould samples were taken from subfloor, occupied and roof space zones of each house. The types of samples taken included scrapings from mould-affected materials and trays placed in rooms to allow for spores settle. In both scenarios the samples were delivered to the Infection and Molecular Diagnostics Research Group, UTAS for incubation and identification. A range of mould genera were identified including; penicillium, zygomycete,
Recent increases in the occurrence of condensation and mould within new Tasmanian housing

**4.3. Building pressurisation**

Even though the NCC includes requirements for improved building sealing, current regulations (ABCB, 2014a; 2016) do not consider measured infiltration and exfiltration. The building pressurization testing was completed to establish uncontrolled airflow between high vapour pressure conditioned and low vapour pressure unconditioned (colder) rooms or zones. This activity brought to light common air leakage points within the built fabric.

The subfloor pressurisation tests of case study house 1, revealed that building regulation compliant ventilation was occurring within the subfloor. This indicates that the regulation does not provide enough ventilation or the build-up of moisture was not resulting from inadequate subfloor ventilation. However, the test did establish significant leakage between the unconditioned and conditioned hall, laundry, and bedrooms and the unconditioned subfloor zone, which would lead to uncontrolled heat loss when the rooms are conditioned. Additionally, on warmer days, when the lower level rooms are cooler, vapour would be travelling from the high moisture content subfloor into the less used lower level rooms. In case study house 1, the unconditioned lower level rooms were directly connected, via a stair, to the upper level, and continuously heated living zone. The pressurisation tests for the conditioned living zones in all three case study houses presented significant points of leakage between conditioned and conditioned zones and the external environment, namely:

- Electrical services like switches and general purpose outlets, and other service penetrations.
- Poorly installed seals between window and door systems and the wall wrap system provided uncontrolled locations of infiltration and exfiltration.
- Vented down-lights and bathroom ventilators, allowing for the free passage of high vapour pressure moisture laden between the often conditioned rooms and the roof space.
- Internal cavity sliding doors, which were found to provide significant leakage between all rooms and the roof space zone.

**4.4. Approved for construction architectural documentation**

The Architectural documentation that was examined included site plans, floor plans, external elevations and construction sections. Generally, the architectural documentation for all three case study houses was found to be deficient in the context of NCC requirements for the control of moisture, namely:

- Site and floor plans, external elevations and construction sections did not show site drainage.
- Subfloor ventilation was often not described or specified.
- Insulation values were listed but products and their relative thickness were not described or shown on drawings (i.e, R1.8 batt – but no one makes an R1.8 batt?).
- Floor and wall sections often lacked adequate detail, which should document connections of framing, wrapping, cladding, insulation and lining elements.
- The roof space information rarely illustrated or annotated any sarking system or when drawn, no annotation was included. When drawn, it was often not to the manufacturers specification.
- Cathedral ceilings focused on the thickness of the structural member, with no consideration of ceiling insulation thickness or ventilation requirements.
Attic type roof spaces did not adequately illustrate to correct scale or annotate how the rafter/top plate connection would allow for the correct fitting of the ceiling insulation.

No houses inspected illustrated or annotated methods for roof space ventilation.

No documentation included climatic appropriate wall wrap systems.

Rarely were there any illustrations, annotations or notes on building sealing.

In summary, much of the provided architectural documentation was extremely diagrammatic within the context of built fabric detailing and material specification for the subfloor, external walls, ceiling systems and roof structure. It appears that the insulation, thermal bridging, vapour pressure management and condensation mitigation would be addressed by the builder or home owner.

4.5. Review of as-built construction practises

The construction practises generally reflected the quality of architectural documentation. It is accepted that the builder is contracted to build as per the architectural documentation. Within this context, current architectural documentation practises are establishing long term built fabric problems for residential and non-residential buildings. The inspection of many new homes in their ‘as-built’ state highlighted a significant lack of understanding of the principles of thermal insulation, thermal bridging, building sealing and vapour pressure management, all of which play a significant role in the management of condensation risk and subsequent mould growth.

In subfloor and roof space zones the installation of ventilation to remove excess moisture and vapour laden air varied significantly. Most roof spaces, (including cathedral style), had no ventilation. The quality of insulation installation between conditioned and unconditioned zones was often incomplete or not installed at all. In many cases the space for the insulation did not allow for effective lofting to achieve the specified thermal resistance. Similarly, in locations like the junction of the roof system and wall top plate, the compression of the insulation provided thermal bridging and moisture transport between the roof and walls. There is a common misconception that the roof space needs to be airtight, which appears, incorrectly, to stem from the NCC thermal performance and bushfire (Standards Australia, 2009) requirements. This practise is not allowing vapour or moisture to leave the roof space. This was often further compromised by the significant installation of insulation as a part of the roof system, rather than on the ceiling over conditioned rooms.

The quality of air sealing between conditioned and unconditioned zones and between conditioned zones and the external environment was often inadequate. This included the inconsistent installation of building wrap systems which was regularly punctured, compromising its air barrier, water barrier and vapour control layer functions. Most installations included a vapour impermeable system which is not suitable for temperate and cool temperate climates. Some products were referred to as breathable, which was normally a vapour impermeable system with regular holes. This type of product does not promote vapour transport and compromises the air barrier properties. Similarly, many items like vented downlights, vented fire-boxes and unsealed cavity sliding doors further compromised air barrier principles and provided locations of intense vapour transport, thermal bridging and condensation.

The sarking system was often installed ‘tight’, which allowed for a significant surface area to be in direct contact and thermally bridged with the sheet metal roofing. This practise caused the sarking material to be much cooler, which promoted the occurrence of condensation on its inside surface. It should be noted that this method does not comply with some manufacturer specifications but is standard industry practise but not queried by most Architects? However, this same principle of thermal bridging applies to walls. Most of the external walls of buildings inspected, with the exception of brick
veneer, had direct fix cladding. In this scenario the wall wrap is cooled or heated by the cladding system. This promoted the regular occurrence of dew point temperature on the inside surface of the wall wrap.

Many issues were identified and many more were seen on drawings or at site visits, which did not have a direct impact on vapour pressure or condensation but may provide ‘lesser-than-code’ buildings. Most of the construction issues mentioned above are the result of architectural documentation.

5. Discussion

The research revealed a seemingly common occurrence of surface condensation, interstitial condensation, mould growth and structural decay as singular or multiple problems within new buildings. In each case the discussion included, but was not limited to, home-owners, building designers, engineers, builders, manufacturers, building surveyors and state regulators. Furthermore, during this research, the team became aware of old houses with new additions, pre 2003 houses, post 2003 houses and houses less than six weeks old with significant condensation and mould growth. The differentiation of pre and post 2003, refers to the introduction of minimum thermal performance requirements within the Building Code of Australia (ABCB, 2003b). Additionally, personal communications with national product manufacturers and more recent research for the Australian Building Codes Board, has highlighted built fabric problems and condensation in all Australian States. Additionally, based on industry responses to a nationwide government survey, up to 40% of new buildings may have significant condensation and mould which is the result of architectural documentation and construction practises.

Within the regulatory context, design and construction ‘checking’ often rests with the building surveyor. However, what should the Building Surveyor be looking for within the architectural documentation. At present, the NCC does not require any documentation which addresses vapour control and thermal bridging management to reduce the occurrence of dewpoint and subsequent moisture and mould growth. Additionally, many of the construction based items listed above fall outside the mandatory inspections provided by the building surveyor. Invariably, the building surveyor requests a statement from the builder, which purports that all construction is to the minimum requirements stipulated within the NCC and applicable Australian Standards. However, during this research task, very few builders admitted to having a copy of or referring to the current NCC, and no builders had copies of the relevant Australian Standards. It was also found that some building designers did not have a copy of the NCC or any Australian Standards. Considering the regular enhancements that occur within these documents, it gives the impression that we are dealing with quite a low base of professional practice.

6. Conclusion

This research found an extensive presence of moisture and mould in new buildings in Tasmania, and via industry collaboration Victoria, NSW, ACT, QLD and the NT. In addition to well-founded structural and durability concerns associated with wet building fabric, the context of human health cannot be ignored. At present there is no regulatory requirement to consider moisture mitigation, vapour pressure management or mould minimisation within new buildings in Australia. Additionally, there are abstract requirements for building air sealing but no quantification to prove compliance. This is in stark contrast to regulations in other nations (British Standards; Ministry of Business, 2014; International Code Council, 2015; National Research Council, 2015). Without a minimum regulatory requirement, there are no demands placed on the architectural design and documentation process or the construction sector to provide moisture and mould free buildings. International experience has shown that built fabric
moisture mitigation and improvements to indoor air quality have only been achieved by regulation. The enhanced regulatory framework would also provide scope for the development and improvement of relevant Australian Standards and other technical documents that professions can use to design and construct condensation and mould free buildings in all Australian climates.

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A preliminary investigation of the rammed earth houses in a vernacular village in China

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Abstract: The current increasing speed of urbanization in China, is threatening to demolish highly significant vernacular buildings in rural areas. Based on this context, the character of vernacular architecture and the construction principles in the local area is the subject of this paper, specifically, their spatial arrangement, structure, enclosure, and other elements of a vernacular building will be summarized. In 2005, the Chinese government first proposed the “Beautiful Village” project, an upgrading plan to improve the life satisfaction of people living in rural areas. In 2013, the first author participated in surveying the historical development of Yangyuan Village, which is involved in the beautiful village project. To assess the village’s typology and buildings techniques, the research project utilized a mixed methods approach that included interviewing villagers and craftsmen, photographing buildings, statistical analysis of the roof truss and computer modelling of vernacular buildings in order to understand the local vernacular construction principles. The vernacular buildings are argued to be ecologically and socially sustainable because of their use of local low-energy materials, traditional construction methods and forms which result from a long history. The paper identifies a typical building type and traditional construction system. We argue that constructing new buildings in traditional villages using the principles derived from their vernacular setting is a sustainable method for the development of villages in the future.

Keywords: China; vernacular village; traditional construction system; rammed earth; sustainable

1. Introduction

In recent years, the rapid pace of urbanization in China has had significant large-scale impacts on rural areas which are now confronted with new economic, social and environmental challenges (Ding, 2013). One consequence is that the young rural labour force typically migrates away from their hometowns to the burgeoning cities, seeking employment and financial success, which causes the rural population to diminish. Some of these rural villages have cultural heritage significance, which dates back to Ming (1368-1644) or Qing Dynasties (1644-1912). Meanwhile, a so-called “vernacular frenzy” is
sweeping rural areas of China in recent years, in which the popularity of rural villages has increased and urban people have started to long for the country life. This may be caused by urban people wearying of modern reinforced concrete buildings in cities or suffering too much mental stress, and so seeking out rural villages and vernacular architecture as alternatives. The mass media and journal papers report there was a trend that architects have designed some modern, but vernacular style, hotels to attract visitors to these areas (Ying & Zhou, 2007). However, a majority of these new buildings in rural villages are typically constructed using reinforced concrete but visually mimicking the vernacular style, and did not conform to sustainable design principles or use vernacular materials and techniques. In the long run, the villages themselves would slowly lose their specific character and craft of vernacular constructions if this development continues.

The theory of vernacular architecture existed as early as the 19th century. In fact, vernacularism has a potential connection with building in British linguistics in the 17th century (Gabriel, 2006). It was not until 1818 that vernacular architecture developed into an explicit term (Oliver, 1997).

In 1976, the International Council on Monuments and Sites (ICOMOS) founded a committee to promote studying and research on vernacular architecture, and in Charter on the Built Vernacular Heritage, defined “Vernacular Building” as “the traditional and natural way that community residents build houses for themselves.” There are six standards for the identification of vernacular architecture (ICOMOS, 1999):

1. A manner of building shared by the community
2. A recognizable local or regional character responsive to the environment
3. Coherence of style, form and appearance, or the use of traditionally established building types
4. Traditional expertise in design and construction which is transmitted informally
5. An effective response to functional, social and environmental constrains
6. The effective application of traditional construction systems and crafts”

Prior to this, in 1964, The Venice Charter, pointed out the importance of reuse in the historical building conservation practice, in article 5, maintaining that “the conservation of monuments is always facilitated by making use of them for some socially useful purpose” (ICOMOS, 1964). Adaptive reuse was clearly put forward as a way of maintaining the physical fabric of important cultural sites when their economies and circumstances change, in this very influential heritage management document.

The Venice charter is not without its critics, however, including the former head of the historic-buildings group in Public Works, New South Wales, Peter Bridges, who claimed that the Venice Charter was European-centered approach, in need of rewriting to fit with the local area being considered (Walker, 2014). Following this the Burra Charter, the Australia ICOMOS Charter for Places of Cultural Significance was published in 1979. It emphasized the concept of significance, apart from a building’s value in utilization, and recognized the values of community and place, as well as the physical fabric (Australia ICOMOS, 2013). These theories and charters are discussed later in reference to the historical buildings and sites examined here.

Compared to historical architecture, vernacular architecture is folk style, and the vernacular focus is on recognizing traditional construction skills and local materials. Typical vernacular architecture is defined as built by the inhabitants, with local materials and traditional technologies, and maintains the regional cultural significance, and so few authors discuss contemporary vernacular styles. However, at times indigenous people themselves do adapt and update their building techniques using new materials that become available, or in response to changing circumstances. This continual change reminds us that vernacular architecture is not static and that vernacular styles can be modified with the passing of time.
2. Objectives

The boundary of the concept of stainability is expanding in recent academic discussion. Generally, it can be divided into four aspects: cultural, social, economic and environmental sustainability (Boström, 2012; Chiu, 2004; Connelly, 2007). All these sustainable factors can be seen in a construction process of vernacular building.

Vernacular construction skills and their associated intangible cultural values should be protected and transferred to next generation. However, not many youngsters seek to learn these because of the small income and lack of work for traditional craftsmen. The construction process for vernacular buildings is related to the whole community, so it is a social event. Furthermore, the organic material typically used for vernacular building activities mainly comes from local sources, so there is no doubt that the economic and environmental aspects of these vernacular architecture is usually excellent.

The objectives of the paper are to record the character of vernacular buildings, the construction skills required and illustrating how these vernacular buildings are built in each part or element in order to educate our descendants how these rammed earth buildings were constructed in North Fujian. Specifically, the characters and construction process including the foundation, rammed earth wall, timber structure, stair case, windows and doors. In the end of the paper, there summarizes a typological unit as a guide for future design for the buildings share the similar characters in these area.

3. Project information

In May 2013, Zhenghe County of Fujian Province joined the “beautiful village” upgrading plan, which aims to enhance the living conditions, infrastructure construction, environmental protection, and the economy of the rural areas. As one of the earlier pilot villages in the plan, Yangyuan Village (27°09'N, 119°00'E) preserves hundreds of ancient dwellings built in the late Ming Dynasty and early Qing Dynasty, which are the most intact and typical old house compounds in the northeast region of Fujian Province. Entrusted by the local government, the team of Professor Chen Zhao, of Nanjing University, developed a proposal for the planning, overall design, and design of individual residences within the ancient village to accord with its original morphology, making it a revitalized village integrating cultural significance and natural landscape (Luo & Zhao, 2015). The next part of this paper will discuss the background and traditional construction skills investigated during the project.

Fujian Province is a mountainous region, and the poor traffic connections are one of the main reasons for its undeveloped economy. Yangyuan Village, an easternmost village of Zhenghe County is located in the middle of Fujian Province, originally named Huangyuan Village, was first constructed by a family surnamed Zhang in 889. The village is located on the southeast slope of the valley between Feng Mountain and Donggong Mountain, with the relief inclining slightly to the southeast and the average elevation above 800m. The highest temperature in Yangyuan is 34.7°C, the lowest -12.2°C, and the average 14.7°C. With the diurnal temperature difference, it has the typical climate of “Northern China”. Culturally significant relics include Yingjie Temple built in the first year of Emperor Kangxi (1654-1772) of Qing Dynasty, Shuiweicuo Bridge built in the first year of Emperor Xianfeng (1851-1861) of Qing Dynasty; scenic spots include the Carp Stream, which was prosperous in the years of Emperor Jiaqing and divided the ancient village into the southern and northern parts, where numerous carp can be found swimming in groups.
In 2012, the Ningwu Expressway was open to high-speed traffic, passing through Zhenghe County and converging with Guping Expressway at Yangyuan Village (Figure 1). Therefore, Yangyuan County will become an important area that embraces the economic development driven by increased traffic.

4. Methods

The research methods for the village analysis comprised of four parts: interviewing villagers and craftsmen, observing and measuring buildings, a statistical analysis of the village buildings’ timber structure and roof truss, and computer modeling of the buildings for analysis.

In terms of interviewing, the research team lived in the village for a week and worked systematically to hear from local residents and builders to gather a thorough oral history of the village, including its history, economy, climate, social customs, techniques of vernacular building construction and the village’s suggestions on required infrastructure. Meanwhile, we examined the whole village street pattern and took numerous photos during the observing process. Twelve vernacular buildings were surveyed and measured in detail and forty buildings’ roof structure data were collected by tape-measure and laser range finder. After returning to the University, all the vernacular building data was collected statistically in order to get to maximum, minimum and average size of each element of vernacular housing there. Based on the all the information above, and with an aim to define the typology of the village buildings, we use computer modelling to conclude the typical unit and define the “traditional construction system”.

5. Observed details of the vernacular construction in the village

5.1. Stone foundations

For the humid and rainy climate in the mountainous area of Fujian Province, stone is used as the foundation of soil walls so as to isolate from moisture. Stone foundations fall into two types: large footings (an underground foundation trench) and small footings (where the wall is above the ground). In the large footing, constructors first excavate the foundation trenches ranging from 60cm to 200cm deep. Foundation trenches are usually twice the width of small footing. After the excavation of
foundation trenches, constructors need to cushion the wall foundation and build wall toes with one or two rows of large stones. If the foundation is soft or subject to flooding, the excavation is made deep enough to reach a solid base; wall foundations can be built with large sized gravel, whose biggest surface should be downward, and their joints are filled with small sized gravel. After wall foundations are built above ground, small footings are constructed using one of three methods: dry masonry, wet masonry, or the “gold wrapping silver” technique, which we go on to explain. Dry masonry refers to constructing a small footing with unprocessed large round river stones on two sides, with the middle cushioned with small rubble. Wet masonry refers to constructing a small footing with rock blocks and cement. “Gold wrapping silver” refers to the small footing being built with one or two layers of stones (about 60cm thick), and the middle part is tamped with red soil or other clays. The wall built with stones accounts for about 35% of the total thickness (Chen, 2012).

![Figure 2: Stone foundation types](image)

Because of the side forces coming from two directions, materials at corners are usually hard and intact, or cut square stones or bricks. Sometimes, these stones are longer than the standard level of stones, rising above to the lowest point of the soil walls. The construction of corners is similar to staggered joints of brickworks, rather than X-shaped joints with 45° inclined stone in the non-corner area (Figure 2). Broken stones or bricks are usually used to produce a flat plane for the sake of tamping soil walls in the future.

### 5.2. Rammed earth wall

Dwellings in Fujian Province are still constructed using a unique rammed earth wall method. Two horizontal planks are erected in parallel, to create a form work for the wall thickness. These clamping planks are supported with external clamping posts, and then earth is filled between the two planks and stamped tightly. Finally, the wall is formed after the removal of planks and posts.

Fujian Province has locally grown fir trees, which are used as material for dwelling structures and ramming tools in the mountainous area of the northern Fujian, including wall frames, bulkheads, clamping posts, clamping planks, etc. (Figure 4). Wall frames are usually 2.5-3.5m high and 30-50cm wide, which is equivalent to the rib plate of a bulkhead. Bulkhead and clamp planks are about 5-7cm thick. The two side edges of a clamping plank are vertical, and the end is fixed with a bulkhead. The other side is opened and connected with therammed wall, and fixed with blocking woods. Then, the earth is filled for ramming to form the minimum unit of a rammed earth wall, namely a “Ban”. After compression the earth comprising the wall is half its original volume. After the completion of one template and the removal of clamping planks, the wall surface should be finished. The wall surface is then beaten strongly to make it solid and then gently to flatten it. Bamboo chips soaked in water are added to the earth during the ramming, similar to rebar in reinforce concrete, they serve as...
reinforcements in the construction. When withdrawing the blocking woods, the earth is rammed to the required length, the template is raised and then the next layer is made using the same method. The rain and humidity are enemies to the life of rammed earth. The top surface of the rammed earth wall is usually covered by tiles and corbelling eaves to stop the rain erosion of the vernacular buildings. And the moisture sometimes that absorbed by the rammed earth may not be that bad, because slight increase (<4% by weight) in moisture will not lead to the drop of the rammed earth (Bui, Morel, Hans, & Walker, 2014).

Modular rammed earth construction is recorded in ancient China as early as 770 B.C. to 221 B.C. We can find units such as “Ban”, “Du”, and “Zhi” (Figure 3) in Rites of Zhou, Chronicle of Zuo, and Commentary of Gongyang. Du is a section of wall formed after ramming in a vertical direction, usually 7-10 Ban in Fujian Province, the common modules of rammed earth wall. Correspondingly, Ban and Zhi are the sub-module and expanded module of the dimension of rammed earth wall respectively (Chen, 2012). Eight workers can ram two Du of earth wall each day with this method, and the second layer of earth wall can be started after the preceding layer is thoroughly dried within 60-80 days, according to local masters. Traditional buildings in China have two directions of width and depth. Earth walls can be defined as eave wall and gable wall corresponding respectively to width and depth direction. The gable wall of a principal room possesses the striking features, and the following are its six most commonly found styles (Figure 5). Eave walls following one of two types, depending on whether the second-layer wood structure has any projection (Figure 6).
5.3. Timber structure

Dwellings in the mountainous areas of the north Fujian Province follow a typical form and structure: a courtyard behind the gate, with wing rooms at two sides separately (Figure 7). Wing rooms are lower than the principal room and are used for placing sundries. Sometimes, two stories are enclosed to form a small room. Behind the courtyard is the hall of the principal room (Figure 8). The size of a hall can be described by the number of pillars flanking the sides of hall, for example “four-pillar halls”, “five-pillar halls”, and “six-pillar halls”. A hall is usually two stories, with an exposed roof truss. The two sides of a hall are bedrooms. Memorial tablets of ancestors or deities are consecrated in front of the wooden partition in the middle of the hall. There are doors at the two sides of the wooden partition leading to the rear room, which is often used as the kitchen. The rear courtyard is usually small, and a small tank is built there for collecting rainwater, washing vegetables, and raising fish.

In the timber structure buildings, the horizontal space between two purlins is called “Bujia” (Zhao, 2015). It is also known as a “Jia” or “Chuanjia”. Two steps are considered one “Bu” in ancient times, which is an abbreviation for “Bujia”. The unit of length for this varied in different dynasties. According to the arrangement of purlins, a timber structure is divided into several Bujia. The Bujia at the two sides of the ridge are called “Jibu”; those at the inner side of eaves are called “Yanbu”; and those between “Jibu” and “Yanbu” are called “Jinbu” (Figure 9).
We mapped and surveyed roof trusses of nearly 40 dwellings, and obtained the maximum, minimum, and average values of each *Bujia* in the region as follows (Table 1).

<table>
<thead>
<tr>
<th></th>
<th>Principal Room</th>
<th>Wing room</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yanbu</td>
<td>Jinbu</td>
</tr>
<tr>
<td>Minimum value</td>
<td>510</td>
<td>700</td>
</tr>
<tr>
<td>Maximum value</td>
<td>1500</td>
<td>1050</td>
</tr>
<tr>
<td>Average value</td>
<td>798</td>
<td>923</td>
</tr>
</tbody>
</table>

### 5.4. Other Elements

Door frames are formed with embedded timber, bricks or stones incorporated in the process of module ramming, and most window frames are timber (Figure 10). Usually, the openings are along with the edge of a piece (*Du*) of rammed earth.

Dwellings in the region are predominantly two stories, and staircases are usually in the middle of the wing room and principal room (there may be staircases leading to the upper level behind the wooden partition of the hall of the second story and corridors at the two sides of the principal room). According to our survey, staircases have of these following types, and the key to staircase design lies in the treatment of different levels of the corridors at the two sides of the principal room and wing room (Figure 11).
6. Results

Dwellings in the region mostly use earth as building enclosure material that provides outstanding performance for heat thermal isolation and timber as structure can easy to adapt different geographical terrace. Through the survey on local dwellings by the typological method, and after item research at the level of construction, we preliminarily abstracted a set of standard typical unit of the traditional construction system (Figure 12) as the basis of preserving these traditional features and continuing the style of the village in the design of new dwellings. This model gives evidence of enduring the test of time and therefore could reliably be used as a typological guide for future sustainable designs or extensions for that region.

![Figure 12: The typological unit of vernacular building](image)

7. Discussion

In the field of architecture, the loss of cultural identity is a world-wide problem. In China, traditional villages are diminishing at an amazing speed. In order to conserve the cultural heritage and improve the living quality, the Chinese government propelled the “beautiful village” plan aims to lead the development of vernacular villages in a sustainable way. In this paper, we summarized the detail of vernacular construction that was observed in the village and identified a type and the “traditional construction system” of Yangyuan Village, albeit it is not illustrated in detail. This investigation and analysis application process can be used as a method for identifying, learning and defining a village building typology in any settlement around the China or even the world.

Since the approach that used to build the rammed earth building last for centuries, it should be assumed that the construction skill is suitable for use to build new housing there and it is of great intangible cultural and architectural heritage value to sustain the local skills. At a higher level, the morphological sustainability is a sub class of cultural sustainability. Therefore, not only the single vernacular building requires protection and adaptive renovation, but the morphology of the whole village also requires such consideration. The building type can give us an original model to be modified into variants for future design work to sustain the village morphology. In addition, we expect in the future that villages can support more employment, and attract migrant labor currently in cities back to their hometowns, so as to keep the balanced development of urban and rural areas. In that way, the social sustainability would operate functionally.

To conclude, selectively using recyclable materials and the original construction principles to reuse existing vernacular housing or reconstruct a new vernacular building, and respecting the pattern of the
village’s original morphology should be not only an eco-friendly and renewable, but also a social and cultural sustainable way of development of rural villages.

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Reference

Knowledge Management Systems in construction: a case study in the Portuguese industry

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Abstract: Knowledge Management Systems (KMS) are a structured framework for the retention and application of organisational knowledge. The costs of investment in KMS can be high and such systems need to be well planned to increase the likelihood of success. KMS in construction companies have been analysed in the last decade by both industry and academia to identify the best solutions for successful implementation. This research reports on a comparative case study in Portugal on the perception of KMS by construction professionals, architecture and engineering consultants and consultants in the business, information technology, and communication sectors. This comparison helped to identify the lessons learned in sectors where KMS are successfully developed and transpose this learning to the construction industry. Research data was obtained through semi-structured interviews encompassing professionals, Operational Managers, Project Managers and technical experts to ensure that a broad range of views was obtained. Findings demonstrate that for a KMS to be effective and successful in the construction industry, the system should be seen as integrated rather than external. This paper identifies the need to prepare a successful KMS in organisational culture with a strategy and identification of values of knowledge into an integrated organisational process.

Keywords: Knowledge Management, Knowledge Management Systems, Construction, Portugal.

1. Introduction

Business strategies are driven by the demands of new markets and new competitors. As such, companies have built new capabilities to learn quickly and change in order to take advantage of and respond to the "knowledge economy". The need for companies to manage change to facilitate innovation in a systematic way is characteristic of how the nature of knowledge has evolved in contemporary organisations (Drucker, 1993; 2009). Knowledge Management Systems (KMS) are known as management models that have allowed organisations to identify, capture, share and reuse their knowledge. The attempt to manage organisational knowledge has seen the development of KMS, such as systems based on tacit and explicit knowledge, the SECI Model and recently the phronesis model (Nonaka et al., 2014) which is a combination of both.
Since 1999, Davenport and Prusak (2000) have argued for the conceptualisation of a firm as a collection of its knowledge, history, and culture all of which need to be aligned with technology for effective and productive KMS. However, knowledge-management programs require organisational commitment and cannot solely be left to information technology systems to garner success (Hauschild et al., 2001). KMS require an environment that allows workers to create, capture, share, and leverage knowledge to improve performance. Malhotra (2004) has argued that the main reasons behind the failure of such systems lay with a lack of robust application in defining, implementing and executing effective KMS. Also, Malhotra (Malhotra, 2004) identified that KMS need to deal with human and technology relations, lo-tech and hi-tech methodologies, and unconventional and conventional means of producing ‘business performance’. The integration of business models as simultaneous and parallel sets of knowledge processes, as against isolated operational modes, facilitates ongoing innovation of business and customer value propositions.

Knowledge sharing and learning behaviours contribute to better performance, business process improvement and have a direct application in the construction industry (Chen and Fong, 2013; Forcada et al., 2013; Serpella et al., 2014; Tkachenko et al., 2014; Lundberg and Lidelöw, 2015; Wibowo and Waluyo, 2015). Approaches to an integration model, such as the concept of the live capture of knowledge (Udeaja et al., 2008) have been seen as applicable to the construction industry. For Sommerville and Craig (2006) good decisions are also the result of careful management and the analysis of project information and knowledge. What has been identified is that organisations encounter a vast range of knowledge zones; however, difficulties are encountered in differentiating between what is essential, important, or merely interesting. For Drucker (2013), making knowledge productive further requires that it be clearly focused, and highly concentrated. Whether done by an individual or by a team, the knowledge effort requires purpose and organisation. An initial lack of focus has been one of the reasons why some KMS fail. As a result, KMS processes are seen to be ineffective and a source of management frustration within organisational structures often leading to an abandonment of KMS at high financial cost. This paper analyses a case study in Portugal where the context of the economic crisis has called for the need of new solutions to reduce costs and improve KMS methodologies for the construction industry.

2. Knowledge management systems in construction

Construction organisations in a knowledge-based industry (Egbu and Robinson, 2005) willing to improve their business performance and achieve sustainable competitive advantage in global markets are looking to implement Knowledge Management (KM) tools that lead to an improvement in their ‘learning capability’ (Ribeiro, 2009). KM concepts and techniques are required to improve lessons learned from completed projects (Forcada et al., 2013), employing ontologies and graph-based reasoning operations in eliciting and visualising knowledge concepts (Kamsu-Foguem and Abanda, 2015) are increasingly being adopted by construction-related firms. Several systems have been developed for the construction industry, such as OSMOS (Rezgui, 2007), CAPRI.NET (Udeaja et al., 2008), KFWFCO (Yin et al., 2008), SPICEC (Vaz-Serra, 2011), CNIM (Lin, 2013) and MBKM (Chih-Cheng et al., 2014). Also, construction companies developing their internal systems include Link.ME (Curado and Ramos, 2010) and Construknowledge (Vaz-Serra et al., 2012) in Portugal and ‘iKonnect’ and ‘EDMS KM’ (Zou, 2012) in Australia.
Investments in KMS can be considerable; Zou (2012) reported on two construction companies in Australia that expend an average of AUD $2.5 million per year in systems related to KM. Given the considerable financial and human resource investment required in the introduction of KMS, some issues have been identified which contribute to the failure of effective implementation. These failures encompass ‘technical, human and business related factors’ (Udeaja et al., 2008) requiring a need to improve KM processes and create new knowledge to ensure that KMS application extends beyond project completion (Wiewiora et al., 2013). Such systems need to respond to human resource issues, such as workload stress, time pressures and long working hours (Forcada et al., 2013).

Drucker (2013) identified the Post Capitalist Society as The Knowledge Economy where specialisation in knowledge has given an enormous performance potential in each area. Drucker also emphasises that to turn potential into performance each organisation needs a process to identify their ‘productive knowledge’ clearly focused. The process to identification of each productive knowledge areas can be done by each organisation through the analysis of the answers of the questions: what do I know? What have I learned? and What I will apply?

Consequently, the definition of different ‘knowledge areas’ has been developed by several authors and organisations and is now a concept accepted worldwide. For construction companies, those different knowledge productive areas have to be identified and prioritised in the moment of developing a KMS.

Generally, construction companies in Portugal have a common organisational structure in several business areas: Financial, Market and Supply Chain, Planning and Scheduling, Production and Technical. For the purpose of this research, those business areas have been used to ask respondents to rate their needs according to their professional activities. The results of the business areas of main focus have been identified as their knowledge productive areas.

3. Research methodology

This research reports on a comparative case study on the perception of KMS in Portugal by construction professionals, architecture and engineering consultants and consultants in the business, information technology, and communication sectors. The focus of this pilot study was to identify sectoral characteristics and issues raised in the perception of KMS by differing communities of practice, determine where KMS value lie and the factors that may contribute to the improvement of KMS processes. A case method study approach was selected, using semi-structured interviews, in order to provide insights into the nature and characteristics of reusable project knowledge and end-user requirements for knowledge capture and reuse (uit Beijerse, 1999). A questionnaire was prepared to guide the interviews and the survey questions were targeted to identify: (1) The perception of firms of the importance of KM to their organisation; (2) methodologies for effective knowledge-creation and continuous improvement; and (3) KM in supporting decision-making and implementation.

Semi-structured face-to-face interviews were conducted with 44 senior staff from 34 companies, 22 participants from the Architecture and Engineering (AE) and construction (C) industries and 22 from other sectors: Business Consultants, Information, Technology and Communication and Training Consultants (BITT). Participants ranged from Operational Managers (commercial and human resources), Project and Construction Managers and Technical Experts (Engineers, Architects) and information technology experts (IT Experts) to ensure that a broad range of views was obtained. This approach
recognises that some of the successful examples of KMS come from other industries (Nonaka et al., 2014), such as the automobile industry (Toyota), technology and telecommunication firms (Fuji Film and Apple). There may be advantages for the construction industry to understand these systems, further, such research also may assist in identifying the unique characteristics of the construction sector in the application of KMS.

Interviews encompassed five sections: Section 1 - Respondents' profile and awareness of internal communication; Section 2 - KMS and value adding; Section 3 - KMS and process improvement; Section 4 - KMS and assistance in decision making, where research results were statistically organised into data sets with a qualitative analysis undertaken to identify common themes arising from the extended responses of participants; and Section 5 - Assessment of different knowledge areas only for the construction companies to identified and assess different areas with a major focus to be used as a starting point for KMS implementation.

4. Research results and discussion

The structure of the interview to collect data was carried out in five sections.

4.1. Section 1 – respondents’ profile and awareness of internal communication

Background information is presented in Table 1 which includes interviewees’ profile by age, position and years in the company and company information identified by type and size. Table 2 summarises aspects related to internal communication awareness.

<table>
<thead>
<tr>
<th>a) Companies</th>
<th>b) Interviewees</th>
<th>C</th>
<th>AE</th>
<th>BITT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure Items</td>
<td>%</td>
<td>Measure Items</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>C (27%) Contractors</td>
<td>27</td>
<td>Age</td>
<td>25 – 34</td>
<td></td>
</tr>
<tr>
<td>AE (23%) Design</td>
<td>14</td>
<td>35 – 44</td>
<td>42</td>
<td>30</td>
</tr>
<tr>
<td>Developers.</td>
<td>9</td>
<td>45 and above</td>
<td>58</td>
<td>70</td>
</tr>
<tr>
<td>BITT (50%) Business Consultant</td>
<td>20</td>
<td>Oper. Manager</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>(with KMS) ITC and Telecom</td>
<td>23</td>
<td>Proj. Manager</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>Training Consultant</td>
<td>7</td>
<td>Tech. Manager</td>
<td>8</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IT experts</td>
<td>42</td>
<td></td>
</tr>
</tbody>
</table>

The large majority of the interviewees (90%) have been working with the company for more than five years, ensuring that participants offered exposure to project experience, had an awareness of knowledge-based requirements, knowledge receipt, its application and retention, and needs of leadership related to knowledge sharing.
Internal communication was seen as being valued by respondents’ organisations, with relative consistency between C and AE firms. A discrepancy was identified in the use of an intranet system in documentation and communication management by AE firms to those of the BITT group. Further research is required to identify the reasons behind such difference, but it is suggestive of communication methodologies in AE being geared towards non-server based systems. The difference is also reflected in the discrepancy between C and AE, where socialisation and workshops of knowledge sharing are central features of AE. However, only 58% respondents of construction identify this as features in their firm. This matter may be influenced by the company size, where AE firms were overwhelmingly small to medium-sized firms and where capital investment in sophisticated networked systems carry greater cost impost and where organisational size facilitates easier direct personal interaction.

The awareness of the value of past experiences in decision-making processes is held to have greater recognition in the C and BITT sectors as against those in AE which rated this question an average 11 percentage points below their industry sector counterparts. Although the AE sector values internal communication, communication strategies do not rely on formal digitally-based systems, while reflection on past experiences does not necessarily translate into informing future decision processes. This case study suggests that there may be cultural and structural differences inherent in communities of practice of industry players, which influence the introduction and form of KMS application.

### 4.2. Section 2 - KMS and value adding

The role of KMS as a value-adding tool in business performance was next reviewed and is summarised in Table 3. Participants were asked to reflect on client recognition of KMS investment and the risks and benefits such systems offer.

<table>
<thead>
<tr>
<th>Question (responses in agreement)</th>
<th>C</th>
<th>AE</th>
<th>BITT</th>
</tr>
</thead>
<tbody>
<tr>
<td>The investment on KMS is valued by clients</td>
<td>83</td>
<td>85</td>
<td>60</td>
</tr>
<tr>
<td>KM can bring risks of leakage of information external to the organisation</td>
<td>68</td>
<td>76</td>
<td>20</td>
</tr>
<tr>
<td>KM helps to improve competitive bids</td>
<td>88</td>
<td>92</td>
<td>100</td>
</tr>
<tr>
<td>Can reduce duplication of works and mistakes</td>
<td>93</td>
<td>96</td>
<td>100</td>
</tr>
</tbody>
</table>

The open-ended nature of the interview process elicited differences between the construction sector and other industry sectors. A point of difference was the value placed by the client on KMS. The
construction sector is characterised by being project-based as against the product-based nature of other sectors in that the project-based nature of the construction industry and client participation in project delivery processes garnered recognition of KMS investment by clients. However, it was observed that this did not necessarily transfer into financial compensation of KMS investment as the industry still operated under competitive fee bidding where clients were focussed on minimum fee strategies. The exception to this was on projects of a specialised nature where the open-market competition of fee bidding was not as prevalent and clients recognised the value of KMS to project outcomes. The product-based nature of other sectors elicited a perception of the lower value of KMS by clients, being 60% as against an average of 84% in construction and AE. An example of this was provided in the telecommunications sector, where client value to KMS was conceived regarding the effective functioning of the final product at the lowest cost.

The risk of information and knowledge leakage outside the organisation were acknowledged as factors for construction (68%) and AE (76%). However, for BITT (20%) it was considered that information leakage was not a risk if organisations have robust systems. Respondents from BITT identified that it was not simply a factor of the KMS per se, but also the manner in which it is used that gives rise to system failure. All sectors affirmed the value of KMS in formulating well-considered bids and in reducing work duplication.

4.3. Section 3 - KMS and process improvement

In this section, Table 4 summarises perceptions of how KMS may assist in the improvement of future processes. Participants were asked to reflect on the use of the KMS and its ‘usability’ features within their respective firms, encompassing such aspects as time investment, ease, and applicability of access, participation rates and integration with organisational culture.

<table>
<thead>
<tr>
<th>Question (responses in agreement)</th>
<th>C</th>
<th>AE</th>
<th>BITT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time commitment in KMS will be recovered in future</td>
<td>90</td>
<td>84</td>
<td>89</td>
</tr>
<tr>
<td>Anyone can record knowledge regardless of experience level</td>
<td>77</td>
<td>88</td>
<td>71</td>
</tr>
<tr>
<td>People prefer to record well-executed processes rather than those not as well executed</td>
<td>73</td>
<td>76</td>
<td>69</td>
</tr>
<tr>
<td>Participation is high where the company recognises KM as being important</td>
<td>97</td>
<td>94</td>
<td>90</td>
</tr>
<tr>
<td>Knowledge is power, but sharing knowledge results in loss of power</td>
<td>87</td>
<td>86</td>
<td>85</td>
</tr>
</tbody>
</table>

Although it was considered by all sectors that time commitment in KMS had benefit recovery in the future, the AE sector rated this lower than their counterparts. This result was linked to a lack of developed performance measurement reporting that demonstrated explicit value back to team members, which in turn serviced improvement iterations. Contribution in recording knowledge regardless of experience was considered favourably by the AE sector, while C and BIIT, comparatively, felt that experience was a necessarily prerequisite in KM.

The type of information recorded favours those processes where it is perceived that they have been well executed, rather than those less successful. This issue was the case particularly in the AE sector, while BITT recognised the benefits arising from KM in learning from mistakes. This difference may reflect the product focus and product improvement imperative under which this sector operates. This is set
against the often bespoke and multifarious nature of projects and the dynamic structure of project teams in the construction sector where value is given to those things that generally worked well as against project specifics of those which did not. Respondents also commented on the need for people within the organisation to recognise the relevance of the knowledge that was recorded in the system. Management recognition of the value of KM was viewed as paramount in the promotion and support of participation in KM processes, ranking highly across all sectors.

A factor identified by interview respondents as being significant from the BITT category was that recording knowledge is mandatory for their companies, where internal systems record levels of individual knowledge sharing. This integrated and obligatory approach (Figure 1) was seen as a feature in the perceived success of KMS in the sector.

![Figure 1 – Separated KMS versus Integrated KMS](image)

Organisational Sociology related to power dynamics as a barrier to KMS (Soenen and Moingeon, 2001) comes into play where respondents acknowledged reluctance to share knowledge. This giving over of knowledge was seen as undermining individual capital, potentially placing at personal risk leverage within the employment setting. Respondents across all sectors had high levels of agreement that there was a risk affiliated with sharing knowledge, not only in the personal loss of power but also at an organisational and market level.

### 4.4. Section 4 - KMS and assistance in decision-making

The primary objective of KMS is to provide a platform for effective decision making through the utilisation of organisational, individual and project knowledge. This section, therefore, addressed the perception of practitioners of how an effective KMS can aid in informing decision-making (Table 5).

<table>
<thead>
<tr>
<th>Question (responses in agreement)</th>
<th>C</th>
<th>AE</th>
<th>BITT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complex accessibility to KMS can create obstacles</td>
<td>82</td>
<td>96</td>
<td>93</td>
</tr>
<tr>
<td>No new solutions developed because it is easy to look only at past solutions in KM</td>
<td>63</td>
<td>72</td>
<td>78</td>
</tr>
<tr>
<td>KM reduces the risk of less optimal solutions in urgent decision-making</td>
<td>78</td>
<td>84</td>
<td>93</td>
</tr>
<tr>
<td>KM access to past examples allows better decision-making</td>
<td>93</td>
<td>96</td>
<td>92</td>
</tr>
</tbody>
</table>

There was a cross-sector acknowledgement, via consistent high affirmative values, that the complexity of KMS ran the risk of generating obstacles in the usefulness of the system in informing
decision making. Some argued that their organisations already had given up on some systems because they were overly complex or slow leading to people refusing to use the system. The need for an integrated and transparent system that was embedded into the particularities of the organisation environment was, therefore, an important aspect for final users.

The perception that reliance on a KMS ran the risk of preventing innovation and de novo solutions was more acutely felt in the AE and BITT companies, where there was a ten percentile point minimum difference with the construction sector. KMS was seen as having significant benefit by BITT respondents (93%) in optimising solutions where urgent decision making comes to the fore. Comments from this sector revolved around the aspect of KMS value in avoiding disputes. This benefit was not as highly valued by construction respondents (78%).

### 4.5. Section 5 - Assessment of different knowledge areas

This section was only answered by construction companies and addressed the perception of practitioners in different knowledge areas as a major focus. Respondents were asked to identify the areas that are important to them and the knowledge of the areas that they need, have, retain and share their professional activity (Figure 2).

![Figure 2: Knowledge areas in a construction company.](image)

At the start of this section the respondents commented that all areas were important, however, at the time of the ranking they agreed that for their professional activity, in the day-to-day, some areas can be more important than others. The answers were that, currently, they have on average 80% of the knowledge that they need for their role, retain 78% and share only 67%. Respondents argued that one of the reasons to share less was due to lack of opportunities to share because sharing knowledge in their organisation is only between small groups and if requested. For the last question, interviewees were asked to classify between the five main different areas of importance for them and their activity. The results on average for each area were: Planning (71%), People (68%), Techniques (61%), Market (55%)
and Financial (45%). Therefore, for construction companies, the information about Planning and Techniques (Projects) and People (Human Resources) are the areas suggested to be used as a focus and starting points for KMS. Nevertheless, all the interviewees argued that all the areas are important and that it was a significant problem to choose the most important one. One of the possible reasons for selecting the financial knowledge at the end was because interviewees in the companies of this research already have sophisticated systems to control costs. Therefore, they may take that knowledge for granted, and might not realise the importance of not having it.

5. Conclusions

Ample literature exists to support a growing awareness of the advantages of using and implementing KMS in the construction sector. Research based on industry practice in the use of such systems can assist in reducing the risk of failure of KMS. This research confirmed an awareness of KMS in the Portuguese construction sector, however, it also identified that there are sectoral characteristics and organisational dynamics that may contribute to the undermining of effective KMS. The findings suggest that communities of practice within the construction sector differ, organisation size influences the nature of KMS, and recognition and commitment to KMS that are both intramural and extramural are necessary. Also, feedback loops that inform iterative improvement underpin user buy-in, and an understanding of organisational sociology dynamics are all necessary prerequisites that require consideration in KMS implementation.

To conclude, this study highlighted that KMS in construction companies to be successful need to start small, in one or two different areas, before spreading to the rest of the company. The steps must be small and incremental to the ambitious KMS global goal. Accordingly, given the results of the survey, and the nature of the people-based and project-based industry, construction companies need to start their KMS to focus in two main areas: managing knowledge of their people and their projects. Further case study research is required to delve into the rationale that lies behind these findings in other regions. In the construction industry there barriers for knowledge management seem to exist and the sector tends to be very conservative, therefore, if KMS introduced high costs can be an additional obstacle. In this scenario research initiatives between academia and industry in KMS can be essential to help construction industry to implement their KMS efficiently and with minimum costs. KMS will help companies to be more competitive to address the economic crisis and to be better prepared to adapt to changes.

References


Going solar: the ramifications

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Abstract: As the number of photovoltaic systems grows and costs decrease dramatically along with their connect-to-grid tariffs, we ask whether our investments all make sense. This is a real case study, comparing energy use before and after going solar, by installing PV, reducing electrical energy use by retrofitting lighting, and storing electricity in a hybrid vehicle. The case study covers more than energy savings and explores the results of these actions. We present and develop data to calculate and illustrate the findings of energy generation, its use and sale back to the grid. We explore the reasons for, and benefits of, each of the investments and justify why ‘Going Solar’ makes plain good sense for the future.

Keywords: Solar energy, usage, storage, cost-benefits.

1. Introduction

In Australia, private solar photovoltaic installations have been growing at a significant rate, both in capacity, more than doubling since 2009, and in number (Chapman et al. 2016). That paper reports an analysis of the outcomes of solar PV policy up to 2012. However, since the Australian Federal Election in 2013, changeable government policies and political attitudes have contributed to uncertainty. Apart from the politics, the environment of supplier tariffs and plans for grid electricity, especially when they involve solar PV, is complex. Ren et al. (2016) have modelled the impact of PV battery systems on energy consumption and electricity bills under various tariffs in several Australian cities. Nichols et al. (2015) have developed a methodology to estimate total cost of ownership and total life-cycle CO₂ emissions. Lastly, Agnew and Dargusch (2015) explore the impact of battery storage in solar PV systems on the electrical distribution network.

In this paper, we present an analysis of data collected by the first author over recent years relating to energy use at home. In 2014, a 3 kW photovoltaic system was installed and a plug-in hybrid vehicle purchased. At the same time, instrumentation was added to record grid energy, solar energy and vehicle charging energy. A smart meter had been installed in 2013, and the grid consumption and generation energy could be obtained from the provider. Data from the vehicle was recorded before and after each charging event and when the car was refuelled. As a result, the data was available to do a before and after analysis of energy generation and consumption.
The genesis of the project arose out of the consideration of what solar energy could be used for, particularly in the light of the very low tariff ($0.05/Kwh) presently offered for energy generation. Given the installation of a solar PV system, environmental benefits (e.g. CO₂ emissions) have been addressed. The remaining efforts achieve benefits for the user, but in the light of addressing global warming, it is important to identify these to encourage the installation of further solar PV and other renewable energy technologies. Hence, the question, “How do we use the energy?” is important.

The other possibility is to reduce energy consumption by replacing all lighting with LEDs. The most commonly used lights were already compact fluorescent globes so the question of how much energy was saved by LEDs is also addressed.

2. Solar photovoltaic energy in Geelong, Australia

In this climate (38°S), the installed 3 kWh photovoltaic system harvested 3.94 MWh of energy from 1 July 2014 to 30 June 2015. There are twelve panels with a total area of 20 m². So, the harvested power density averages 22.8 W/m² over a year. This figure is 1.7% of the solar constant of about 1,350 W/m² (Duffie and Beckman 1991). It is also 12% of the annual averaged direct normal radiation of 193 W/m² as reported, for example, in NASA (2016). Some of the difference is cause by the innate efficiency limits of Silicon solar panels and the angle of installation, flat on the roof of about 5° incline. The figure is consistent with (of the same order as) that reported for the United Kingdom by McKay (2009).

Each solar panel is rated at 250 W, contains a micro inverter, so generating 240 V AC power, and communications to report to the system controller. The controller is connected to the ADSL router and serves web pages which can be used to collect performance data. A display summarising a week’s output from the whole system is shown in Figure 1.

The system was switched on at the convenient date of 1 July, 2014. Data logged on the controller are only for the previous 30 days, deleting the oldest day at midnight. Collection of the data was done manually, and so, sporadically. Fortunately, the life-time energy harvest is recorded (LTE, the stepped line in Figure 1).

The data reported is for each panel and contains date and time, life-time energy harvested, power, voltage, current, grid frequency and inverter temperature. For our purposes, date, time, life-time energy and power are of interest. Table 1 shows the data collected from the installation for a number of periods of 29 or 30 days.

Initial and final energies are the life-time energy harvest to date, respectively. The difference (“Total” column) is the energy harvest for the period. Maximum, minimum and average daily figures are extracted. Average power is found from the daily average energy by dividing by 24 hours/day. Average power density is derived by dividing by the panel area. Extreme values in the table have been emphasised. As expected, the maximum energies harvested occur in December and January, the minimums in May, June and July.

3. The house

The house was built ten years ago, fully insulated and double-glazed with eaves to control the summer sun, a gas-boosted solar hot water service and 10,000 L of water storage. Some outside blinds were installed after building to manage summer and autumn heat. As shown in Figure 2, the house performed well during the heatwave in January 2014. Table 2 shows the annual energy consumption of the house and car, a two-person household, on a flat electricity tariff. The petrol used is tabled, because a hybrid
vehicle is introduced later as a means of energy storage and household cost reduction. Furthermore, the solar HWS system energy estimates are also listed here because they too could be conventionally powered by electrical or gas supply.

![Solar panel system output](image)

**Figure 1:** Display of solar panel system output

**Table 1:** Energy harvested from a 3 kW photovoltaic system

<table>
<thead>
<tr>
<th>Start</th>
<th>End</th>
<th>Initial Energy (Wh)</th>
<th>Final Energy (Wh)</th>
<th>Harvested Energy</th>
<th>Power (W)</th>
<th>Power density (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-Jul-14</td>
<td>14-Aug-14</td>
<td>79221</td>
<td>265475</td>
<td>186254</td>
<td>258.69</td>
<td>12.93</td>
</tr>
<tr>
<td>20-Aug-14</td>
<td>18-Sep-14</td>
<td>297408</td>
<td>584718</td>
<td>287310</td>
<td>399.04</td>
<td>19.95</td>
</tr>
<tr>
<td>3-Oct-14</td>
<td>1-Nov-14</td>
<td>752742</td>
<td>1147288</td>
<td>394546</td>
<td>566.88</td>
<td>28.34</td>
</tr>
<tr>
<td>2-Dec-14</td>
<td>1-Jan-15</td>
<td>1644589</td>
<td>2135213</td>
<td>490624</td>
<td>659.44</td>
<td>32.97</td>
</tr>
<tr>
<td>1-Jul-15</td>
<td>31-Jul-15</td>
<td>3940583</td>
<td>4093349</td>
<td>152766</td>
<td>212.18</td>
<td>10.61</td>
</tr>
<tr>
<td>15-Dec-15</td>
<td>13-Jan-16</td>
<td>5711243</td>
<td>6238898</td>
<td>527655</td>
<td>732.85</td>
<td>36.64</td>
</tr>
<tr>
<td>30-Mar-16</td>
<td>29-Apr-16</td>
<td>7232765</td>
<td>7490149</td>
<td>257384</td>
<td>355.41</td>
<td>17.77</td>
</tr>
<tr>
<td>22-May-16</td>
<td>20-Jun-16</td>
<td>7630434</td>
<td>7774272</td>
<td>143838</td>
<td>199.77</td>
<td>9.99</td>
</tr>
</tbody>
</table>
Figure 2: House performance in 2014 heatwave

Table 2: Energy use prior to installing solar panels (May 2013 – April 2014)

<table>
<thead>
<tr>
<th></th>
<th>House</th>
<th>Electricity Grid</th>
<th>Gas</th>
<th>Solar HWS</th>
<th>Car (9696 Km)</th>
<th>Petrol</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3,806 kWh</td>
<td>3,842 kWh</td>
<td>Up to 1,694 kWh available (NASA 2016)</td>
<td>10,685 kWh</td>
<td>(1,113 L x 9.6 kWh/L)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$1,524.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$1,524.26</td>
</tr>
</tbody>
</table>

Total running cost: $3,682.87

The solar panels were installed and became active on 1 July 2014. Data from the panels dates back to 15 July 2014, but was not regularly collected. The smart meter, installed in February 2013 and providing half-hourly consumption data, was reprogrammed, and generation data became available from 28 July 2014.
4. Ways to use the solar energy

If all the solar energy generated was fed to the grid at a rate of 5c/kWh, the annual harvest of electricity would earn about $200. As the panels, installation and “meter alteration” cost $8,300, the pay-back period would be over 40 years. However, solar energy may be used in a number of ways, which include heating water, running air conditioning systems, or charging electric vehicles. The energy may also be stored in batteries for later use. A solar hot water service is already installed, the house does not need air conditioning, and battery storage systems were expensive.

A plug-in hybrid car was purchased, conveniently replacing a twenty-five year old second car, used by a non-resident family member. The solar panels and car changed the energy flows in the household significantly, as Figure 3 shows for the year from July 2014 to June 2015. The Solar Panels generated 3,941 kWh of electrical energy. However, there remains an energy requirement from the grid of 4,017 kWh even though 2,047 kWh is provided to it from the PV system. Several points are:

- Not all the energy from the solar panels (Item a, 3,941 kWh) is used locally;
- Grid energy of 4,017 kWh (Item b) is imported;
- About half the energy from the solar panels is exported to the grid (item c, 2,047 kWh)
- The net energy from the grid is 1970 kWh (item b less item c)
- The petrol used is 191 L (item d). Assuming 9.6 kWh/L this is 1,833 kWh of energy. However, at best, a 30% thermal efficiency yields 550 kWh of mechanical energy. The car demands 15 L per quarter to maintain fuel quality; so this could be as low as 60 L per annum).
- The electrical energy used by the car is 1892 kWh (item e), some of which is derived from the solar panels during the day and the balance from the grid at night;
- The electrical energy demand of the house is the remaining 4,019 kWh (item f). Together with the gas used for heating, solar hot water boosting and cooking of 3,573 kWh (item g) gives a total energy demand for the house of 7,592 kWh.

The last step taken was to replace all incandescent lamps and compact fluorescent lamps with LED lamps throughout. This was completed late in November 2014. As a result, of all these changes, the total running costs have been reduced by $1,390.63. What is interesting about the saving is that most of it comes from the reduction in the demand for petrol.

Table 3: Energy use after installing solar panels (1 July 2014 – 30 June 2015)

<table>
<thead>
<tr>
<th>Item</th>
<th>Energy in (kWh)</th>
<th>Payments</th>
<th>Energy out (kWh)</th>
<th>Receipts</th>
</tr>
</thead>
<tbody>
<tr>
<td>House Electricity Grid</td>
<td>4017</td>
<td>$1,641.98</td>
<td>2047</td>
<td>$145.20</td>
</tr>
<tr>
<td>Solar Panels</td>
<td>3941</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>3573</td>
<td>$544.56</td>
<td>3573</td>
<td></td>
</tr>
<tr>
<td>Solar HWS</td>
<td>1694</td>
<td></td>
<td>1694</td>
<td></td>
</tr>
<tr>
<td>Electricity Petrol (191L)</td>
<td>1833</td>
<td>$250.90</td>
<td>1833</td>
<td></td>
</tr>
<tr>
<td>Electricity (10,519Km)</td>
<td>1892</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>$2,437.44</td>
<td></td>
<td>$145.20</td>
</tr>
<tr>
<td>Total Energy (kWh)</td>
<td>15058</td>
<td></td>
<td>15058</td>
<td></td>
</tr>
<tr>
<td>Net running cost:</td>
<td></td>
<td></td>
<td></td>
<td>$2,292.24</td>
</tr>
</tbody>
</table>
5. Instrumentation and data collection

A cheap, commercial energy logger was used, and this can read multiple channels from remote wireless stations reading current clamps. The current clamps were installed as follows:

- the 3-phase grid connection (3 clamps)
- the single phase solar connection
- the 15A power point feeding the vehicle

The reading from the clamp for the vehicle was reliable, but those from the clamps installed in the switchboard were not, which was disappointing. Perhaps distance between transmitters and receiver or interference from cables in the switchboard may have either magnetically saturated the current clamps, or electromagnetically interfered with the transmitters. However, one can obtain ½-hourly data from the supply biller, for both consumption and generation. Summaries can also be made from invoices.
5.1 Vehicle data

The vehicle itself reports the energy of the most recent charge numerically so that it could be recorded. The following information was recorded each time before charging the vehicle:

- Odometer reading;
- Trip meter reading (for error checking);
- Predicted range available from the batteries;
- Predicted total range from batteries and petrol.

During a charge, the energy logger tracking the mains supply would record the minute by minute energy flow. After charging the log was downloaded so that the total energy used to charge the vehicle, the time the charge was started and finished and whether the vehicle had been fully charged could be recorded.

After charging, the following was recorded from the vehicle:

- Predicted range available from the batteries;
- Predicted total range from batteries and petrol;
- The energy added to the batteries.

The trip-meter was reset. This information was transferred to a spreadsheet on which was calculated or recorded:

- Accumulated energy use and its cost;
- The decrease in range to compare with distance travelled;
- The estimated petrol equivalent in litres, based on the energy density of petrol (9.6 kWh/L) and the thermodynamic efficiency of the petrol engine (30%);
- The current petrol price and the estimated petrol cost.

Petrol purchases were also recorded.

This data has been collected since purchasing the vehicle. In the year from July 2014 to June 2015, the distance travelled was 10,519 Km, using 2007 kWh. Hence, the electrical economy measured was 5.24 Km/kWh or 19.1 KWh/100Km. The petrol used was about 191 L, so the petrol economy was 1.82 L/100Km.

A word of caution is in order, as the battery use and petrol use cannot be readily separated. The instrumentation provides battery range, total range and battery economy, but it is not clear what algorithms are used to estimate these figures.

The car operates in three modes: battery only; series mode, in which the petrol engine charges the battery which drives the car; and parallel mode, in which the petrol motor and the batteries together drive the car. Switching between modes is seamless and depends on how the car is driven. Apart from that, the driver can choose to charge the battery or “save” the battery while driving. Regenerative braking is also available and under full control of the driver.

5.2 LED globe data

After installing the PV system, all lighting in the house was changed to LED lighting. The commonly used lights were already compact fluorescent globes. Kitchen lighting and outside lighting used halogen globes, but they were used with care and were always turned off when not in use. Tubular fluorescent
lighting in the garage and under the house, and compact fluorescent floodlighting in the garden was not changed as they were used infrequently.

Does the data collected show any saving? It is difficult to say because the globes were changed gradually late July to November, 2014, the house was unoccupied for a week in August, and the hybrid car was also being charged at the time. Nevertheless, an attempt was made to compare year on year consumption by using the data from the electricity provider, a month at a time. For a particular half hour time slot, the total power for the month was calculated. Daytime data was excluded, as lighting was rarely used during the day. Data that coincided with vehicle charging was cleared (i.e. removed rather than set to zero) and the total power for that slot recalculated from the average of what remained. As a result, the lighting upgrade saves about 15 kWh/month or about $60 annually.

6. Discussion

The surprise for the first author, obvious in hindsight, was that the savings came from reducing the purchase of petrol by 925 L. Without the vehicle, a significant portion of the solar energy used to charge it would have been exported to the grid. To save $1,390 at the current 5c/kWh generation feed-in tariff would require the export of 27,800 kWh of energy, seven times the capacity of the installed system. Alternatively, if the car were petrol only, for the electricity supplier to rebate $1,350, less the actual rebate of $145.20, for 2,047 kWh fed to the grid and 1,892 kWh used by the car, the feed in tariff would need to be 31c/kWh.

What of carbon dioxide emissions? These are calculated according to DOE (2015) for electricity from Victorian brown coal and are summarised in Table 4. Three cases are presented, pre-solar installation in 2013-4, and with and without charging the hybrid vehicle. The data in the last case is estimated from the petrol vehicle case, assuming the same fuel economy, but feeding all the excess harvested energy to the grid. The solar energy harvested reduces emissions by about 54%, whether a hybrid vehicle is used or not. These emission calculations ignore indirect emissions such as energy used to deliver the resource: vehicle fuel or electrical transmission losses.

<table>
<thead>
<tr>
<th></th>
<th>Before Solar Installation</th>
<th>With Hybrid Vehicle</th>
<th>Without Hybrid Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO₂-e</td>
<td>CO₂-e</td>
<td>CO₂-e</td>
</tr>
<tr>
<td>Grid (net)</td>
<td>3806 kWh</td>
<td>4301</td>
<td>1970 kWh</td>
</tr>
<tr>
<td>Gas</td>
<td>3842 kWh</td>
<td>711</td>
<td>3573 kWh</td>
</tr>
<tr>
<td>Petrol</td>
<td>1113 L</td>
<td>2451</td>
<td>191 L</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7463 kg</strong></td>
<td><strong>Total</strong></td>
<td><strong>3308 kg</strong></td>
</tr>
</tbody>
</table>

The fact that there is no reduction in emissions when using the hybrid vehicle is because the emissions factor for Victorian electricity is 1.13, yielding emissions of 2,226 kg CO₂-e. At the other extreme, in Tasmania, the emissions factor is 0.12, achieving a CO₂-e of 236 kg. Table 5 establishes a compelling case for using hybrid vehicles, whether solar panels are installed or not.

<table>
<thead>
<tr>
<th></th>
<th>Before Solar Installation</th>
<th>Hybrid Vehicle Only</th>
<th>Solar PV &amp; Hybrid</th>
<th>Solar PV Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO₂-e</td>
<td>CO₂-e</td>
<td>CO₂-e</td>
<td>CO₂-e</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
There is a time-of-day problem because energy supplied to the grid during the day is redrawn after sunset. Battery storage of PV generated energy would avoid exporting energy to the grid. This would not impact emissions but would reduce energy costs. However, storage could be used to drive heat pumps to replace gas heating which would reduce gas emissions. The house has no air-conditioning, but if installed as summers grow hotter, it could draw on PV generation during the day.

In January 2015, the average daily energy harvested was 17.6 kWh (Table 1), of which about 9 kWh average is exported daily to the grid. So, 10 kWh of storage seems about right. In winter, less than 5 kWh per day is harvested and the batteries would rarely be charged. So, driving heat pumps is likely to draw on grid energy. Precisely how to exploit heat pumps to replace gas heating is another open question. Which is better in these circumstances: reverse-cycle air conditioners or a solar hot water system backing a heat pump?

While collecting data, it was easy to forget to charge the vehicle at a suitable time, particularly if the computer running the data collection was not already running. Time of use tariffs were not exploited as the energy flows are the items of interest. But, it is likely that an energy management system would be required to optimise energy flows in the system.

The cost-benefit analysis and justification of a photovoltaic installation with electrical storage is not simple and straightforward. Rather, it is one that requires attention to detail on multiple levels of photovoltaic sizing, type of electrical storage, and electrical energy consuming devices used. Furthermore, it is an analysis that will vary according to the user of the household, where in this particular case, it is a house often occupied during weekday working hours.

Once a solar PV system is installed, environmental savings follow without further investment, because it displaces energy generation from the grid system. However, the economic argument begins to make sense because the cost of the panels is paid for by the annual savings of fuel costs in about five or six years. This community does not need to wait for cheaper battery storage requiring further capital investment to achieve savings. Of course, the capital cost of the car has been ignored here, but, as in this case, if a new vehicle is required much of the cost may be written off against this need.

7. Conclusions

Installing photovoltaic solar cells reduces carbon dioxide emissions significantly, in this case, by 54%. One may expect using a hybrid vehicle would reduce CO₂ emissions further. But, in Victoria, at present, using a hybrid vehicle has little impact on emissions. We are left with increasing the capacity of PV generation to reduce emissions. In other states, where the emissions factor for electricity is lower, a hybrid vehicle does reduce emissions. Indeed, “Going Solar” in Tasmania does little to reduce emissions unless hybrid or electric vehicles are used.

However, a hybrid vehicle does yield significant financial savings by reducing petrol use. In this case, annual energy costs fell by about $1,390. This means that finding ways to use harvested energy makes economic sense. Another possibility is to use heat pumps to reduce gas used for heating, but this implies a need for energy storage so that heating can be done at night.
Energy storage avoids exporting energy, and so can achieve the “Grid (net)” figures in Table 4. The analysis has not been done here, but lesser savings may be achieved by battery storage, because the cost of electrical energy is much less than that from burning liquid fuels, because of the low thermodynamic efficiency.

Finally, optimal usage will require an energy management system to ensure that energy is harvested, stored and used to best effect in the prevailing conditions. Questions of time of use tariffs have been ignored, as the house supply is on a flat rate; a time of use tariff may have made analysis very difficult. In any case, an up-to-date design of the grid would allow energy trading at the household level and automatic buying and selling of electrical grid energy whatever the time of day, to meet the distributor’s needs.

This paper is based on real-world data and provides analytical results of solar energy use in a residential situation. It demonstrates energy flows in a household and how these impact CO\textsubscript{2} emissions and financial costs. In particular, the impact of using a plug-in hybrid vehicle for electrical storage is studied.

References


Cork matters: towards new applications of cork agglomerates in architecture and product design

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Abstract: This paper proposes an innovative way to interpret surface intelligence by merging both design practice and design research introducing projects in both fields of architecture and product design. Interpreting material properties of cork agglomerates allowed a new way of thinking about elementary design questions: as formulated through its physical characteristics of mechanical resistance, 100% raw material, lightness, density, impermeability. The Nuspa project utilises the material resources efficiently in its attempt to save material and thus energy. In this sense, it explores advanced computation and robotic fabrication along with the idea of total recycling of cork agglomerate waste after conception of the design products. The Nuspa design collection concept is based on the idea of tense contrast between computationally generated free forms and industrially manufactured products. The design process is a cross of the creator’s individual motivations, computational generative design, industrial optimization and functional and material requirements. The same principles are applied to the Cork façade project built in Portugal, a pioneer study on agglomerated cork envelope systems, demonstrating that industrial processes that incorporate the material properties of cork can be applied in the architectural field and specifically to the production of waste-free recyclable façade systems. The paper also discusses the possibilities of application of this material in humid subtropical climates.

Keywords: Cork; architecture; building envelopes; product design; sustainability

1. Introduction

The aim of this paper is to investigate the application and conception of both architecture and industrial design products based on natural cork agglomerates. This project intends:

- To explore the possibilities of application of agglomerated cork in the product design and architectural façades as an eco-friendly approach.
- To present an overview of the environmental aspects of the cork agglomerates, processes and technologies available for sustainable design of building envelopes.
To research robotic milling techniques and the possibilities of recycling the cork waste powder as an ecologically friendly contribution to the idea of sustainable design.

Cork is a natural material. It is obtained by removing the outer layer of bark of the cork oak, Quercus suber L. (Silva et al, 2005). Because the outer skin grows again to its full thickness every twelve years, cork-related products can be produced as a natural, renewable material. It is therefore a product that contributes to environmental sustainability; it is a natural material, biodegradable and totally recyclable. Cork is still an underexplored material in product design and architecture, and it has a vast hidden potential for application. Along this paper, cork agglomerates are used in its raw state as a finishing material, without adding other binding material or composites, and it requires no special maintenance after application. Thus, it constitutes an important theme when exploring the contribution of cork design to a more sustainable production process (Manzini, 2003).

Cork façade project proposes a building envelope system that tests the use and limits of cork agglomerates. The project was built in 2007 in Portugal (Afonso and Magalhães, 2012) as a pioneer study on the application of an eco-innovative envelope system made entirely of agglomerated cork modules. This experiment introduced for the first time a new system of modular panels based on agglomerated cork that offers an improvement for the interior comfort of a residential building.

Nuspa project is about the design and making of a collection of objects using cork in its natural state. It defies the inherent materiality of cork composites used so far in design products and appropriately performs for a set of functional demands such as impermeability, density and material stability. This is an innovative proposal, introducing a raw material, making use of agglomerated cork as a light, resistant and water-proof material, without any additional surface treatment or chemical constituents. Also the use of robotic technologies to directly produce design objects from the machining of solid agglomerated cork block allows the creation of complex computationally-generated geometries that contribute to the idea of innovative design.

Bauer et al (2010), describes important physical properties of cork agglomerates and other bark tree products - waterproof material, thermal and acoustic insulation - just to list few, that should stimulate the interest of researchers and designers to explore and develop possible solutions for building envelopes and product innovation. Also the majority of the applications of agglomerated cork in the field of Product Design and Architecture and are related to moulding and cutting technologies from the raw material. Although an increasing number of applications in industrial design demand it, hardly any data exist which have revealed the properties of natural cork agglomerate in relation to robotic technology of production of cork design objects. The scientific information relating to cork agglomerates and its characteristics is not specific to design objects and hitherto no specific methodology has been applied to the conception of cork design products that make use of robotic arms to shape complex geometries. We tried along this paper to overcome the limitations of standardization, rethinking of new applications for existing and traditional materials (Addington and Schodek, 2004).

For these reasons, much research work is necessary to assess the importance of cork as a design product and its contribution to a more sustainable design practice; to recommend a methodology of design conception that integrates advanced fabrication techniques; to investigate the previous methodology as a waste-free cycle, by providing solutions for recycling the cork products (objects or façade modules), contributing to a greater ecological sustainability in the architecture and product design industries.
2. Related work and historical overview

2.1. Background of research in product design

In Product Design, interest in automation and computation has a long historical background (Kusiak, 2000). This paper revisits this field of knowledge and proposes a creative approach to the current tools available in the industrial modes of production that integrate agglomerated cork materials. The recent related work focuses primarily on the application of automation in the vast field of industrial design (Gero and Maher, 1993; Benton, 2000). Some of the examples found in literature relate the agglomerated cork material with fabrication techniques, including advanced digital tool and numeric control technologies (Sousa, 2010). The innovative technologies we are mentioning focus mainly on the production of agglomerates where cork granulates are mixed and compressed with a natural binder called suberin (Awad et al, 2003). Only few applications on automation are specific to product design made out of cork composites. Composite Cork Product Design is a new field in the cork sector, and there have been some isolated experiments taking place mainly in Portugal by Portuguese designers (Mestre, 2008). This has not been explored as yet within a context of scientific research in the cork sector, as an innovation for new product development. The first experiments with specific fabrication technologies on cork composites took place from the 1970s onwards, in the form of isolated design products by designer like Eduardo Dias and Paulo Parra. Since 2003 the design studio Simple Forms is being exploring the characteristics of cork agglomerates in a series of award-winning products. Such products made use of important characteristics of cork as impermeability and mechanical resistance, but also explored for the first time the tactile and sensorial aspects of natural/raw cork as the primary conceptual requirement for a product. Recent explorations with composite cork material by the designers Afonso and Magalhães (2013) make extensive use of numeric control fabrication technologies for the production of the “Zalma” chair. As described by Mestre (2008), besides the Portuguese contributions, the international designers Daniel Michalik and Jasper Morrison are widely known by their contribution to the potentiality of agglomerated cork, by applying handmade manufacturing processes mainly. The computationally driven methodologies and the use of automation and industrial robots remain still underexplored. This paper explores the increasing interest in cork as a raw material when allied to a context of creativity and advanced fabrication technologies, opening the discussion of production methods in the cork industry and the need for more extensive research in the field of Cork Design.

2.1. Background of agglomerated cork building envelopes

There are not many approaches to the investigation of cork as a material for building envelopes, besides the direct application of expanded cork agglomerates in buildings, or singular experiments without a scientific research output from architects and cork industry (as an example: the Portuguese Pavilion in the 2010 World Expo Shanghai, designed by Carlos Veloso, Quinta de Portal Winery, designed by Álvaro Siza, and recently the Herzog & de Meuron and Ai Weiwei’s London Serpentine Pavilion). Cork agglomerates and cork composites are being used in construction mainly as insulation materials, as thermal and acoustic insulation, as core material in concrete structures, or as finishes for interior walls and pavements, but underused as façade system (Castro et al, 2010; Moreira et al, 2010). There is no specific methodology that has hitherto applied in the investigation of cork composites on envelope systems (Silva et al, 2005).
3. Applications in product design: towards a more sustainable approach

The environmental properties of cork have made it a firm favorite within ecologically conscious designers. Not only are Nuspa products created from waste cork supplied by wine stopper manufacturers, cork in itself is derived from the bark of a tree, which regrows over time. This means that cork can be harvested from the same tree for up to 200 years, and no trees are harmed in the process (Caldas et al., 1986). Figure 1 shows the cork material extracted from the bark of the cork oak and after the transformation process into a design object. This project contributed to the development of a more efficient production process in the design industry, helping to reduce the amount of waste, being itself almost a carbon zero product, as this project involves the total recycling of the cork waste generated during the production process of Nuspa objects. The cork granulates and cork powder resulting from the milling process is again agglutinated through the application of heat and pressure in autoclaves, giving rise to new agglomerates (Díaz-Parrallejo et al., 2003). In this research, cork agglomerates are being used in an innovative way as they are applied in its natural state – as a raw cork material – to create a collection of bath products, making use of its specific properties of density, impermeability, thermal insulation and resilience, shock absorption capacity (Duchemin and Touche, 1989).

Figure 1: Natural material versus advanced production. Left: bark of the cork oak. Right: detail of the machining process of an agglomerated cork block, (source: image by the authors)

3.1. Design process

The methodology applied in the Nuspa project explores the inherent materiality of cork agglomerates used so far within a limited applications in the field of Product Design, resulting in an innovative approach that addresses functional demands and design intentions. This research project started with a detailed study about the characteristics of cork composites and expanded granulated cork in order to establish a context and process-oriented solution for the production of the Nuspa objects. It means a consistent study of the agglomerates characteristics and execution of prototypes to test its mechanical resistance, density and impermeability as outlined in Table 1. Next phase was the digital simulation of the possible geometries for the Nuspa collection – bathtub and washbasins – applying cross-disciplinary graphic software platforms using COM technology that allows the implementation of code in Visual Basic for Applications. This approach will be discussed in section 5 for more detail. The objective was to create a family of possible geometries and test the designer’s aesthetic concerns with issues of functionality, materiality and economy of form.

This paper uses a design research approach, borrowing the concepts of the so-called “new” mathematical surfaces as a starting point to generate the geometries of the proposed object. The project represents an exercise about the manipulation of patterns and geometry elasticity applied to the
generation of design objects, shifting the emphasis from a single design to a design of the process. The use of computer-assistance in design and manufacturing permitted the design object to emerge as a result of a generative sequence of geometries (Picon, 2003). Nevertheless, functionality in the Nuspa project is constantly present, driving the process of form-finding and adjusting the three-dimensional patterns we generated to issues of ergonomics, safety, material resistance and texture in relation to the human body.

3.2. Generating variation and controlling the performance

As Afonso and Magalhães (2012), there is always an aesthetic motivation underlying the computational processes of design making. It is no exception with the Nuspa project. This is a dynamic process, it means after generating the first set of objects, designer and technicians can debate about the outcome and redefine and adjust in real time all or some parts of the previous design. The digital development of the parametric shapes allows us to create endless variations of the objects.

The configuration of the aforementioned computational system to generate the desired geometry must cross aesthetic interests with functional demands. For example, the definition of the right density of the expanded cork agglomerates was decisive to achieve a desirable degree of impermeability, material density and mechanical resistance (Table 1). The robotic milling process was tested starting by machining the final design objects in several cork samples with density between 100 and 150 kg m\(^{-3}\). The use of a customized end-ball milling tool, with 20mm diameter, attached to the spindle mounted in the robotic arm, required a density of 150 kg m\(^{-3}\) for the agglomerated cork to produce a smooth but resistant tactile surface. At the same time, this is the right density to make the agglomerated cork block impermeable to water and liquids, with a coefficient of permeability to steam (kg Pa\(^{-1}\) s\(^{-1}\) m\(^{-1}\)) of 12x10\(^{-12}\). In general, cork exhibits different behaviour in tension and in compression. For this project is the compression characteristics that interest us mainly. The tested sample with density 150 kg m\(^{-3}\) registers a compressive modulus, unboiled, of MPa 18 (measured in radial direction).

The digital parametric system was adapted to specific functional demands. Here the real-scale prototyping demonstrated to be of extreme importance. Also the previous mechanical and physical tests we conducted were crucial in order to get the appropriate composition on the raw agglomerate blocks. Then the translation of the three-dimensional model into Machine data, and consequently the optimization of the cork material to mill, the time of machining spent to produce the objects. Finally devising a method to fully recycle the cork grains produced as waste during the milling process into new raw agglomerated cork blocks. The granules resulting from the milling fabrication can be collected to generate other applications besides new cork blocks, for example, as an aggregate for concrete mixtures or combustible material (Hebel et al, 2014).

3.3. Interdisciplinary engagement, design and automation

The widespread availability of computational technology and automated fabrication tools is allowing for a new discourse in how product design can be conceived (Leach, 2002). This paper proposed a generative computational tool to facilitate the collaborative dialog between designers, product and automation engineers. This means: we created a collaborative platform linking in real time 3D graphics software, common in the design field, with robotic controlling software. A Script was written for the programming interface Grasshopper, which is a visual programming language running with the Rhinoceros graphic software. It integrates a Kuka KR120 r2700 HA robot into a parametric environment that can be visualized in real time using Rhinoceros. The component we made for Grasshopper has the ability to export multiple surfaces and lines generated in Rhinoceros3D to the robotic arm. This application was programmed in
Visual Basic, benefiting from the specific API of the Rhinoceros 3D graphic software. The next section is a transcription of the V. B. script written for this objective, and a pseudo-code that summarizes its functionality.

Table 1: Material properties of cork agglomerate elected to the fabrication of Nuspa prototypes (Rosa and Fortes, 1991)

<table>
<thead>
<tr>
<th>Property</th>
<th>Range of values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, kg m⁻³</td>
<td>100-150</td>
</tr>
<tr>
<td>Thermal conductivity at 20°C (x10⁻⁵ kJ m⁻¹ s⁻¹ K⁻¹)</td>
<td>4.0 x10⁻⁵ to 4.2 x10⁻⁵</td>
</tr>
<tr>
<td>Permeability to water vapour (x10⁻¹² kg Pa⁻¹ s⁻¹ m⁻¹)</td>
<td>4.2x10⁻¹² to 12x10⁻¹²</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>0.05</td>
</tr>
<tr>
<td>Compressive strength at 10%, MPa</td>
<td>0.25</td>
</tr>
<tr>
<td>Bending tension (bending material with cross surface) kN m⁻²</td>
<td>1.6x10⁻⁴</td>
</tr>
</tbody>
</table>

### 3.4. Robotic fabrication and prototypes

Robotics is a known area of interest in Product Design. The focus of this paper is given to the application of industrial robotic arms that are common and comparatively accessible to small dimension industries (Brell-Çokcan and Braumann, 2012). As such, this research work is an example study for a context with existing manufacturing processes that integrate automation mechanisms (Figure 3). Our speculative research proposes developing software modifications that can control such robots towards specific operations and tasks by designers and technicians, but that can be easily implemented by local cork producers. In this context, their purpose is to benefit from financial opportunities that might be available through the reduction of waste, improvement of quality, decrease of downtime and so on. According to our findings in literature, the majority of developments of products using agglomerates apply molding techniques or cutting processes (Sousa, 2010). There is yet a vast space for speculation on the integration of robotic technologies to the production of cork design. The use of a last generation anthropomorphic robot (Tuijthof and Herder, 2000) allowed the creation of complex forms, optimizing innovative design in the industrial design and specifically the product design field.

![Figure 2: robotic machining process with industrial robot. The experimental results show that higher productivity as well as better surface quality of the agglomerated cork block can be achieved. This approach is experimental concerning the production of design objects through an environmentally-friendly waste-free cycle. Comparing to other natural or raw materials, the cork provides the plasticity,](image-url)
lightness, warmth and comfort functionality, and the sustainability of a recycled harvested natural product, being this way suitable for the application in the product design field (Figure 4).

Figure 3: Final physical prototypes in agglomerated cork, milled from monolith block of cork with 150 kg m$^{-3}$ density (left: bathtub) and 120 kg m$^{-3}$ density (right: freestanding washbasin).

4. Applications in architecture: towards sustainable envelope systems

Agglomerated cork demonstrates a potential for application in architectural envelope systems. In fact, the experiments presented along this paper are the result of previous work in the field of architecture. In particular, the Cork House, a built project in coast line north region of Portugal by the authors of this paper, was a pioneer experiment applying agglomerated cork block as a full coating system - façade and rooftop - for a residential project (Dent and Sherr, 2014). A density of 100 kg m$^{-3}$ represents a thermal conductivity of 4.0 x 10$^{-5}$ kJ. Within the Cork House project the authors substituted conventional 60 mm polystyrene insulation for an equivalent 150 mm thickness of 100 kg m$^{-3}$ density cork blocks, providing this way a façade that performs at the same time as an insulation system (Afonso and Magalhães, 2012). The thermal and mechanical characteristics of this specific cork agglomerate (very similar in composition to the ones applied within Nuspa project) make this material suitable as exterior façade system for temperate and dry climates. Figure 5 shows the façade system developed for the Cork House project, as a single layer of agglomerated cork blocks attached directly to the external wall of the building using a specially developed glue based on mineral binders, co-acrylic polymers alkali-resistant (adherence >1,0 N/mm$^2$).

Figure 4: Left: section of the façade system (1-waterproof coating and Adesan-viero glue layer, 2-150mm agglomerated cork panels 120 kg m$^{-3}$ density, 3-concrete structure. Right: image of the built house.
4.1. Energy simulations and contributions to sustainability

The evaluation by life cycle assessment of environmental impacts has been performed after the completion of this project. Results of the impact assessment for the life cycle of a 1m² of Cork House envelope:

- Abiotic Depletion Potential: kg Sb-eq. U (unit), 6.25E-01 CtG (cradle to gate)
- Global Warming Potential: kg CO₂-eq. U, 3.02E+01 CtG
- Ozone Layer Depletion Potential: kg R11-eq. U, 6.09E-06 CtG
- Photochemical Ozone Creation Potential: kg Ethene-eq. U, 4.40E-02 CtG

The unit basis of the calculations correspond to a 1m² of façade composed of 150mm thickness agglomerated cork panels. Environmental impacts evaluated are abiotic depletion, global warming, ozone layer depletion and photochemical ozone creation using the CML 2001 methodology according to the European standard EN 15804 about sustainability of construction works. The cork façade system has a tendency to lower the inner temperature conditions, with a difference of 5°C in comparison with other traditional façade solutions that employ double wall system with 60mm extruded polystyrene insulation. Being a natural insulation material and an exterior finishing at the same time, agglomerated cork eliminates the façade insulation layer while still complying with the requirements of the European building codes (EN Eurocodes). As a conclusion, the benefits are to ensure better indoor conditions and reduce energy consumption, particularly in warm temperate moist climate summer conditions registered in Portugal.

4.2. Envelope system simulations in high-rise construction

Further studies were conducted by the authors addressing the ability of cork agglomerated envelopes to perform in high-humid subtropical climates. The majority of the applications of cork as façade systems nowadays are registered in Mediterranean and Submediterranean climate regions in Europe. The authors executed a selection of scale model tests adjusted to specific environmental conditions in the Hong Kong façade testing laboratory R.E.D. (Research Engineering Development). Isothermal, mechanical resistance and impermeability tests were performed under temperature and environmental conditions in air at ambient relative humidity. Thermal transitions of cork have been tested by calorimetric analysis. Cork contains more than 3.5% adsorbed water at ambient relative humidity, which is likely to produce modifications in its physical properties, but that do not affect its mechanical properties at temperatures between 30–80°C. Within this range of values the Thermal conductivity (W m⁻¹ K⁻¹) is 0.045. Heat treatment with water was tested, and we concluded that water absorption softens the cell walls of cork agglomerates only at very high temperatures, during boiling (Compressive modulus, heat treated at 100°C, 28 days, is MPa 11, in radial direction). This allowed to verify the suitability of the introduction of this material under the subtropical monsoon climatic conditions of Hong Kong (Peel, 2007).

Finally, the use of computational generative tools and robotic fabrication methods grants the possibility to produce non-standard façade panels (Lança, 2005). It is also important to notice that being the cork a renewable and reusable material, cork agglomerates contain lower levels of embedded energy and carbon.

5. Conclusion and discussion

To what extent can one indicate solutions for the development of agglomerated cork design products as a raw material, taking into consideration the issue of sustainability? A large part of design research is presently measured not so much with forms and objects as with the conditions in which these forms can
emerge (Beaucé and Cache, 2007). Thus, under this paper, the design process derives from dynamic balance characterized by multiple and interdependent fluctuations: the creator’s individual design intentions, computational generative methods, industrial optimization, robotic applications and functional and material requirements that promote a novel design approach to produce 100% recyclable object into a waste-free cycle. This study also offers a new perspective on energy saving by implementing an exterior coating based on agglomerated cork. It reported (being a pioneer application of this material as a façade system) for the first time that cork-related products make a contribution to greater ecological sustainability in the architecture practice.

This paper’s experiments allows us to conclude:

• The use of higher-level tools, such as industrial robotic arms for hardware and programming languages to generate design forms can bring obvious benefits to the current cork-related industrial design modes of production.
• The introduction of a novel methodology that consists of real-time interaction between designers and fabrication technicians has an impact in the design process efficiency. Experimental results of Nuspa project show that higher productivity and an environmentally-friendly approach can be achieved, a promising and practical use of industrial robots for machining agglomerated cork surfaces.
• The application of cork in building envelopes is of great importance to design innovation, producing a cost effective, environmentally friendly and recyclable technology for reducing the energy demand of the building.
• Envelope systems built on natural composite materials such as agglomerated cork are suitable for application in distinct climatic conditions.

This project is introducing a new methodology for the cork design-related industry, built upon a sustainable process of production and crossing advanced computational techniques and robotic applications. Produced by machining a solid block of agglomerated cork with robotic technology that is capable of intricate and large forms, this papers breaks new ground in the product design and in the conception of architectural façades, harnessing the material properties of cork in an application of raw a material as a finished product for design and architecture fields.

This paper tracked a built project that promotes a direct relationship between manufacturing technologies, industry and design conception. Exist still a great number of possibilities to explore such synergies between local industries, industrial expertise, new technological solutions and the making of design, in search for economic, environmental and energy efficient design products (Kolarevic and Kingler, 2008). This research can also be extended to other architectural solutions as façade systems, where the use of agglomerated cork demonstrates and energetic and environmental gain. The capacity to combine cutting with milling operations using a robot makes 3D subtractive fabrication a flexible technology for the production of façade components in cork. Given the fact that cork is a 100% natural and recyclable material, the released granules can be collected to produce new agglomerates. The waste material resulting from the subtractive fabrication is part of a sustainable process.

We can discuss how to develop further the conceptual ideas of this study in order to provide planers and researchers in the field of architecture and design an objective evaluation tool for the advantages of introducing cork-related products in façade systems and product design as a contribution for the sustainment of the environment.

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Modeling based-on semi-tensor product for the start-up stage of the radiant cooling system

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Abstract: For nonlinear systems with multiple outputs and multiple inputs which cannot be decoupled, we make use of the sampling data of the real system to obtain a fuzzy relation matrix model via the semi-tensor product (STP) operation of matrices, and establish the mathematical model for a complicated system based on STP. This method has been applied to analyze the dynamic performance of floor for the radiant floor system. In this paper, a radiant floor cooling system based on concrete core radiant floors is examined. To analyze dynamic behavior of floors during non working time operation, model of fuzzy relation matrix based on STP is established. The model is used to estimate quantitatively related parameters in the start-up period of the floor systems under the impact of outdoor environment such as temperature and humidity during the actual cool-down times. The results show that it is not evident to time delay of the floor surface temperature and indoor air temperature due to the thermal inertia while the amplitude of outdoor air temperature vibration is reduced significantly.

Keywords: semi-tensor product; fuzzy relation matrix; radiant cooling system; dynamic performance.

1. Introduction

Energy and environmental problems are becoming a big concern across the world. High energy efficiency system and renewable energy application are good solutions for these challenges (Saidur et al. 2010). Water-based radiant floors with good features are getting more and more attention (Olesen,
The application of radiant floor cooling has been extended from western and northern European even in southern and eastern Asia (Simmonds et al., 2000; Zhao et al., 2011; Song et al., 2008; Zhao et al., 2014).

The dynamic performance and control methods of the radiant systems are the subject of many studies (Deng et al., 2012; Zhao et al., 2014). Zhao (2014) gave the time constant for concrete floors about 2.4 h. As for the dynamic heat transfer process, methods are often very complicated and difficult to be applied in applications especially for many coupled parameters. A novel method based-on matrix product, semi-tensor product (STP) of matrices, was proposed (Cheng, 2007; Cheng et al., 2011) and developed to fuzzy control (Feng et al. 2013; Lv et al. 2012). This method is suitable for solving the multiple coupled variables simply.

This paper tries to use the STP with fuzzy relation matrix to study the dynamic performance of the radiant system in an existing application. It aims to develop a simple method to analyse the basic parameters including indoor air temperature and floor surface temperature which are playing important roles in the control of radiant systems.

2. Methodology


2.1 Preliminaries

First, we give some necessary notations and concerning results for logic.

For the convenience, necessary symbols and definitions are introduced first.

Let $D_k = \left\{0, \frac{1}{k-1}, \frac{2}{k-1}, \ldots, \frac{k-2}{k-1}, 1\right\}$, $k \geq 2$. $D_k^{mn}$ is the set of $m \times n$ matrices with their entries in $D_k$, which are called $k$-valued Boolean matrices.

**Definition 1** let $A \in D_k^{mn}$, $B \in D_k^{pq}$. Let $s=\text{lcm}(n, p)$ denote the least common multiple of $n$ and $p$. Then the semi-tensor product of $A$ with $B$ is defined as $A \triangleright B := \left(A \otimes I_{s/n}\right)\left(B \otimes I_{s/p}\right)$.

Note that $\otimes$ is the Kronecker product. The STP is denoted by $\triangleright$. Because $A = (a_{i,j})$, $B = (b_{i,j})$, all product operations are taking the min, and addition operations are taking the max in the STP operation.

**Definition 2** Assume the universe of discourse is finite, we express it as $E = [e_1, \ldots, e_n]$. Let $A$ be a fuzzy set over $E$. Then $A$ is conventionally expressed as $A = \alpha_1/e_1 + \alpha_2/e_2 + \cdots + \alpha_n/e_n$, Where $\alpha_i = \mu_A(e_i)$ is the membership degree of $e_i$ on $A$. The vector expression of one fuzzy set is denoted by $\nu_A = (\alpha_1, \ldots, \alpha_n)^T \in \mathbb{R}^n$. Where $\mathbb{R}^n$ is an n-dimensional real space.

To present the matrix expression of a multiple fuzzy relation, we introduce a multi-index notation.
**Definition 3** Let \( A = \{ a_{i_1, \ldots, i_k} | i_j = 1, \ldots, n_j ; j = 1, \ldots, k \} \) be a set of data, labelled by \( k \)-fold index \( i = (i_1, \ldots, i_k) \). Then \( Id(i_1, \ldots, i_k; n_1, \ldots, n_k) \) is an index order, which arranges the data in such an order that \( a_{i_1, \ldots, i_k} \) is ahead of \( a_{i_1', \ldots, i_k'} \) iff there is an \( 1 \leq s \leq k \), such that \( i_j = i_j', j < s \), and \( i_s < i_s' \).

In one practical system, we assure there are \( p \) input and \( m \) output variables named \( \{ Y_1, \ldots, Y_p; U_1, \ldots, U_m \} \).

Now assume \( E_i = \{ e_{i_1}', \ldots, e_{i_k}' \} i = 1, \ldots, k \). Denote by

\[
r_{j_1, \ldots, j_k} = \mu_R(e^1_{j_1}, \ldots, e^k_{j_k}), j = 1, \ldots, n, t = 1, \ldots, k. \tag{1}
\]

Let \( \{ \alpha_1, \ldots, \alpha_p \} \) and \( \{ \beta_1, \ldots, \beta_q \} (p + q = k) \) be partition of \( \{1,2,\ldots,k\} \). We can arrange the data \( \{ r_{j_1, \ldots, j_k} \} \) into a matrix \( M_R \in M_{(n_1 \times \cdots \times n_p)}(n_q \times \cdots \times n_q) \) in the order of \( Id(j_{\alpha_1}, \ldots, j_{\alpha_p}; n_{\alpha_1}, \ldots, n_{\alpha_p}) \times Id(j_{\beta_1}, \ldots, j_{\beta_q}; n_{\beta_1}, \ldots, n_{\beta_q}) \), which means that the rows of \( M_R \) are arranged in the order of \( Id(j_{\alpha_1}, \ldots, j_{\alpha_p}; n_{\alpha_1}, \ldots, n_{\alpha_p}) \) and the columns of \( Id(j_{\beta_1}, \ldots, j_{\beta_q}; n_{\beta_1}, \ldots, n_{\beta_q}) \).

### 2.1 The matrix expression of semi-tensor product based on fuzzy sets

Assume the system has \( m \) inputs and \( p \) outputs, then the fuzzy relation has the form as

\[
\sum_{E \in F(Y_1 \times \cdots \times Y_p \times U_1 \times \cdots \times U_m)} \tag{2}
\]

Where \( Y_i, i = 1, \ldots, p \) and \( U_j, j = 1, \ldots, m \) have been fuzzificated, and the fuzzification process has been described in the previous subsection. Note that the controller \( \{ Y_i \} \) becomes the input set and \( \{ U_i \} \) the output set.

In general case, a fuzzy controller is mathematically equivalent to a fuzzy relation (5). We describe this as follows. First, we specify degree-based fuzzy sets of \( \{ Y_i \} \) and \( \{ U_i \} \) as

\[
E_{Y_i} = \{ y_{i_1}', \ldots, y_{i_p}' \} i = 1, \ldots, p;
E_{U_j} = \{ u_{j_1}', \ldots, u_{j_m}' \} j = 1, \ldots, m. \tag{3}
\]

Note that \( y_{k}' \), \( k = 1, \ldots, \alpha_i \), correspond to “negative big”, “negative middle”, ..., which are what we mean the degree-based fuzzy sets.
We use dual fuzzy structure. That is, consider $E_{Y_i}$ as the universe of discourse for $Y_i$, and $E_{U_j}$ as the universe of discourse for $U_j$; and meanwhile, consider each true value $y_i \in Y_i$ as a fuzzy set over $E_{Y_i}$ and $u_j \in U_j$ as a fuzzy set over $E_{U_j}$.

A fuzzy controller is a fuzzy relation among $\{Y_1, \cdots, Y_p; U_1, \cdots, U_m\}$. This fuzzy relation comes from experience etc. Now assume it is known as $\Sigma$. That is, $\Sigma$ is a fuzzy relation on $\prod_{i=1}^{p} Y_i \times \prod_{j=1}^{m} U_j$. Then for each element in this product space we have its membership degree as

$$
\mu_{\Sigma}(y_1^1, \cdots, y_p^1; u_1^1, \cdots, u_m^1) = \gamma_{\xi_1^1 \cdots \xi_p^1},
$$

$$
\xi_i = 1, \cdots, \alpha_i, i = 1, \cdots, p; \eta_j = 1, \cdots, \beta_j, j = 1, \cdots, m. \quad (4)
$$

Arranging $\gamma_{\eta_1^1 \cdots \eta_{m}^1}$ into a matrix in the order of $Id(\eta_1, \cdots, \eta_m; \beta_1, \cdots, \beta_m) \times Id(\xi_1, \cdots, \xi_p; \alpha_1, \cdots, \alpha_p)$, we have

$$
M_{\Sigma} = \begin{bmatrix}
\gamma_{1-1}^{1-1} & \gamma_{1-1}^{1-1} & \cdots & \gamma_{1-1}^{1-1 \alpha_p} & \cdots & \gamma_{1-1}^{1-1 \beta_m} \\
\gamma_{1-1}^{1-1} & \gamma_{1-1}^{1-2} & \cdots & \gamma_{1-1}^{1-1 \alpha_p} & \cdots & \gamma_{1-1}^{1-1 \beta_m} \\
\gamma_{1-1}^{1-1} & \gamma_{1-1}^{1-2} & \cdots & \gamma_{1-1}^{1-1 \alpha_p} & \cdots & \gamma_{1-1}^{1-1 \beta_m} \\
\vdots & \vdots & & \ddots & \ddots & \vdots \\
\gamma_{1-1}^{1-1} & \gamma_{1-1}^{1-1 \alpha_p} & \cdots & \gamma_{1-1}^{1-1 \alpha_p} & \cdots & \gamma_{1-1}^{1-1 \alpha_p}
\end{bmatrix} \quad (5)
$$

A fuzzy relation is essentially shown as fuzzy matrix above among the outputs and the inputs.

3. Modelling the start-up performance of the radiant cooling performance

3.1. The study background

Antaeus Building, located in Jinan City Shandong Province China, has a radiant floor system. It is built for office which was put into services at the end of 2012 with construction area of 5483m², one underground floor and 5 floors on the ground and mainly for office and research. The radiant system embedded in Antaeus Building uses the water from the U-shape tubes of the underground heat exchanger to cool the floors which is called direct cooling system. Non working schedule of the companies in Antaeus Building is 17:30-8:30 (next day). Pump for circulating the high temperature cold water from the U-shape tubes still works during the non working time. We choose the 19:00-8:00 (next day) as the start-up time for there is less load from people and solar radiation. Results of the study will be helpful to decide how long start-up stage will be ok which is very important to operating control.

We obtain the operating data from 2013 till 2016 which provides us with sufficient conditions to obtain the fuzzy relation matrix. We take the cooling operation as an example. The radiant system cools the building directly with the 18 °C water. All data involved in this study are from the operation data in period of 2013-2015.
Modeling based-on semi-tensor product for the start-up stage of the radiant cooling system

3.2 Steps of modelling the radiant system

There are many factors which affect the performance of the floor. Outdoor parameters have great impact on buildings and their HVACs. The temperature of the supply water and the floor surface are very important to the radiant floor systems. That is why we choose these five variables including outdoor air temperature, outdoor relative humidity, indoor air temperature, the mean temperature of supply and return water to analyse the start-up performance. After addressing the operating data, condensation is not problem in the start-up stage. Indoor relative humidity is not in those parameters.

(1) \( N \) groups of sampling data pairs about the input and output variables obtained from the operating data, that is

\[
(H_{oi}^*, T_{oa}^*, T_{wi}^*, T_{si}^*, T_{ia}^*)^T, i = 1, \cdots, N
\]

Where \( H_{oi}^* \), input variable, is the outdoor relative humidity in the \( i \)-th data pair; \( T_{oa}^* \), input variable, the temperature of outdoor air; \( T_{wi}^* \), input variable, the mean temperature of the supply and return water; \( T_{si}^* \), output variable, the mean temperature of floor surface; \( T_{ia}^* \), output variable, the mean temperature of indoor air.

(2) Firstly we specify the degree-based fuzzy sets of \( Y_j \) and \( U_j \) as

\[
E_{Y_j} = \{H_{oi}^*, T_{oa}^*, T_{wi}^*, T_{si}^*, T_{ia}^*\}, i = 1,2,3;
\]

\[
E_{U_j} = \{T_{ia}^*, T_{si}^*\}, j = 1,2.
\]

(3) Through the fuzzification, we convert these data into the fuzzy vector forms:

\[
V_{H_{oi}} = \left( \mu_{Ho_1}(H_{oi}^*), \mu_{Ho_2}(H_{oi}^*), \mu_{Ho_3}(H_{oi}^*) \right)^T
\]

\[
V_{T_{oa}} = \left( \mu_{Toa_1}(T_{oa}^*), \mu_{Toa_2}(T_{oa}^*), \mu_{Toa_3}(T_{oa}^*) \right)^T
\]

\[
V_{T_{wi}} = \left( \mu_{Tw_{i1}}(T_{wi}^*), \mu_{Tw_{i2}}(T_{wi}^*), \mu_{Tw_{i3}}(T_{wi}^*) \right)^T
\]

\[
V_{T_{ia}} = \left( \mu_{Tia_1}(T_{ia}^*), \mu_{Tia_2}(T_{ia}^*), \mu_{Tia_3}(T_{ia}^*) \right)^T
\]

\[
V_{T_{si}} = \left( \mu_{Ts_{i1}}(T_{si}^*), \mu_{Ts_{i2}}(T_{si}^*), \mu_{Ts_{i3}}(T_{si}^*) \right)^T
\]

(a) Outdoor relative humidity (b) Temperature of outdoor air (c) Average temperature of supply and return water
Figure 1: Membership functions of fuzzy variables

(4) Get the input/output fuzzy relation matrix

The fuzzy relation matrix among all input variables of the i-th data is

\[
R_{H_{si}, T_{si}, T_{ui}} = v_{H_{si}} \triangleright v_{T_{si}} \triangleright v_{T_{ui}} = R_{Y_i}
\]  

(13)

The fuzzy relation matrix among all output variables of the i-th data is

\[
R_{T_{si}, T_{ui}} = v_{T_{si}} \triangleright v_{T_{ui}} = R_{U_i}
\]  

(14)

(5) Then the i-th fuzzy relation matrix between the input and output variables from the i-th data is

\[
R_i = R_{Y_i} \triangleright \left( R_{Y_i} \right)^T
\]  

(15)

(6) The end fuzzy relation matrix from all \( N \) groups of data is

\[
R = \bigcup_{i=1}^{N} R_i
\]  

(16)

(7) We can obtain the output fuzzy vector through the fuzzy relation matrix

\[
R_U = R \times R_Y = (b_{11}, b_{12}, b_{13}, b_{21}, b_{22}, b_{23}, b_{31}, b_{32}, b_{33})
\]  

(17)

(8) Reference[31] proposed two methods to deal with defuzzification of multiple control case. One method is Jointed Defuzzification (JD). Because the temperature of floor surface and the temperature of indoor air are coupled variables, we find the JD method.

\[
\left( T_{ia}', T_s' \right) = \sum_{p=1}^{3} \sum_{q=1}^{3} \left\{ \frac{\sum_{p=1}^{3} \sum_{q=1}^{3} b_{p,q}}{b_{p,q} \times \mu_{T_{ia} \times T_{sq}}^{-1}} \right\}
\]  

(18)

Where \( \mu_{T_{ia} \times T_{sq}} \left( T_{ia}, T_s \right) = \mu_{T_{ia}} \left( T_{ia} \right) \land \mu_{T_{sq}} \left( T_s \right) \land \) is taking the min.
4. Validation and results

4.1. Validation of the model

As we get in section 3, a fuzzy relation matrix has been set up through the operating data in the past three years. After that, we can get the indoor air temperature and floor surface temperature when outdoor air temperature, relative humidity outside, mean temperature of supply and return temperature are given. According to the operation data, results from the model are compared to the field measured data. That shows the results from the model can follow the measured data very well as shown in figure 2. It is satisfying that error of the results from the model is within 10% through the analysis. In figure 2, Tia and Ts mean the indoor air temperature and the temperature of floor surface from operating data respectively, Tia’ and Ts’ out of operation data.

4.2 Results of model analysis

For the convenience of analysis, we choose the beginning of cooling season which is commonly on 15th May every year and the hottest day (19th June). Weather data in these two periods are from Chinese Standard Weather Data (CSWD). Actually the hottest day (the highest temperature on average) is also the hottest day (peak temperature) in a typical year. For the convenience, we assume the average temperature of supply and return water is 19 °C which is the mean for a whole year. The results are shown in Figure 3 and Figure 4. Toa, Tia and Ts are outdoor air temperature, indoor air temperature, temperature of floor surface, respectively.

Figure 2: Validation result of the model

Figure 3: Dynamic performance at the beginning of cooling season (in average)
5. Discussion and conclusion

Because of the complicated factors for a radiant cooling system, it is very hard to predict the main variables such as the indoor air temperature, the temperature of cooling floor surface. The method of STP is a powerful tool to this problem, especially in practical applications. As Zhao (2014) pointed out that the response time for the concrete floor is about 2.4 h while the cooling capacity reaches 63% of its maximum. According to the results of the model, the time of cooling the floor is shorter than the time constant for the radiant system in the case. That is because the temperature of supply water is 18 °C or higher and the temperature difference of supply and return water is about 2 °C. As figure 3 and 4 show, the temperature of indoor air follows the changes of the outdoor air temperature. The changes in the mean floor surface temperature are not evident, only 0.5°C, which reflects the feature of radiant floor system although it shares the same trend with outdoor air temperature.

Compared to the beginning of the cooling season, it is very steady for indoor air temperature changes in the start-up stage of the hottest day (in average). Period from 18:00 – 8:00(next day) is regarded as the start-up time when there is no load from people and small load from solar radiation. In order to cool the floors, building envelopes and furniture inside sufficiently, the cooling period is set at will by operation staff as long as the non-working time. The results of the study shows it is not necessary to take 14 hours to cool the building. It will be a appreciate duration to take less than 2 hours to cool the building. The specific time will be the subject in the future study. It is also necessary to understand whether it brings impact on the cooling capacity of the radiant system.

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F. Qin, C. W, H. Lv and C. Liu
Architectural science and national master specification systems

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Abstract: Those researching the science of construction Products, Systems, Elements, Spaces, Entities and Complexes may wonder how best to deliver their findings to designers and builders. One such route is through national master specification systems (NMSS). Designers creating project specifications typically use NMSS as an aid in this process. The best of these systems are comprehensive, consistent, current, structured and editable, include guidance, are delivered in object-oriented databases, can form part of the built-environment information model (BIM), are discipline- and sector-neutral, and serve more than the construction phase of the project timeline. Such systems are intended to facilitate the sound and efficient specification of project requirements, potentially from a project’s inception to its eventual demolition and beyond. Architectural science informs many of the choices offered in the specification system text, much of the content of the guidance, the selection of many of the links provided to external information from the NMSS, and the content of much of that external information. This is illustrated in NBS Create, a national master specification system published by RIBA Enterprises in the UK, which meets the criteria mentioned.

Keywords: Specification; national master specification systems; NBS Create; Building Information Modelling.

1. Introduction

This conceptual paper shows how the findings of research into architectural science, embodied in documents such as Australian standards and the literature of industry associations, are routinely communicated to working designers and builders through the medium of national master specification systems. This communication mechanism and its contents are imperfect and both can perhaps be improved through more direct input from architectural scientists. The work presented in this paper is based largely on the critical reflection of the author, who has been involved in the development of national master specification systems in Australia and the UK since 1992.

The practice of preparing the brief, construction specification, operation and maintenance (O&M) manuals, and the deconstruction specification for construction projects – collectively the ‘lifetime’ specification – was quite primitive in 1963 when the first meeting of the Architectural Science Association (ASA) was held in Adelaide. These documents were written from scratch or using cut-and-
paste, with little or no consistency between, and even within, each design and construction organization. They were typewritten, generally not by their authors but by an office typist. They were geared for the most part to build-only procurement. These documents were independent of each other. The standards and other documents they referenced had to be accessed in hard-copy libraries, office-based or central, as did any work on architectural science the specifier might have relied upon. The working drawings were drafted by hand. They might have been cross-referenced here and there within the specification, and may likewise have referenced the specification, but were otherwise independent of it.

In the 53 years since the first meeting of the ASA, the authoring, production, and use of the project specification has developed significantly, through five major developments in information technology:

- National master specification systems (NMSS).
- Personal computers.
- Built-environment information modelling (BIM).
- The Uniclass 2015 classification system (in the UK).

1.1. National master specification systems

National master specification systems such as those published by NATSPEC (Australia), RIBA Enterprises (UK) and ARCOM (USA) became available in the early 1970s (NATSPEC, 2016; NBS, 2013; ARCOM, 2016). The publishers of these and a number of other NMSSs are members of the International Construction Information Society (ICIS). Though NMSSs have existed in various forms since at least 1840 (Gelder, 2008), this new breed has a number of advantages. Most are centrally maintained. Many are now delivered in object-oriented databases (but not, for example, NATSPEC). The best are comprehensive, consistent, current, structured and editable, include guidance, can form part of the built-environment information model (BIM), are discipline- and sector-neutral, and serve more than the construction phase of the project timeline. Such systems are intended to facilitate the sound and efficient specification of project requirements, potentially from a project’s inception to its eventual demolition and beyond. The systems are subscribed to rather than purchased, to ensure currency and to license breach of copyright.

NBS Create, a NMSS published by RIBA Enterprises in the UK, is one such system. It was first published in 2012, and was devised, prototyped and co-developed by the author.

National master specification systems are the central topic of this paper, and are discussed in more detail below.

1.2. Personal computers

Personal computers became commonplace after 1981, with the launch of the IBM PC (Wikipedia, 2016). In design offices, personal computers have replaced typewriters and drawing boards, and in construction offices they are replacing sheaves of drawings and piles of specifications. Designers create their own project building information models. They also create their own project specifications, though not all designers specify – they do not all have the required time, interest or expertise. Those who do specify usually use NMSSs, which are loaded onto their personal computers, as the main source for the project specification.
1.3. The World Wide Web

The World Wide Web came into existence in 1989, entering the public domain in 1993 (CERN, 2016). At this stage many organizations were wary of giving their staff access to the Web, but this access is now ubiquitous, within offices, at home, and indeed at all points in between. This access is essential to the production and use of project specifications, and to the use of NMSSs. Resources such as regulations, standards, manufacturer’s literature, journals and industry guidance (on architectural science, for example) are all delivered via the Web. Many of these are linked from within the NMSS. In many cases, updates to NMSSs are also delivered via the Web, and project specifications may be held remotely (on the ‘cloud’), for convenience and security, and accessed using the Web. As a result of this shift to the Web, most architectural practices no longer maintain traditional hard-copy libraries (hence the closure of the RIBA’s Office Library Service some years ago).

1.4. Built-environment Information Modelling

‘Open’ built-environment information modelling (BIM) began in earnest in 1996 with the establishment of the International Alliance for Interoperability (IAI), now known as buildingSMART (buildingSMART, 2014). Open BIM requires the use of the neutral IFC file exchange format developed by buildingSMART and now at version 4.0. The project specification is sometimes described as the ‘I’ in BIM, though many still see BIM as being mostly about the project geometry (Waterhouse, 2012). For a complete model, both specification and geometry must be integrated.

Over recent years BIM has been moving beyond buildings to include civil engineering and the like, and moves are underway to integrate it with Geographic Information Systems (GIS) (Andrews and Kuehne, 2016). A number of governments have mandated the use of BIM for construction projects, most recently the UK (‘level 2’ BIM, mandated from April 2016), but not all (Gelder, 2016a).

NBS Create is a ‘BIM-ready’ specification system – it has an appropriate data structure, provides the basic property sets for many objects (P-sets, in the terminology of IFCs), exports to COBie (Construction-Operations Building information exchange), and links to the project geometry, but does not (yet) export or import using the IFC format (COBie UK, 2012).

Intelligent property sets in BIM specifications are key to developing models that can be interrogated to determine the performance of objects of various classes (e.g. Entities) and types (e.g. residential buildings). This would be very useful for regulatory and non-regulatory compliance purposes, for example, but few such simulation tools are certified for use in compliance (ARUP MassMotion is one), and none are designed to interrogate both the BIM geometry and the BIM specification (ARUP, 2015). There is a lot of work still to be done.

1.5. Uniclass 2015

Uniclass 2015 was launched in the UK to replace earlier classification systems such as CI/SfB and Uniclass 1997, which were seen as no longer fit for purpose (Gelder, 2015). Behind this development is the 2015 edition of ISO 12006-2. Uniclass 2015 forms the backbone of NBS Create, and defines a standard object hierarchy that spans all construction disciplines and sectors. The physical hierarchy comprises Products, Systems, Elements, Spaces, Entities, and Complexes (Districts and Regions will be added in the future). Different strands of architectural science have something to say about all of these object classes, and so does the sector-neutral lifetime specification. Though confined to the UK at
present, it is likely that Uniclass 2015 will be adopted into other countries over the next few years, including Canada, Singapore, Malaysia, New Zealand, and Australia (private communication, 2016).

However, Uniclass 2015 is still in development. From the point of view of architectural science, a very important table that is missing is that for Properties. This means that object properties in master specification systems are likely to be identified and defined inconsistently. Indeed, if the properties used in NBS Create (the property part of the property:value pairs, such as Colour: or Illuminance: or Thickness:) are to be used to ‘seed’ the Uniclass 2015 Properties table, which was the intention, they first need to be edited to remove duplicates and the like. Once the Properties table is developed, then NBS Create will need to be aligned to it. The Properties table will be complex as it will have to deal with all properties of all objects of all classes, from Regions down to Products in the hierarchy, but also of all objects in the tables outside the hierarchy, such as Phases and Construction aids. Table 1 shows key property classes used for objects of different classes in the physical hierarchy, in row 3 (Performance specification).

1.6. Procurement and the lifetime specification

The rise of design-build (D&B), build-own-operate-transfer (BOOT), partnership and other forms of procurement, in parallel to the developments listed above, has led to the concept of the lifetime specification, integrating into a seamless stream the various specifications produced along the project timeline. This is managed by dealing with objects formally, using the object hierarchy, and through allowing each object class to be specified in different ways, depending on the state of design at the time specifying. For example, a System may be specified by some or all of its performance (performance specification), by listing some or all of its component Products (compositional specification), by describing some or all of its component Products in terms of performance, composition or brand, by identifying the brand of the System itself (where branded systems are available), or some combination of all this. Assembly of component Products into the System, commissioning of the System, operation and maintenance of the System and its eventual deconstruction may also be specified. Other object classes – such as Entities, Elements and Products – can be dealt with in the same way. NBS Create allows all of these options, and so is flexible enough to deal with any procurement route. Table 1 illustrates the consistent approach to this provided for in Uniclass 2015 and in NBS Create.

Table 1: The specification of object classes.

<table>
<thead>
<tr>
<th>Object class:</th>
<th>Regions</th>
<th>Districts</th>
<th>Complexes</th>
<th>Entities</th>
<th>Activities</th>
<th>Spaces</th>
<th>Elements</th>
<th>Systems</th>
<th>Products</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compositional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>specification:</td>
<td>Dist.</td>
<td>Complexes</td>
<td>Entities</td>
<td>Activities</td>
<td>Spaces</td>
<td>Elements</td>
<td>Sub-activities</td>
<td>Sub-spaces</td>
<td>Activities</td>
<td>Systems</td>
</tr>
<tr>
<td>Performance</td>
<td>Context</td>
<td></td>
<td>Functional</td>
<td>Structural</td>
<td>Fire</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2. Lifetime specification and architectural science

The specifications that comprise the ‘lifetime’ specification all flow into each other, forming a continuum. In BIM, these are reports from the model. The model holds them all, but a given report will only contain the relevant information from the model. For example, a specification produced for construction tender will not contain briefing requirements that have long since been solved. But briefing requirements are still held in the model, and may be put to use in the O&M manuals, as the basis of performance triggers for lamp replacement, for example.

2.1. The design and specification process

Specifications are a written record of the design requirements at a particular stage in the project process. They are produced all along the project timeline, sometimes to be passed from one team to another within an organization (e.g. from the design team to the documentation team), sometimes to be passed from one organization to another as part of an approval or procurement process (e.g. from the architectural designers to the council planners for approval).

Design decision-making follows two sequences simultaneously. The designers generally make decisions about object classes high in the hierarchy (such as Complexes) before they make decisions about object classes lower in the hierarchy (such as Products). And, for each object, designers generally progress from identifying the problem, to elucidating the problem, to solving the problem generically, and finally to solving the problem by brand where available (which may then be substituted). Several designers such as the client, the architect and the subcontractors might be involved in this process (Gelder, 1997). At any point in time, for objects of a given class such as Spaces, some may be resolved fully, and some not at all. The process is not tidy.

Architectural science informs these two processes all the way through, or it should: there are several breaks in transmission from source to outlet. The source – the architectural science ‘body of knowledge’ – is generated by researchers, in industry and academia, and is reported for the most part in technical industry journals and academic literature intended for specialist readership. Examples include *Architectural Science Review* and *Construction and Building Materials*.

Architectural science should inform many of the choices offered in the specification system text, much of the content of the guidance, the selection of many of the links provided to external information from the NMSS, and the content of much of that external information. But NMSSs are prepared by
teams of design professionals – architects, engineers, landscape architects and so on. They are not architectural scientists – they are generalists, with a wide range of interests. They obtain information about architectural science from sources such as BRE publications, the technical publications of industry associations produced for specifiers, the standards published by BSI and Standards Australia, and so on. In the UK, a very good collection of such sources is held on the IHS/NBS Construction Information Service (IHS, 2016) – works from 510 publishers are carried, and many are linked from within NBS Create. There is no equivalent in Australia.

Generally, master specifiers (i.e. those preparing NMSSs) do not learn about developments in architectural science from technical industry journals or academic journals. This is partly because they have neither access nor the time and expertise to digest the material, and partly because nor do their target audience of working architects, engineers and other construction professionals. Both groups do, however, have access to paid-for resources such as BRE Digests (in the UK), and to the free technical publications of trade organizations and others such as the CSIRO Building Technology Files (in Australia – a shadow of the defunct CSIRO Notes on the Science of Building) and the BRANZ Study Reports, in New Zealand. These are produced for working architects, engineers and other construction professionals.

The master specifiers bring this all together, or as much of it as they can readily find, bearing in mind that they operate in a commercial environment. They digest it, note inconsistencies and occasionally try to resolve them by talking to experts. They provide access to the documents in the NMSS, by paraphrasing them where appropriate, by linking to the documents themselves, or to documents that interpret them, on the Web, and by authoring their own guidance. Authoring and maintaining this information is a costly task, and has often been underestimated, even by very large organizations.

Another gap in transmission is that project specifiers may or may not read and use the guidance provided in the NMSS. The best will, but the conventional construction-phase project specification is often prepared in a hurry, towards the end of the documentation process. The result is that, occasionally, one sees ‘project specifications’ which comprise the unedited NMSS, with none of the inserts completed, or with them all deleted, for example. However, NBS Create is designed to encourage and allow specifiers to start the process earlier (Gelder, 2011). It is also designed to allow the contractor to prepare the record specification, for use in the O&M phase of the project. But, at the moment, this is still uncommon. There is room for improvement.

Finally, the audience for the project specification may not read it at all! Conventionally, construction specifications are kept in a drawer on site, and only referred to when a problem arises, rather than as a matter of routine (Bentley, 1981). This is one reason why designers annotate drawings with simple specification notes, which makes it even less likely that the full specification will be read, and may contradict it. Subcontractors may not even be familiar with central standards (Nawar & Zourtos, 1994). It is hoped that, as contractors get used to BIM, to the integrated lifetime specification, and to collaborative working, they will increasingly use the specification on site, and continue to develop it for O&M purposes.

2.2. Guidance in the NMSS

The NMSS can be viewed in its entirety as guidance (Gelder, 2009b). In many respects it contains a lot more information than the project timeline specification. This is partly because it provides guidance at different levels, from general guidance at section level (where a section is about an object class such as Masonry walling systems), down to guidance at property level, by suggesting objects and properties to be specified (by providing lists of alternative values, and (often) guidance about how to select them).
This information is available to specifiers (who can add their own guidance, if using NBS Create), but is not included in the contractual specification. However, an NMSS subscriber contractor should be able to read the project specification alongside the original NMSS guidance (but not the specifiers’ own guidance).

It contains more information also because an NMSS will describe many objects not used in a particular project. For example, the project may use timber structural framing systems, but the NMSS will also describe concrete and steel structural framing systems. The NMSS text (as distinct from the NMSS guidance), which is a form of guidance in its own right, deals with all possible methods of procurement. For a given System, the NMSS will provide for specification by brand, by performance, by composition, and by description – but the project specifier may simply opt for a brand specification.

To illustrate the concept of NMSS text and guidance, an extract follows from an NBS Create System outline clause from section 20-15-05 Asphalt paving systems (2014). Clause-wide guidance is given under the clause title. Values are suggested for properties, and guidance on specification of values is given in the third column. Many documents are referenced and linked, including internal material such as ‘general guidance’, which applies to the whole section. Specifiers would use System manufacturer if specifying by brand, and the other Properties if specifying by composition (i.e. listing the component Products).

105 Asphalt concrete light duty paving system
Use clause for footways and cycle routes with asphalt concrete (formerly macadam or coated macadam). Footways and paved pedestrian areas do not require a base course. See general guidance 2 for further information on applications using asphalt surfaces.
See general guidance 4.2 and 8.1 on accessibility; BS 8300 gives recommendations for slip resistance for footways, if applicable.
See general guidance 6.2.1 for further information on asphalt concrete.
See general guidance 7 regarding BREEAM.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>System manufacturer:</td>
<td>[...].</td>
<td>See general guidance 3.3 for guidance on sub-grade improvement. Manufacturers may also specify these as:</td>
</tr>
<tr>
<td>Subgrade improvement layer:</td>
<td>Coarse aggregates for bases, beds and fill. Highways Agency unbound mixture Type 1.</td>
<td>• Highways Agency Cl 803 Type 1 unbound mixture.</td>
</tr>
</tbody>
</table>
Type 1.
Highways Agency unbound mixture
Type 2.
Highways Agency unbound mixture
Type 4.

It can be seen that values and guidance in an NMSS deal with and are informed by architectural science. Other clauses in the section address the performance specification of the Asphalt concrete light duty paving system, its component Products in detail, its site assembly and testing, and perhaps its operation and maintenance and eventual deconstruction.

As noted, the master specifiers find guidance in a number of places, and reference many of them in the text of the specification itself or in the guidance. Project specification authors can follow them all up, if they wish, and if they have access to them, and project specification users can follow up those cited in the text. The references in the text, values and guidance are mostly to Standards. Accordingly, in NATsource (NATSPEC, 2015) Australian Standards alone account for 70% of the content, but documents published by 84 other organizations are also cited. The committees developing Standards generally include manufacturers, users and designers, and academics. This way, architectural science finds its way into Standards, and hence into specifications. Standards contain default requirements which will not be repeated in the specifications that cite them. Specification users are meant to have access to them – NATsource includes lists of ‘suggested standards for offices’ of architects and others.

Though text books on architectural science might still be held by design practices, they might not be current. They might not be relevant, either. For example, in Australia textbooks from the UK and USA on construction materials, products and systems might be used as they are (e.g. in University courses), because there are no Australian ones, but are misleading in terms of cited standards, regulatory context, sourcing, environmental impact and so on (for example, Lyons, 2014; and Hall and Greeno, 2013). It is suggested that NATSPEC itself can be seen as a maintained computer-based Australian textbook on architectural science, dealing with construction Products and Systems for architects, structural and services engineers, landscape architects, and municipal engineers. The same can be said for NBS Create and the other NMSSs around the world. Some, such as NATSPEC, are free to students and academics, and for some, such as NATSPEC again, their use is mandated by government procurement agencies. They are widely available resources.

As well as linking to guidance, hyperlinks within the UK’s NBS Create are also used for automated specification assembly, and to link to BIM geometry tools such as Autodesk Revit and the National BIM Library, and to the government-funded BIM process management tool, the NBS BIM Toolkit. The BIM specification is thoroughly integrated into the design and documentation process.

One problem with documents referenced from within a BIM specification is that they are not a part of the BIM. They are digital ‘dead-ends’ (Gelder, 2009a). This will hamper efforts to interrogate the model for compliance and other purposes. To rectify this it is suggested elsewhere, for example, that building codes be published in IFC format (Gelder, 2016b).

2.3. Reports

Being delivered in an SQL database, with the smallest reporting unit comprising property:value pairs, NBS Create can support many classes of report, such as reports on referenced documents cited,
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Architectural science and national master specifica

submittals requested, Properties (e.g. Acoustic performance), text flagged as ‘sustainability’ or
‘regulatory’, and any of the subsections such as Execution or Operation and maintenance (Table 1, left-
hand column). Many of these reports pertain to aspects of architectural science. NBS Create reports to
several formats: COBie, Systems (Product clauses held in the Products sections), and Work sections
(Product clauses held in the Systems sections, and therefore repeated where common).

The use of metadata is another characteristic of using a database. NBS Create automatically
supplements changes made to the content of the office master or project specification, by dating them
and assigning the responsible author. This allows users to investigate the development of the
specification, by date and/or by author. Authors can also add their own metadata, such as the reason
for the change. These might include a client request or variation, a condition imposed by a regulatory
authority, an approved substitution, or a ‘contractor’s choice’, where a generic specification in the
contract is replaced by the specification of the chosen brand. This metadata is available to subsequent
users of the project specification.

3. Conclusion

The project timeline specification can be viewed as a key mechanism for applying architectural science
to construction projects, through its description of requirements all along the timeline for objects of all
classes and types, ranging from Regions to Products. These descriptions are authored and used by
designers, builders, operation and maintenance (O&M) personnel and demolishers. Project
specifications are prepared using national master specification systems (NMSSs), which might therefore
be seen as a convenient conduit for the transmission of knowledge about architectural science to the
industry at large (rather than doing this practice-by-practice, or specification-by-specified).
Architectural scientists have contributed to their development indirectly, and perhaps unwittingly,
through contributing to the development of Standards and other technical publications. They might also
be able to contribute to their development directly and actively, to improve the scientific basis of their
content, perhaps through organizations such as the ASA. The description provided in this paper, of the
development and use of national master specification systems with particular reference to architectural
science, should be of use to those wishing to do so.

Acknowledgements

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and through visits to master specification system publishers around the world, over a 22 year period.
This included contributing to NATSPEC’s SPECnews and editing the NBS Journal and the ICIS Newsletter,
all of which are now defunct. My thanks to all those I worked with, talked to, and edited.

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Platforms for industrialised construction – lessons from Sweden

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Abstract: This paper describes the platform concept which has been specifically developed for industrialised construction in Sweden. The paper outlines the concept and discusses its development. Conclusions are drawn from the range of Swedish research projects, to present key findings which are summarised and discussed for implementation by industry in an ongoing applied research project in Australia.

Keywords: Platforms; Prefabrication; Industrialised Construction; Process.

1. Introduction

A recent body of work from Swedish researchers, who have been working on applied research projects with industry, has highlighted the importance for industrialised builders to develop unique platforms for the delivery of their products to market (Lessing 2015; Jansson 2013; Johnsson 2013).

As a method of sharing components and production processes, a platform allows companies to develop differentiated products efficiently through a flexible and responsive manufacturing process (Robertson & Ulrich 1998; Lehnerd & Meyer 1997). Originating from developments in traditional manufacturing, platforms have been developed and utilised by companies ranging from the automotive and aeronautical sectors to pharmaceutical and consumer electronics. Importantly, the platform concept allows business to respond to demands for mass customisation, while increasing efficiency of production and design through improved systems focused on process improvements.

The platform approach is now expanding into new fields and industries, for example car and home sharing, (Choudary et al. 2015) but the origins of the concept lie with manufacturing industries seeking innovation and increased productivity (Lehnerd & Meyer 1997). To a degree, construction research has often focused on the physical product, and less so on the process of development. It is this deficiency that research into platforms has sought to address (Koskela & Vrijhoef 2001).

The potential to develop a platform approach for industrialised construction appears significant, as the concept’s promise of “Increased product variety, decreased costs, faster time to market” (Simpson et
al. 2014 p.v) would respond to key criticisms of industrialised construction only being quicker than tradition, yet not being as cost effective or flexible.

Recent research from Sweden has investigated and demonstrated the applicability of platforms to the mature Swedish industrialised construction industry, though little research has been conducted outside of Sweden. This paper will discuss the core concepts behind the platform approach, with specific attention paid to the findings from research into platforms for industrialised construction, and will then draw conclusions as to how this approach may be implemented for industrialised construction in less mature contexts, for example, Australia.

2. Defining the need for a platform approach

2.1 Demand for change

The development of the platform approach has arisen through demands on manufacturing businesses to develop a greater variety of products to meet shifting market demands, reduce costs and speed up the delivery of these products (Simpson et al. 2014). These demands on manufacturing are similar to those that the contemporary construction industry experiences:

“Current demands for shorter lead times, customized buildings, and quality of deliveries compel construction firms to systemize work in their own supply chain.” (Jansson et al. 2014, p.71).

Recently, Australia has witnessed an increased appetite for productivity and value gains in the construction sector (Victorian Government 2015; Chandler 2013). How to facilitate these gains, is being debated across government, academia and industry, and it is clear that these sectors must work collaboratively to understand global precedents, implement reforms and record the effectiveness of innovation (Steinhardt et al. 2013). However, the act of simply acknowledging the challenges has been a valuable first step.

The platform approach to be discussed, not only focuses on hard changes to the technical approach of industrialised construction, but also softer elements which are often process-focused and which create value for both business and consumer, through increased customisation, changes to the business model (Lessing & Brege 2015; Johnsson et al. 2013; Wikberg et al. 2014), or greater involvement of clients to drive market acceptance and innovation in construction (Engström & Levander 2010). In Australia, the challenges that industry faces have largely been discussed purely at a conceptual level (Botsman 2015). So far, there has been little to no academic research to consider and analyse specifically how Australian industry can apply a platform approach, which again underscores the importance of this analysis of international case studies.

2.2. Evolution of industrialised construction

The path to contemporary manufacturing practice can be traced back to the development of the factory and unification of craft practices. The subsequent American system introduced a number of elements still recognised today: a greater reliance on mathematics; specific tools for purpose; and greater middle management to co-ordinate work practices. Mass production of the early 20th century then saw significant advances in productivity and efficiency realised through increased wages for production workers, integration of the supply chain, and the dominance of production over the market (Winch 2003).
In the pursuit of more efficient construction, the building industry has looked to manufacturing for techniques to increase production and streamline work processes for a number of years (Davies 2005; Finnimore 1989). Post-World War II, a housing shortage saw industrialised construction develop as a means of responding quickly. This concept progressed prefabrication beyond that of historic examples of colonial house production of the 19th century or the ready-cut houses of the 1920s and 30s. Industrialised construction evolved from the development of systems building, during this post-war period; an approach which relied on advanced process considerations facilitated by a combination of standardised building components and prefabrication (Crowley 1998). Following a period of intense critique of the quality and effectiveness of the post-war industrialised construction output – more recently, it has been lean production principles with its focus on waste and value that have occupied construction researchers looking to learn lessons from contemporary automotive manufacturing to address these criticisms.

It is debatable how relevant the automotive sector is to construction as key differences exist (Gann 1996). Especially the diverse needs of: customer participation in the design process; flexibility; and the number of components required for building production. Lean has been shown to be most applicable in low-level instances of mass customisation during assembly or distribution, while high-level mass customisation taking place during design and fabrication is much harder to achieve using lean principles (Stump & Badurdeen 2009). Other limitations of lean principles are that they have a tendency to be suited to stable and standardised products (Thuesen & Hvam 2011).

Winch (2003) asserts that neither mass production nor the lean approach is entirely suited to construction, and instead a complex systems production model may be the best. Increasing demand for greater mass customisation is often cited as a reason to progress beyond the pure rationale of lean. The platform approach can be read as a strategy for applying a form of complex systems production to construction. Winch’s (2003) findings regard the importance of project management to complex systems manufacturing and has been further developed to understand and highlight the significance of separating project-to-project management from that of the overall platform management and development (Lessing 2006).

2.3. Platforms for construction

To develop a complex systems approach for construction, the platform concept provides a basis to establish,

“a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced” (Lehnerd & Meyer 1997, p.39)

Companies have traditionally designed products one at a time which has resulted in lost opportunities to review designs in the search for platform-based opportunities of standardisation, commonality, compatibility and modularisation (Simpson et al. 2007; Lehnerd & Meyer, 1997).

Product platforms have emerged as companies have sought ways to create these opportunities and to successfully implement mass customisation (Spring & Dalrymple 2000), by producing “highly differentiated products...delivered to the market without consuming excessive resources” (Robertson & Ulrich 1998, p.20). These companies look to fill market niches using a basic kit of parts which can be assembled in a number of configurations, each appealing to a different sector. So was born the platform approach to product development. The definition that Robertson and Ulrich (1998) developed has become the standard description, defining the platform as; “the collection of assets that are shared by a
set of products.” (Robertson & Ulrich 1998, p.20). these assets being tangible and intangible: components, processes, knowledge and relationships.

3. Discussion

3.1. Tailoring the platform

3.1.1. Defining an organisation’s platform

Simpson et al (2007) establish two approaches for the use of the platform approach by manufacturing businesses. The first sees product development managed proactively through top-down means where designs are created from a range of elements which constitute the product-family and form the business’ predefined and agreed upon platform. By contrast, using the other approach, business may choose a bottom-up approach to platform development, where existing products are interrogated and redesigned to create and ensure commonality of parts and thereby establish a platform approach for the company’s range of offerings. Describing a platform in either of these ways, is beneficial to a business seeking to commence an understanding of their offerings and processes from a platform perspective.

These approaches bear similarities to the outside-in, or inside-out product development methods discussed by Lessing and Brege (2015) with relevance to construction and the market in which a business is operating. In this way, platforms are inextricably linked to the overall business model of the company that has developed it, each being tailored to the other. Business models help to provide an overview of how companies operate, and provide a broad view of operations (Brege et al. 2014) which is helpful when defining a platform approach.

Further, platform definition is achieved through either a supplier-led platform, which focuses on commonalities of process in the supply chain and results in a flexible offering that is able to adapt to design inputs from external companies, or a client-driven platform which sees a clearly defined product offering developed from research to suit certain market sectors (Jansson et al. 2014).

In their usage, platforms can be defined as either open or closed, and this definition must be understood to ensure suitability for construction which relies on a more developed and responsive design phase than many traditional manufacturing businesses (Jansson et al. 2014). Open platforms are well suited to construction, as they allow the client access to the design-phase. In creating a separate configurable design platform, which then directly affects the production platform (Lidelöw et al. 2015), while a closed platform will have a product focus and seek to limit design changes in order to streamline production efficiency. Creating openness will standardise processes and provide clarity in the design process enabling mass customisation (Johnsson, 2013; Lidelöw et al. 2015), this redefinition and integration of the design phase with the platform is important, as;

“Traditional iterative design processes used in construction often fail to adapt customer requirements to the constraints of the platform. (Wikberg et al. 2014, p.196)

3.1.2. Views of the platform

In his work defining industrialised house building, Swedish researcher Jerker Lessing (2006), bisects the platform approach into technical and process platforms that must exist in parallel. Further, from a traditional manufacturing perspective, four stages of a platform are identified: the product portfolio, the product platform, the process platform and the supply platform (Jiao et al., 2007). Using the Platform
Variant Master concept developed by Hvam et al. (2008), manufacturers similarly can describe their platform using three key ‘views’ which relate to the aforementioned stages; the customer view, the engineering view and production view. These perspectives are advanced by Thuesen and Hvam (2011) for construction, so as to describe a platform in terms of the market that the platform addresses, the design of the platform, and how it responds to individual projects, and the processes involved in the development and production of projects. These four focus areas which are tied to traditional construction, have been refined by Malmgren et al. (2010) to fix four views for industrialised construction platforms:

- **Customer view.** Displays the company’s offering, and is used by the client and sales agent, to understand and communicate design work.
- **Engineering view.** The working, customized design, bridges the customer and production views, essential for regulatory compliance to describe the product.
- **Production view.** Specific information on the parts for manufacture and how components are to be assembled for workers in the factory, technical process focus.
- **Assembly view.** Relates to the supply platform and facilitates an on-site perspective describing how components are to be put together.

### 3.1.3. Elements within the platform

As an architect, or a company looking to engage with industrialised construction, it can be easy to get caught up in the design of physical (or ‘hard’) components that form the platform. However, there lie a range of other ‘soft’ elements which describe how the platform is used, and which determine its effectiveness and potential for development. Robertson and Ulrich (1998) define four constituent parts of a platform:

- **Components.** The aforementioned parts of the product family,
- **Processes.** The design of the offerings, production process, how offerings are fabricated and assembled, through to delivery,
- **Knowledge.** Stored design, technical, production, assembly and testing knowledge, and;
- **People & Relationships.** Relationships internally between team members, and externally with organisations, and the broader supply chain.

Similarly, these elements can be alternatively considered as focuses on: customers, information flows, logistics and collaboration (Lessing, 2006). However, it is in the use and development of the platform by the unique business setting that these descriptions will be most clearly defined.

### 3.2. Using the platform

#### 3.2.1. Support

The four elements identified by Robertson et al. (1998) are described as platform assets, and can exist within each of Malmgren et al.’s (2010) views. When applied to industrialised construction, these assets form the basis for a structure of support for each view of a company’s platform. A range of support methods are essential to facilitate the successful use of the platform concept, and these are described by Jansson et al. (2014) who worked with two Swedish industrialised construction companies to investigate
their implementation. Support methods are especially useful during the design-phase, where high-end mass customisation occurs, and as has been described, where lean principles have been the hardest to implement. Jansson et al.’s (2014) support methods help to bridge gaps in the platform and facilitate a flow of knowledge and are summarised below:

- **Planning.** Design tasks and deliverables are broken down to create a clear structure to assist with production timing. Supports the overall process.
- **Collaboration.** Matches the timing of design and production through regular meetings, acts as the basis for the design plan, and ensures buildability.
- **Optimisation.** Stored feedback regarding continuous improvement from both internal and external sources (especially client responses). Helps balance commonality and distinctiveness.
- **Iteration.** Ensures that the best design outcome is achieved for both regulatory compliance and technical buildability on the factory floor, a form of quality control.

![Diagram of the platform’s central role for industrialised construction](image)

**Figure 1:** Diagrammatic summary of the platform’s central role for industrialised construction

### 3.2.2. Balance

There lie a number of dichotomies at the heart of the platform concept, and it is in keeping these balanced that a successful platform is utilised and maintained.

In seeking to implement a platform approach and establishing support methods for its development, the product families (physical components which define the platform) can be classed as either **modular** or **scale-based** (Hirshburg & Siddique 2014). A modular platform, means that the components are interchangeable, allowing parts to be substituted for one another, and a resulting platform that can be accessed by clients during the design phase in a simple manner (Jansson 2013). Those which are scale-based, rely on parts which can easily change dimension to create new products parametrically (Simpson et al. 2007; Hirshburg & Siddique 2014).
Within a platform’s assets it is critical to ensure that there is enough *commonality* to create efficiency, yet enough *variety* to allow design possibilities, market acceptance and interest to consumers, as, “Customers care about distinctiveness; costs are driven by commonality” (Robertson & Ulrich 1998, p.21). This applies not just to the physical components of the platform, but also to processes, knowledge and working relationships.

*Platform development* must also sit distinct from *product development*. Creating clear channels of feedback to enable continuous improvement is critical to achieve this (Jansson 2013). Feedback can act as a foundation for increased standardisation in processes, design and manufacture of components, as well as integrating the supply chain (Lidellöw et al. 2015). It is important for the construction industry to invest in effective knowledge management practices in order to facilitate this feedback (Bresnen 2004) at both a platform level, as well as from the view of product development. It is suggested that the creation of a *process owner* role, distinct from the traditional *project manager* can help clearly manage this flow of information and transition construction towards a product-approach rather than the traditional temporary approach of the project (Lessing, 2006). The building industry has typically been reluctant to structure operative knowledge, largely due to this project-based nature of building, with workers relying on tacit knowledge and an informal ability to share (Styhre & Gluch 2010). However, the importance and value of feedback for the continuous improvement of the platform cannot be heavily stressed enough (Söderholm 2010; Meiling & Johnsson 2008).

3.3. Advantages and barriers

3.3.1. Advantages

The traditional construction and design industries can at times be disorganised, or rely on tacit knowledge and working methods passed from one worker to another without being formally documented, organised, or communicated. Platforms seek to integrate knowledge and experience, without being so rigid as to determine exact working practice, meaning that participants can still bring their own experience to bear (Styhre & Gluch 2010). As mentioned, balancing the platform is critical, as the construction industry is particularly susceptible to working with ‘strong but now wrong’ methods (Barrett et al. 1999). Both
industry and clients will benefit from a structure to guide decisions and choices, and an effective platform will help create this environment:

“narrowing down the number of possible choices while at the same time allowing for some local variation and individual creativity.” (Styhre & Gluch 2010, p.593).

Platforms allow companies to tailor products to suit specific market preferences, without excessive work required to design these options due to a modular or scalable approach. Costs are also typically reduced, as business will re-use already tested design and assembly processes, while there is a natural economy of scale introduced through the use of common parts (Robertson & Ulrich 1998). This design-process led approach to platforms enables cost reductions with an increase in market-driven product offerings without excessive spending on machinery or facilities, and responds to criticisms of industrialised construction raised by Gann (1996), where manufacturers,

“often did not perceive markets for mass produced housing as being stable enough to warrant the huge investment costs that would be required to tool up new factories.” (Gann 1996, p.440).

Cost reductions also mean reduced risk, especially for the client for whom a construction project typically represents a significant investment. A platform’s focus on process, will result in increased service levels for the customer, as service practices can be re-used and refined, driving a strong customer-focus which is essential for industrialised construction (Lessing 2006).

3.3.2. Barriers

There are a number of barriers to the effective use and uptake of platforms by construction. Generally, in manufacturing, it has been witnessed that most companies will have a singular focus, and are

“not prepared to think across multiple generations of products and long term about their product lines.” (Simpson et al. 2014 p.v)

For the many benefits that platforms bring in reducing costs of iterative design development which respond to market sectors, a consequence is that initial design costs are increased. Care must also be taken during the platform planning phase to ensure the correct balance is struck between commonality and distinctiveness (Simpson et al. 2007), as a lack of variety can have a significantly detrimental effect on how the market regards the offers. Balancing the full separation of day-to-day platform usage and its long-term development can also be very difficult to achieve (Jansson 2013). One of the most significant problems that the platform approach faces with regards the construction industry generally is that they are:

“not very easily implemented in the construction industry since there is a strong instituted principle in the construction industry to avoid standardized solutions and off-the-shelf design of buildings.” (Styhre & Gluch 2010, p.590).

However, the demonstrated benefits of a process focus for industrialised construction (Lessing 2006), and the importance of feedback and continuous improvement to these processes (Jansson 2013), may stand contemporary industrialised construction apart from historical systems building and traditional construction. For industrialised construction, Jansson (2013) notes that there has been little study into the long term use of platforms, with particular regard for maintaining the platform and its responsiveness to an, at times, rapidly changing market. This criticism with regards responsiveness to market and long-
term use, also goes to the detail of working practices. As has been noted platforms must remain flexible in order to be responsive for those who are using them and for the local environment (Styhre & Gluch 2010) and must balance standardisation of working practice with freedom for the platform user.

4. Conclusion

As outlined, research concerning the platform approach for industrialised construction has brought significant benefits for both industry and, importantly, clients. Due to their integrated and holistic nature, platforms are highly specific to individual businesses and their operational contexts. Therefore, there are gaps in knowledge and research as to the application of this important concept outside of Sweden.

Recent travel undertaken by the author to Sweden has underscored the discussion in this paper: that platforms are unique to business models, resources, and the markets that companies operate in. Some investigated had a strong technical-focus, seeking improved production techniques using timber, steel or concrete; while other companies had design-led platforms which ranged from a highly defined catalogue of client views to fully flexible offerings allowing customers and architects sophisticated levels of customisation. On top of this, there are of course local constraints unique to the Swedish context, with regard the political system, history, regulations and cultural dynamics which to a greater or lesser degree impact on how platforms operate and are used by business and clients alike.

A deeper analysis of these Swedish case studies is outside the remit of this paper, suffice to say that an Australian industry looking to learn from Sweden and to adopt a platform approach must be willing to test ideas and adapt them to the specific local context. This has been at the core of research in Sweden, also apparent during visits to universities and industry. Highlighted by Jansson’s (2013) thesis, it stresses the importance of testing research through its application in construction. The next phase of my research will test the lessons and opportunities of the platform concept in a series of live projects to establish the validity and viability of the concept in the Australian context. This applied research approach allows ideas to transition from academic concepts to be tested in industry, and as with platforms themselves, means that the research can benefit from feedback for critique and improvement.

References


Green roofs in Australia: review of thermal performance and associated policy development

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Abstract: In Australia, there is an increasing interest in using extensive green roofs to make buildings more sustainable and provide a number of social, ecological, aesthetic and thermal benefits to cities. The potential of green roofs to reduce building energy consumption has been extensively studied overseas in a variety of different climates. However, in Australia the green roof industry is relatively new. There is still very little information on the thermal properties of Australian green roofs and their performance. Further, as a relatively new industry, there is a general lack of specific policies and initiatives to promote green roofs. In this paper, we briefly review the research investigating green roof thermal performance in various climates and analyse policies and actions that have been implemented internationally to foster green roofs with an emphasis on their thermal performance. The results showed that most policies were focused on ecological benefits, such as stormwater runoff reduction, rather than thermal benefits. Many green roof policies had difficulty interpreting the thermal performance of green roofs, because of the dynamic nature of green roof R-values. In this study, the effectiveness of overseas green roof policy is discussed and recommendations how they could be adapted for Australian cities are provided.

Keywords: Green roofs; thermal performance; building; policy.

1. Introduction

Cities, as the locations of substantial resource use and pollution, are increasingly focused on measures to reduce their environmental impacts and carbon footprint (Gill et al., 2007). Globally, buildings consume about 40% of the annual energy consumption and are responsible for CO₂ and NOₓ emissions, as most of the energy used is produced by burning fossil fuels (Omer, 2008). Strategies to reduce the environmental impact of buildings include incorporating passive cooling systems (Doulos et al., 2004), adopting energy efficient design and techniques (Sadineni et al., 2011), using recycled materials in construction (Chwieduk, 2003), using or even producing renewable energy (Chwieduk, 2003) and mimicking nature for sustainable design (John et al., 2005). Green roofs, also called vegetated roofs, are increasingly popular worldwide as they can ameliorate some of the environmental impacts of buildings,
including energy savings – particularly for low rise buildings (Martens et al., 2008), providing cooling effect and, to some extent, the mitigation of the urban heat island effect (Berardi et al., 2014).

Numerous studies conducted all around the world, have investigated the thermal performance of green roofs. Generally, it has been found that their thermal performance varies across climates and depends on the materials used to construct the green roof and their associated thermal properties (Parizotto and Lamberts, 2011; Schweitzer and Erell, 2014; Zhao et al., 2014). Varying results have been found among different typologies of buildings: generally, low rise buildings, such as one-storey buildings, had the best positive outcomes in terms of energy saving compared to multi-storey buildings, because of high roof-envelope ratio (Martens et al., 2008). As green roofs are relatively new in Australia, we have very little information about their thermal performance. This is complicated by having various climate zones in Australia (Figure 1), implying that green roofs may need to be designed differently to maximise their thermal performance in each climate zone.

This paper reviews research investigating the thermal performance of green roofs across different climates globally, to inform the selection of the most appropriate green roof materials for Australia, and maximise their thermal performance. We also analyse policies and actions implemented around the world to encourage green roof construction, to inform the integration of the thermal benefits into Australian green roof policies including the National Construction Code (NCC).

1.1. How do green roofs reduce the thermal load for buildings?

The components of energy balance equations on green roofs differ depending on the conditions of the roofs. For a bare roof, the incoming solar radiation is equal to the sum of four main components: (1)
radiation reflected to the surrounding by the roof; (2) heat stored within the roof layers; (3) heat
transferred to indoor; (4) heat loss to the surrounding from the roof. For a green roof with plants, the
incoming solar radiation is equal to the sum of several components: (1) radiation reflected to the
surrounding by plants; (2) radiation reflected to the surrounding by substrate; (3) energy consumed for
evaporation, transpiration and photosynthesis; (4) heat loss by leaves; (5) heat loss by the substrate; (6)
heat stored within the foliage; (7) heat stored within the green roof layers; (8) heat transferred to
indoor. While for conventional roofs the reflectivity and emissivity values are mostly constant over time,
this is not the case for green roofs as the thermal characteristics of plants and the substrate change over
time. For example, plant density and substrate moisture content strongly affect the values of the energy
balance components. The reflectivity of the substrate changes according to its moisture content (Sailor
et al., 2008). The cooling benefit provided by the plant transpiration is dependent on vegetation density.
Vegetation density, together with the total plant coverage, also reduces the substrate temperature due
to shading. Table 1 presents a qualitative summary of the functions performed by green roofs to reduce
the building thermal load. In a green roof, conduction, radiation and convection heat transfer
mechanisms occur simultaneously with moisture transfer. Quantifying the dynamic heat flux through a
green roof is thus complex and requires simplified assumptions, such as one-dimensional heat transfer,
to make the model tractable.

<table>
<thead>
<tr>
<th>Green roof component</th>
<th>Technique</th>
</tr>
</thead>
</table>
| Vegetation           | Direct solar shading provided by the foliage  
                       | Cooling by plant transpiration which is controlled by leaf stomata  
                       | Direct solar reflection by the leaves (proportional to reflectivity)  
                       | Heat loss by the leaves (proportional to emissivity) |
| Substrate            | Providing additional thermal mass  
                       | Cooling by evaporation of water bounded in the substrate  
                       | Direct solar reflection by the substrate (proportional to reflectivity)  
                       | Heat loss by the substrate (proportional to emissivity) |

2. Green roof and thermal performance: a brief review

The transient nature of green roof heat fluxes affects the thermal performance of green roofs. The
thermal performance of green roofs is most easily demonstrated when only measuring indoor
temperature under different roof types (Parizotto and Lamberts, 2011). However to maximise the
thermal benefits, attention must also be paid to selection of materials used in the green roof ‘build-up’
(the overall combination of substrates and plants), its design, climate and seasonality.

Most studies of green roof thermal performance prove that they reduce the heating and cooling
loads for buildings, but as green roof build-ups used in overseas studies are not necessarily the same as
those used in Australia, specific knowledge and experimental set-ups are essential to guarantee full
understanding of green roof thermal performance in Australia (Chen, 2013).

Cold climates countries, such as Canada, benefit from green roofs during summer and winter as they
reduce both heating and cooling demands (Sadineni et al., 2011). As a proof that the selection of
substrates and plants is essential to maximise the green roof thermal performance for cold climates
(Zhao et al., 2014), it was found that in summer a thick and light substrate offers higher insulating
thermal mass and retention of moisture for evaporative cooling than a thin dark substrate (Liu, 2003). In winter, the thermal advantage is considerably smaller than in summer, because the extra snow layer facilitates the heat loss from indoor to outdoor and drastically reduces the insulation properties of the green roof (Liu, 2003; Zhao and Srebric, 2012). Even doubling the thickness of substrate from 75 to 150 mm, has no significant impact in enhancing the thermal performance in winter (Lundholm et al., 2014).

Studies in hot and wet tropical and subtropical climates found that the vegetation selection, rather than substrate selection, is the green roof component that makes the green roof effective in reducing the energy demand for cooling. A vegetated green roof in Singapore performs better than a non-vegetated roof, which in turn is more effective than a bare roof (Wong et al., 2003). In Singapore, it was also found that low groundcover plants are not the best choice for extensive green roofs when it comes to passive cooling (Wong et al., 2007): shrubs had a better cooling performance (Wong et al., 2003). The advantage of an intensive green roof in hot and wet climates is reported in a few studies (Wong et al., 2003; Darkwa et al., 2013), however the difference is due to having a dense and vigorous vegetated layer (Onmura et al., 2001; Jim, 2012), rather than having a deeper substrate. Although an intensive green roof provides greater thermal mass, only a shallow layer up to 100 mm is needed to reduce heat penetration into the building (Jim and Tsang, 2011). In contrast, for hot and dry climates plant selection is important for enhancing the green roof thermal performance (Dvorak and Volder, 2013; Schweitzer and Erell, 2014), as plants need to survive long drought periods to provide shading. However, employing alternative types of shading rather than plants, such as mesh or lightweight gravel, can still guarantee a passive cooling benefit for green roofs in hot and dry-arid countries (Pearlmutter and Rosenfeld, 2008).

Dense vegetation was also found to be the key attribute for cooling for an extensive green roof in southern Spain, a Mediterranean climate region (Olivieri et al., 2013). However, in temperate northeastern Italy, substrate thickness and substrate moisture content were found to be the key parameters to enhancing the thermal performance of green roofs (Lazzarin et al., 2005; Nardini et al., 2012).

Greece, with a southern Europe Mediterranean climate, shares some similarities with southern Spain where dense and dark green vegetation performs better than scarce or no vegetation for cooling during summer (Niachou et al., 2001). However, it has also been found that the composition and porosity of the substrate and its thickness can help reduce the heat flux penetrating the roof of a building (Kotsiris et al., 2012). Overall, in the Greek climate it has been found that green roofs are highly effective in reducing summer cooling demands, while they provide no thermal advantage during winter, regardless of the green roof build-up type (Santamouris et al., 2007; Sfakianaki et al., 2009; Theodosiou et al., 2014). This is different to green roofs in cold (Sadineni et al., 2011) and temperate climates (D’Orazio et al., 2012) where a thermal advantage was found even in winter, although smaller than that in summer.

This review illustrates the complexity in determining the best green roof build-up to maximize the thermal benefits of green roofs as they depend on specific location and climate. It may be one reason why green roofs are barely integrated into Australia’s Green Star rating system (Green Building Council Australia), as difficulty interpreting research findings to a local context is a barrier to their uptake and success (Williams et al., 2010). Countries with many climate zones, such as Australia (Figure 1) or China, need to identify through experimentation the best green roof build-up for each zone (Kokogiannakis and Darkwa, 2014; Xiao et al., 2014) as those used in Europe or North America may not be appropriate (Williams et al., 2010). Synthesising research findings from similar climate zones have enabled us to provide initial green roof build-up recommendations across the eight Australian climate zones (Table 2) to maximise thermal performance. However, these initial recommendations should be supported with
local experiments as performances also vary with green roof build-up and existing insulation layers (D’Orazio et al., 2012).

The complexity created by different climate zones and associated thermal performance variations in large countries such as Australia, means that developing consistent green roof policies at a national level is challenging. Nonetheless, given the substantial benefits provided by green roofs, both at the individual building scale as well as at precinct scale, there are significant opportunities for policy development. These research findings can potentially support the inclusion of green roofs into Australian building energy rating schemes. Globally, some governments, particularly those with broader sustainability strategies and targets, have developed policies to encourage or mandate green roof installations. The policy perspectives of green roofs are considered in the following section.

<table>
<thead>
<tr>
<th>Climate zone (ABCB, 2016)</th>
<th>City / Town</th>
<th>Recommended green roof build-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Hot humid summer, warm winter</td>
<td>Darwin, Cairns</td>
<td>Extensive green roof (100 mm) with dense and vigorous vegetation</td>
</tr>
<tr>
<td>2 Warm humid summer, mild winter</td>
<td>Brisbane, Mackay</td>
<td>Extensive green roof (100 mm) with dense and vigorous vegetation</td>
</tr>
<tr>
<td>3 Hot dry summer, warm winter</td>
<td>Alice Springs</td>
<td>Extensive green roof (100 mm) with drought tolerant plant species</td>
</tr>
<tr>
<td>4 Hot dry summer, cool winter</td>
<td>Mildura, Kalgoorlie</td>
<td>Extensive or semi-intensive green roof (150 mm) to maximise moisture retention</td>
</tr>
<tr>
<td>5 Warm temperate</td>
<td>Sydney, Perth</td>
<td>Semi-intensive green roof (&gt;200 mm) with porous substrate and selected plants</td>
</tr>
<tr>
<td>6 Mild temperate</td>
<td>Melbourne, Adelaide</td>
<td>Semi-intensive green roof (&gt;200 mm) with porous substrate and selected plants</td>
</tr>
<tr>
<td>7 Cool temperate</td>
<td>Canberra, Hobart</td>
<td>Semi-intensive green roof (&gt;200 mm) with porous substrate and selected plants</td>
</tr>
<tr>
<td>8 Alpine</td>
<td>Cabramurra</td>
<td>Semi-intensive green roof (&gt;200 mm) with porous substrate and selected plants</td>
</tr>
</tbody>
</table>

3. Policy perspectives

Internationally, cities and countries with more experience in the installation, operation and maintenance of green roofs, have a range of policy approaches to encourage or mandate the use of green roofs. We now provide a brief overview of policy approaches internationally, and highlight Australia’s few examples of green roof policies, before making recommendations for further policy development in the Australian context.

3.1 Green roof policies: an international perspective

Green roof policies have been applied extensively in many countries in the northern hemisphere, utilising a range of policy instruments. Policy instruments can be categorised into four different types: information and advocacy; incentives; government demonstration and provision; and regulation (Maddison and Denniss, 2009). Most issues, including environmental issues, usually require a range of policy instruments to address the different types of barriers and challenges that are limiting the adoption of the desired practices (Taylor et al., 2012; Dovers and Hussey, 2013). Policy measures may be either binding or voluntary, and may take the approach of regulating minimum standards or providing incentives for best practice.

In Germany, where there has been substantial experimentation, innovation and development of green roof techniques since at least the 1970s and 1980s (Appl, 2009), mandatory green roof regulations have been in place at local and national levels for more than 30 years (Ansel, 2015). Several North American cities, including Toronto, Chicago and Portland have employed a range of policy instruments
to successfully promote green roof installations in urban areas (Carter and Fowler, 2008). Most of these policies aim to promote the ecological benefits of green roofs, such as stormwater runoff reduction and provision of biodiversity habitat, rather than energy savings associated with the insulating value of green roofs (IMAP, 2014).

Internationally, most green roof policy mechanisms are based on regulatory requirements, direct and indirect incentives (Shiah, 2011). There appears to be less focus on information and government provision mechanisms, potentially in part because the familiarity in these cities and countries with green roofs decreases the necessity for these types of public policy mechanisms. Examples of green roof policy mechanisms across each of the four mechanism types are shown in Table 3.

![Table 3: Green roof policy mechanisms: international examples.](image)

<table>
<thead>
<tr>
<th>Policy instrument</th>
<th>Advocacy</th>
<th>Incentive</th>
<th>Government provision</th>
<th>Regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community information, engagement, participation</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guidelines and toolkits</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incentives during the planning process for proposals that incorporate green roofs:</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Increased floor area ratios</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• ‘Green door’ fast tracking of planning approvals</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Waiving planning fees</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Exempting certain works related to green roofs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stormwater fee discount with increased pervious surfaces</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grants, rebates, financing for installation</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leadership, including demonstration green roofs</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrated government decision-making on urban infrastructure and land use planning</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrated government decision-making: ensure existing regulations do not pose a barrier for green roof installations</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Mandatory green roofs/rooftop landscaping on all new buildings (may only apply to specific building types, such as commercial, multi-residential, or to buildings above a certain threshold area)</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Planning scheme overlays (identifying specific areas for mandated green roofs on new buildings)</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Green building certification (voluntary or mandatory sustainability rating schemes)</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data collection, monitoring, evaluation</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Awards, recognition programs</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

3.2 Green roof policy approaches in Australia

Green roofs are still relatively rare in Australia, and policies to promote them are also rare (Williams et al., 2010). However, there are recent initiatives indicating a growing interest in encouraging green roof installation. In April 2014, the City of Sydney adopted its ‘Green roofs and walls policy’, the first of its kind in Australia (City of Sydney, 2014). Supporting its policy, the City of Sydney has also developed a
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range of information resources and technical guidelines (Table 4). Inner Melbourne councils (Cities of Melbourne, Port Phillip, Stonnington and Yarra) in partnership with the Victorian state government and the University of Melbourne, developed a technical guide to support green roof planning, design and installations (DEPI, 2014), and undertook a review of policy options for green roofs (IMAP, 2014). The policy options that were identified focused on mechanisms to encourage installation of green roofs. Whilst regulatory mechanisms were canvassed in the review (IMAP, 2014) pp 44-53), at the time of writing (June 2016), none of these had been mandated by the councils involved. The organisation of regular ‘Canopy’ forums by the City of Melbourne aims to encourage green roof installations and foster green roof industry development (Table 4). At a national level, the Green Building Council of Australia has included green roofs as a ‘creditable feature’ in the ‘Green Star – Design and As Built’ rating system, the voluntary sustainability certification for new buildings in Australia (GBCA, 2015).

Table 4: Australian green roof policies and programs.

<table>
<thead>
<tr>
<th>City</th>
<th>Policies and programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sydney</td>
<td>• Green roofs and walls policy, 2014. Key mechanisms include:</td>
</tr>
<tr>
<td></td>
<td>o Leadership, awareness raising, demonstration sites on council buildings</td>
</tr>
<tr>
<td></td>
<td>o Information resources for technical and general information</td>
</tr>
<tr>
<td></td>
<td>o Development of guidelines and standards</td>
</tr>
<tr>
<td></td>
<td>o Technical advisory panel</td>
</tr>
<tr>
<td></td>
<td>o Promotion and training</td>
</tr>
<tr>
<td></td>
<td>o Support for research partnerships</td>
</tr>
<tr>
<td></td>
<td>o Identification of opportunities in existing planning scheme and local planning</td>
</tr>
<tr>
<td></td>
<td>controls, regulations, environmental upgrade agreements (EUAs), rating tools</td>
</tr>
<tr>
<td></td>
<td>o Monitoring</td>
</tr>
<tr>
<td></td>
<td>• Implementation plan 2014</td>
</tr>
<tr>
<td></td>
<td>• Design guide</td>
</tr>
<tr>
<td></td>
<td>• Resource manual</td>
</tr>
<tr>
<td></td>
<td>• Listing of green roof locations in Sydney on website</td>
</tr>
<tr>
<td>Melbourne</td>
<td>• Growing Green Guide, 2014: industry knowledge and academic research: technical manual, case studies</td>
</tr>
<tr>
<td></td>
<td>• Policy options background paper, 2014: international case study research; application to Victorian/metro Melbourne policy and planning; recommendations for more research in Australia to support establishment of min standards specifications</td>
</tr>
<tr>
<td></td>
<td>• ‘Canopy’ green roof seminar series: industry network facilitation and information dissemination/generation</td>
</tr>
</tbody>
</table>

Given the early stage of green roof research and practice in Australia, mandating green roof installation through policy regulations would be premature, because there is not sufficient data to allow specification of minimum performance standards, and the construction industry (including green roof specialists) is not yet developed enough to support wide-scale installation and maintenance. In addition, with perhaps the exception of stormwater retention, there is a lack of research data to enable the definition of minimum standards for green roof technical and ecological functions, including thermal performance. This is necessary if financial incentives are offered as minimum standards ensure the quality of installation and to reduce the risk of tokenism or abuse of subsidies (Ansel, 2015). The immaturity of the industry also means that there is uncertainty for developers in the costs of installation and maintenance, and lack of understanding about why cost estimates can vary significantly between
different suppliers and installers. Until cost benchmarks exist, there would be significant industry opposition to mandating green roofs for new developments.

Given green roofs are still considered a novel innovation in Australia, policies should therefore focus on addressing key barriers to uptake; including provision of information, building awareness and public interest; technical capability and expertise in green roof installation, operation, maintenance; and financial support and incentives for installation and maintenance. In addition, policy makers should review building and planning regulations to remove existing policy barriers to green roof installations and ensure existing policies do not provide barriers to uptake.

Demonstrations sites are useful for this purpose. A green roof installed in Athens (Georgia, USA) was used as a test study to monitor stormwater runoff and rooftop temperatures. The data collected provided evidence of the benefits from green roofs and enabled policy makers to mandate policy recommendations at federal and local levels, in particular to control stormwater (Carter and Fowler, 2008). Similar test studies could be undertaken in Australia to collect green roof thermal data from different Australia climate zones. This will test and validate the best green roof build-up for every different climate zones (as recommended in Table 2), and will provide sufficient data to support green roof policy measures, including building energy rating schemes.

4. Conclusion
Thermal performance of green roofs varies globally across different climates; research is providing evidence of the most suitable green roof build-up to maximise their thermal benefits in different climates. Understanding and assessing the thermal performance of green roofs for Australian climate zones will not only help integration of the green roof building component into building energy rating schemes, but also will contribute to implementation of green roof policies and promotions in Australia.

Policy development and the selection of appropriate policy instruments needs to address the local context, the barriers to uptake and the state of development of the technology and the associated industry (construction, installation, operation and maintenance). Industry development and policy development are mutually supportive. The capital city councils of Australia’s largest cities, Sydney and Melbourne, have begun to address some of the barriers to green roof implementation, uptake and success (Williams et al., 2010; Zhang et al., 2012) through green roof policy development and integrated programs of information and industry support.

To support continued policy development and strengthened policy prescriptions, further research on the technical performance of green roofs in Australia’s different climate zones is required, as well as fostering community interest and industry development.

Acknowledgements
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Architectural specialisation and the death of architectural practice

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Abstract: In the past 50 years the traditional role of the architect to supervise and control projects has been eroded. The last remaining bastion maintain this traditional role of the architect is in small practice. Using a survey that firstly looks at how architects are engaged via either full or partial services we explore how architects identify with and deliver specialised services. The respondents in the survey were taken from a sample of 1200 Australian architects. Data was collected regarding specialisation, service provision, outsourcing and contractual arrangements. This is positioned alongside a historical account of the profession which suggests that technology and changes within legal frameworks, strategy, marketing, operations, project management, and finance are leading to the marginalisation of architects. We test this assertion by investigating evidence for these changes and the extent to which specialised architectural knowledge is being created in firms. For architects, specialist architectural knowledge is integrative and resides in the traditional service delivery particularly in the realm of housing. However, fee competition has hampered the ability of architects to specialise. As a result, in the future the role of the architect may be non-existent.

Keywords: Architectural practice; architectural fees; architectural knowledge; architectural specialisation.

1. Introduction

In the RIBA’s report, 2011 Future of Architecture (Jamieson, 2011), the RIBA explored how architectural practice would change in the future and in particular what it might look like in 2025. The report was a broad survey of different types of practices based on interviews with senior members of a range of practices, roundtable discussions and insights of industry leaders. In conclusion the report eschewed a singular conclusion as to how practice would develop in 2025. The report’s nonetheless embraced a number of broad conclusions. The report’s authors proclaimed that in 2025 architects would shift to a consultant style of practice, make a greater distinction between production oriented practices and design practices, and adopt networked working systems where services are outsourced across the
These broader conclusions suggest the degree to which the architect’s role and the scientific domain of knowledge that underpins architectural work is also in a state of flux.

Although in Australia many architects feel that there has been significant change to their role and a devaluation the title “architect” (both from an internal and external perspective), when we examine the historical development of the profession in Australia, we can see that it has been in a constant state of flux (figures 1, 2 & 3). Nevertheless, developments in technology (both for the production of documentation and construction materials and methods), business operations (trade practices, legal frameworks and liability for “risk”), and competition (specialised consultants working in the same area and globalisation) have altered the position of the architect in the construction “pecking order”.

Because of this transformation and flux the role the architect may feel diminished and their position of power/responsibility in the construction industry is arguably eroded. This raises a number of questions. Firstly, will architects exist in the future or will they became specialised design consultants as the RIBA report suggests? Or are these changes freeing architects to do something better? In adopting, and shifting to new models of practice, to what extent is specialised knowledge being developed by architects?

Prior to the 1930s, architects in Australia were trained using a system of apprenticeship (as trainees who were articled to practicing architects). Eventually, by the 1940s, schools of architecture developed leading to university based training, followed by national registration requirements that protected the title ‘architect’ and developed into a representative body for the profession. With these developments and regulations came additional and trade practices designed to influence the method of operation for the architectural profession. Using various ‘Architects Acts’ these rules and regulations developed as a result of the application of competition policy guidelines and requirements for risk management and professional accountability.

<table>
<thead>
<tr>
<th>University of Melbourne – Diploma course in Architecture offered</th>
<th>Architects Act established in NSW, WA, Vic., Qld. &amp; Tas.</th>
<th>University of Queensland and NSW</th>
<th>Architects Ordinance Act of Northern Territory</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 1900s</td>
<td>1910s</td>
<td>1920s</td>
<td>1930s</td>
</tr>
<tr>
<td>University of Sydney School of Architecture established</td>
<td>RAIA established (National)</td>
<td>Architects Act SA</td>
<td>Architects Ordinance Act ACT</td>
</tr>
</tbody>
</table>
By the mid 1960s, Project Management had been practiced in Australia for around 10 years, originating with the major industry employer – Civil & Civic. While originating in traditional military operations for specific construction and logistics, it was now being applied to the traditional peacetime building industry. By the 1990s the project manager as a producer of specialised knowledge had fully emerged and was in direct competition with, and to a degree has supplanted, the architect.

In the 1980s, as Duffy highlighted a number of problems for the architectural profession in relation to its traditional domain of knowledge emerged. He proclaimed, “design is often considered an optional extra”. Duffy argued that architects and been trained to “design within a wide programmatic range, but did not gain a mastery of the entire range of tasks performed by their predecessors.” (1986). This complex and complicated industry had for some architects meant they were unable to offer clients specialised skills and were unable to develop new consultancy services over time.

Since the 1980s numerous researchers have sought to examine the role of the architect in relation to other professional specialists. A central element of this discussion has been the relationship of architecture to that of the project manager which emerged fully in the 1990s. Traditionally architects by and large acted as project managers when providing a full fee service, including overseeing, administering and managing the construction process for a project.

Once a building contract was signed between the client and builder, the architect’s role change from that of an agent for the client, to that of contract arbiter – outside the parties of the contract – and designed to act as an independent consultant to the contract parties. But, as researchers began to examine this issue it became apparent that the architect’s role had shifted with the rise of project managers, alongside client demands for a single contact point for a construction package, (promoted by project managers) to provide more certain time and cost outcomes.
2. Research into the role of Architects

In the UK as Cohen Wilkinson and Finn (2005) note in their study that, along with the above developments, there was an increase in different procurement methods adopted for the industry over time. For example, in the 1980s 70% of UK construction in value was procured via traditional methods. However, by the 1980s “the contractor’s managerial role and the proportion of building work carried out by sub-contractors have increased”. Resulting from their study of forty-two UK architects they claimed that globalisation and technological change have altered the contexts in which professions such as architecture operate.

The Cohen et al study highlights the manner in which architects see themselves and their practices. They concluded that architects remain attached to the idea that creativity is at the core of the profession. It was noted that many of the architects in their study regarded this foundation of their profession as being placed under pressure by a, “raft of economic, political, managerial and cultural pressures.” Drawing on data generated in interviews with these forty-two architects, the study incorporated responses from varying levels of seniority across fifteen diverse organizational settings. The study captured how architects depict professional change: a profession under threat that sees its creative core as systematically undermined. However, this either/or view as reported in the study takes little account of how architects have incorporated these perceived professional pressures into the development of their profession. The researchers concluded that an analysis of individual architects and their perceptions of their work roles reveals a picture that is less about wholesale change, and more to do with negotiation and accommodation. It illuminates the elasticity of notions of professional work, and how individuals construct models which are flexible versions of their work descriptions and practices, and which make sense and are viable at particular moments in time.

Since the early 2000s there has been an emerging consensus that globalisation, deregulation, the diffusion of managerialism, rapid technological change, and an ever more knowledgeable and empowered consumer base, have significantly altered the contexts in which the traditional professions operate (Reed, 2000; Leicht and Fennell, 2001; Dent and Whitehead, 2002). One key study at this time by Chan et al (2000) reported on a study of the diverse ways professionals collaborate and overlap traditional work responsibilities – in a survey of 300 senior Hong Kong building professionals. They conclude that at that point in time in Hong Kong, among these professionals, there was ongoing structural change in their roles within built environment. Professionals were operating overlapping roles, and increased competition between different building professionals suggested that some building professionals were facing an “identity crisis.” They argue that project managers, at least in Hong Kong, were seen as a newly emerging profession, one that is the result of construction projects becoming more complex and that, “demand inputs form different disciplines of building professionals, the role of project leader traditionally belonging to architects is often shared or taken over by other building professionals”.

In Australia very little work has been done by the Australian Institute of Architects (AIA) or its predecessor the (Royal) RAIA, in collecting data or quantifying how much work has been done or completed by project managers. Take 5 a compilation of works around the issue of the future of a “sustainable architectural profession”, presented macroeconomic data on the profession’s position in the Australian economy. Tombs, Gardiner and Mussen the editors of Take 5 present data that shows the number of registered architects in Victoria remained stable between 1995 and 2005 despite a marked increase in building output. Michael Jansen of Satellier, a leading offshore CAD and BIM partnering firm argues in an article on outsourcing, that the rise of off-shore services for a “new model” of architectural practice will evolve alongside the evolution of current design and implementation practices. Jansen claims that this evolution will lead to architecture firms emerging as “think tanks dedicated to high-end, value added design, with many of their traditional production and other operations delegated to workshare partners and contractors.” In another contribution to the same publication citing fee competition, client driven demands and managerialism, Hughes argues that the professions within the construction industry have been “fighting a battle of survival for decades.” Hughes contends that mechanical notions of productivity, quantitative benchmarking and targets, do not suit professional consultancies because such notions ignore issues of professional expertise, knowledge and judgement.

In a 2013 historical survey of the Architects Accreditation Council of Australia (AACA) and its relationship to architectural standards of competency of Australia, Orr notes how the AIA argued that a singular model of practice should not be promoted through the competency standards determined by the AACA (2015). The AIA argued that the diversity of practice as a result of technology and globalisation amongst other things should be recognised. The AIA suggested that architectural competency, “can be acquired in a variety of modes of architectural practice.”
3. Survey questions

In order to investigate how Australian architects currently approach issues in relation to their role, disciplinary specialisation, competition and the future we surveyed 1200 practice based architects with a relatively low rate of 65 responses. The survey consisted of 26 questions and was delivered electronically via email to AIA members and via social media through the author’s networks. The survey included questions about architect’s current professional service offerings. In order to understand shifts in the services offered by architects, survey questions focused on perceptions of the changing role of architects in the construction industry. Questions regarding the types of services being offered and the degree architects were only offering partial services or outsourced current services were asked. Further, questions were asked about specialist expertise and knowledge within the practice and the degree to which respondent architects competed with other specialists. A number of questions examined to what degree architects felt they were being supplanted by other specialists. Finally, the survey also included questions focused on the degree to which architects were developing future specialist services and knowledge.

Overall the respondents were experienced architects who were directors of their own small practice. However, the response rate was low but this may be reflected in the relatively short time that the survey was available in June 2016. All of the respondents were in private practice. The majority of the respondents were small practices with 32% of respondents being sole practitioners and 38% responding practices that were 2-5 staff. In answer to the question how long has your current practice been established 44% responded that they had been in practice for more than 20 years. 27% had been in practice for more than 10 years. Only 9% of respondents were responding from a practice that was less than 5 years old.

4. Results and discussion

Overall respondents offered the full range of architectural services with an emphasis on design services. Respondents were asked what services they normally provided and the majority of practices stated they provided Schematic Design (100%) services along with Design Development, Fewer practices offered feasibility (82%) or town planning services (65%). Most practices (69%) stated that they typically provided full services on any given project and 75% of practices argued that they charged a full fee on projects. Respondents stated that full fee for service projects constituted about 60% of their work as compared to partial services.

Architects responded that they outsourced services in order to account for resource efficiencies in their firms but respondents rarely, if ever, outsourced design services. However, occasional outsourcing was a feature of the way that respondent practices operated. Only 25% of practices responded that they outsourced on a regular basis. Nonetheless, practices were more likely to outsource Construction Documentation (58%) rather than Design Services. 25% of practices responded that they outsource work on a regular basis and almost would do so in the future (58%). Many of these services are outsourced to other practices or architects (43%) rather than specialist knowledge competitors. However, the predominant competitor to which architects reported outsourcing services to was Town Planners services (44%) and in this was presumably in order to take advantage of expertise they did not have. This was reaffirmed in open text response to the question “to whom do you outsource services to” in which many of the architects (37%) who responded stated that outsourced work to specialist consultant’s especially urban planners and other related professional consultants such as town planning, and heritage experts.
Specialist services were a key component of the service offering of many practices with 85% of practices reported to have specialisations. However, these specialisations appeared to be based in, and reliant on, traditional architectural knowledge and expertise. Expertise in housing was a predominant response. The largest being in the area of bespoke housing (25 respondents), education (19 respondents) and interiors (15 respondents) and community buildings. As seen in Table 1. Specializations within the practice respondents covered a range of areas. Many of these areas such as accessibility, ESD, health, planning, retail, Sport and recreation, Transport and Urban Design were ranked low. No respondent architects offered highly specialized services such as seemingly scientific advice on materials or construction technology advice or consulting services or project management services.

Table 1: What is your area of specialisation? (please select all that apply)

<table>
<thead>
<tr>
<th>Specialisation</th>
<th>% of total respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Housing - bespoke</td>
<td>46.3</td>
</tr>
<tr>
<td>Education</td>
<td>35.2</td>
</tr>
<tr>
<td>Interiors</td>
<td>27.8</td>
</tr>
<tr>
<td>Housing – single dwelling/duplex</td>
<td>24.1</td>
</tr>
<tr>
<td>Community (e.g. public building such as community centres, public facilities)</td>
<td>24.1</td>
</tr>
<tr>
<td>Sport and recreation</td>
<td>18.5</td>
</tr>
<tr>
<td>ESD</td>
<td>14.8</td>
</tr>
<tr>
<td>Housing – medium density</td>
<td>13.0</td>
</tr>
<tr>
<td>Housing – high density</td>
<td>13.0</td>
</tr>
<tr>
<td>Accessibility</td>
<td>13.0</td>
</tr>
<tr>
<td>Housing – special needs</td>
<td>9.3</td>
</tr>
<tr>
<td>Hospitality</td>
<td>9.3</td>
</tr>
<tr>
<td>Planning</td>
<td>9.3</td>
</tr>
<tr>
<td>Health</td>
<td>9.3</td>
</tr>
<tr>
<td>Urban Design</td>
<td>7.4</td>
</tr>
<tr>
<td>Housing - public</td>
<td>5.6</td>
</tr>
<tr>
<td>Humanitarian</td>
<td>5.6</td>
</tr>
<tr>
<td>Retail</td>
<td>3.7</td>
</tr>
<tr>
<td>Transport</td>
<td>3.7</td>
</tr>
</tbody>
</table>

The above responses appear to paint a picture of a profession that is agile in regards to outsourcing and also secure in the knowledge that there is still a full fee for service market. However, over time in practice, many of the architects responded that there had been either high levels or very high levels of change in relation to: the architect’s role (51%), their position in the hierarchy of power in a building project (41%), and demands for specialist expertise (41%). They also reported that architects controlled less power over building projects than in the past (42%) and that there was more competition for specialist services (52%). 60% of respondents reported that within their specialist area they competed with other specialists. This is perhaps why many respondents felt that there has either a high level of change or a very high level of change in the replication and delivery of other architectural services by other consultants (40%).

As one respondent stated:
As the focus of my current business (for the last 8 years) has been primarily large new houses I have been able to offer a 'traditional' architectural service on percentage-based fees. This market is being eroded by 'project builders' employing in-house 'architects'. I am able to make this work financially as I keep a tight rein on the design and documentation of projects. I do all of this work myself and outsource on a project by project basis to reliable drafts people to electronically reproduce my own hand drawn detailing. Previously I was working on multiple dwellings and mixed use buildings. That market is highly competitive and the fees were not sustainable and the liability was enormous. The role and respect for architects in those areas has dramatically reduced over the last 15 to 20 years.

Another respondent stated:

We see that conventional Architectural Services are not going to be sustainable in the future and are looking at other services and models of practice to survive.

These above statements point to why many architects (41%) responded that the fees they charged for traditional or partial services were not sustainable. Yet, in contrast only 18% of architects felt that the fees they charged for specialist services were not sustainable and 70% of respondents felt that the fees for specialist services were more sustainable. This may be because 30% of the architects were predominantly charging fixed fees for traditional services such as design, design development and contract documentation.

In terms of fees most architects appeared to charge a combination of either fixed fees (29%) or fixed fees with hourly rates for variations (37%) rather than fees based on a percentage of work. Fees charged on the basis of a percentage of the cost of works varied more and were reported to be: 22% for Schematic Design, 29% for Design development and 33% for Contract Documentation. This raises the spectre of fee competition is a key driver of why architects think that the fees they charge for the traditional services of sketch design, design development, contract documentation and contract administration were not sustainable. As one respondent proclaimed:

Specialist Services, sadly, are a precursor to the shame of an industry being eroded by the increasingly acceptable practice of piecemeal delivery; where each element that is considered and delivered in isolation simply contributes further to the deteriorating quality of our built environment.

Whilst respondents in the survey felt that fees for specialist services were more sustainable very few architects appeared to have strategies or programs in place in order to Many architects believed that the development of specialist services within their firms had been as a result of informal practical research and random development (43%) rather than the result of ongoing professional development strategies and planned structural redevelopment (13%). 30% of respondents stated that they thought it was not worth developing new specialisations at present.
5. Conclusion

This suggests that for architects the primary basis, for the formation, generation and application of knowledge is through design itself as compared to applying forming and applying knowledge through other consulting or through the application of expertise and “scientific” knowledge. By and large architects are struggling to deliver traditional services in a sustainable fashion. Architects see the need to go “upstream” as a more sustainable way to support the profession. But, at the moment this is not reflected in firm strategies that seek to develop new knowledge and new areas of specialization through research and development or innovation. For the most part architects see their areas of specialisation and disciplinary knowledge as being embedded in their traditional service offerings. This approach is best exemplified in the area of housing. At some point architects must expand their capacity to develop new specialised services based on scientific knowledge and innovation rather simply seeing specialised services as the particular building type that they as architects focus on.

References


Liveability in the Gold Coast: neighbourhood as social practice

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Abstract: This paper presents initial findings of a study on what constitutes liveability for two neighbourhoods in Gold Coast, Queensland. The study approaches neighbourhood as a social construct or practice, deriving meanings residents have about their neighbourhoods. The analysis of responses to a semi-structured interview reveal 22 dimensions of neighbourhood classified into four major themes: personal, physical, social and political. The results demonstrate the multidimensionality of the idea of “neighbourhood” from the residents’ point of view, and indicate how the social dimensions play a crucial role in determining neighbourhood satisfaction and liveability.

Keywords: Neighbourhood; liveability; Gold Coast.

1. Introduction
Attaining social sustainability and its sub-component, liveability, have been the latest challenge in improving sustainable development among urban theorists and practitioners. Frameworks and criteria have been developed in pursuit of these goals. However, a number of existing frameworks have been found to be wanting in relevance and/or practicability, especially at the neighbourhood level. As such, there remains a disparity between what experts & professionals deem as liveable and what people hold as a good place to live. This study is an attempt to derive liveability indicators from residents’ views on what constitutes a liveable neighbourhood. This paper focuses on the initial results of a study of two neighbourhoods in the City of Gold Coast, Queensland.

2. Background and objective
In clarifying the concept of "social sustainability", various definitions were examined to arrive at the working definition: A process of meeting the needs of a society in consonance with that society’s desired quality of life, through succeeding generations (Bramley, Dempsey, Power, Brown, & Watkins, 2009; Colantonio & Dixon, 2010; Littig & Griebler, 2005; Spangenberg, 2010 and Smith & Metcalfe, 2014). The concept of "liveability", on the other hand, is often related to quality of life factors (Aranoff, Clark, Lavine, & Suteethorn, 2013; Commonwealth of Australia, 2012). Although the concept of liveability...
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connotes present concern for habitation and survival, Ruth & Franklin (2014) bring its definition closer to the concept of sustainability, where liveability has two elements: (1) the fulfillment of human needs and aspirations, and (2) the quality of the built and natural environment supporting the intended population (p.18). How liveability translates to the built environment, particularly the neighbourhood, has become the latest concern of the building professions.

The terms "community" and "neighbourhood" are often used interchangeably in the literature on social sustainability (Martin, 2003; Peters, 2010; Wimberly & Haught, 2009). However, Barton, Grant, & Guise, (2010) provide a clear differentiation: neighbourhood is about place while community is about people (p.31). The importance of neighbourhood in attaining desired individual outcomes has been proven by Ellen & Turner, (1997) and by Humber & Soomet, (2006). The idea that neighbourhood is the appropriate scale for achieving social sustainability has been proposed by Barton et al., (2010); Dixon & Woodcraft (2013); Fraker (2013); Sharifi & Murayama, (2014).

Sustainability at the neighbourhood scale has become a contentious issue of measurement. Studies on various neighbourhood sustainability assessment (NSA) tools have shown that: (1) neighbourhood sustainability is contextual, and may not be global (Sharifi & Murayama, 2013); (2) NSAs are reliant on technology as drivers of sustainability (Fraker, 2013); and (3) NSA tools are mostly applied at the beginning of a development, revealing the motivation to sell "sustainability" as a brand (Berardi, 2013), or to qualify for government subsidies (Sullivan, Ridin, & Buchanan, 2014). Sustainability at the neighbourhood scale has also been strongly linked with liveability, as related by Aranoff et al., (2013) in their evaluation of the LEED-Neighbourhood Development criteria. Their study revealed a gap between what people deem satisfying and liveable, and what experts deem as a liveable neighbourhood. (Aranoff et al., 2013).

The commitment to attain sustainability necessitates the development of indicators and ratings to track policy implementation. However, current indicators use a myriad of complex aspects such that they miss the target in representing the essence of sustainability. As Scerri & James, (2010) succinctly point out: "Emphasis on indicators per se tends to privilege technique over reflexively engaging people in the job of creating and reproducing a sustainable community over time." (p.42).

It is thus the objective of this paper to demonstrate how neighbourhood liveability indicators may be improved through this reflexive engagement of communities and framing the liveability problem contextually.

3. Framework and methodology

3.1. Conceptual framework

Portraying neighbourhood liveability starts with Spaargaren’s Social Practices model (Spaargaren, 2003) where residents’ perceived needs and aspirations are articulated into the relevant indicators. The Four Perspectives on Life of Capra & Luisi (2014) introduces “meaning” as mediator for the social domain. The study of Del Castillo & Corpuz-Mendoza, (2010), show that neighbourhood may actually be viewed through the lens of "self", where people’s meanings are derived from perceptions of the built environment and what they expect from it. These meanings may then be taken as the needs and quality of life (QoL) people aspire for.

The conceptual framework used in this study combines the three aforementioned frameworks in Figure 1 below. The framework provides an opportunity to frame the liveability problem contextually.
Neighbourhood is analyzed here as a social construct, where meanings ascribed by residents to their neighbourhood are mediated by their individual perceptions of their environment. The framework also identifies how neighbourhood meanings may be derived and analyzed.

3.2. Methodology and limitations

In order to see if neighbourhood design affects liveability, the two study areas selected for the Gold Coast are from an old neighbourhood and a relatively new one. The old neighbourhood in Southport is the oldest settlement, established in 1875 (City of Gold Coast, 2015). The new neighbourhood is in Varsity Lakes, a private development, established in 2002 (City of Gold Coast, 2015). Socially, Southport has a lower median household income than Varsity Lakes (Australian Bureau of Statistics, 2011). Both study areas: (1) are inland residential areas, not along the coast line; (2) have a mix of housing typologies to ensure diversity in socioeconomic levels; (3) immediately adjacent to community facilities, such as parks, education and commercial buildings; (4) are bounded by natural landscape formations; (5) have an area of around 50 hectares, which corresponds to a walking distance radius of 400 meters, or an easy 5-minute walk (Barton, Grant, & Guise, 2010).

3.2.1 Sampling scheme and selection criteria

The study area in Southport has a 2011 population of 3,071; while that in Varsity Lakes has 2,140 (Australian Bureau of Statistics, 2011) Twenty-one (21) residents per neighbourhood were chosen to attain a survey confidence level of 95%. Cluster sampling was done to get a geographic representation of each study area. Respondents had to be residents of the study area for at least a year, and should be at least 22 years old, in keeping with the Australian government definition of minimum age of independence (Department of Human Services, Australia, 2015).

3.2.2 Instruments and variables

A semi-structured interview was used following the questionnaire protocol in "The meaning of houses" study (Del Castillo & Corpuz-Mendoza, 2010). The protocol has five basic questions and a rating scale. (1) Describe your neighbourhood, is asked to derive non-evaluative descriptions about neighbourhood; (2) What do you like about your neighbourhood, and (3) What don't you like about your neighbourhood, are meant to derive evaluative judgments about their existing neighbourhood; (4) Describe your ideal
neighbourhood, and (5) Describe the neighbourhood you don't want to live in, are meant to derive evaluative judgments on an ideal plane; and (6) Rate your experience living here (using a 5-point Likert scale), is meant to gauge residents' degree of satisfaction with their neighbourhood. The questions are deliberately open-ended so that the broadest possible range of descriptions and evaluations about their neighbourhoods can be elicited. The use of face-to-face interviews was deemed the best way to derive information as it offers complete control and compliance with the questionnaire; ensures legitimacy of the respondent as participant; and allows for the researcher to probe and clarify answers (Neuman, 2011).

3.2.3. Analysis

Interview responses went through a three-step coding process. Answers were first condensed into preliminary analytic categories; organized into key categories; and lastly, matched or linked with existing categories found in the existing theories or frameworks. The physical survey of the study areas was compared with respondents' answers to identify relationships. This paper will only focus on the initial comparative analysis between residents' neighbourhood meanings and their places.

4. Results and discussion

4.1. Profile of respondents

The Southport study area had 10 male and 11 female respondents, while the Varsity Lakes study area had 9 males and 12 females. Two-thirds of respondents in Varsity Lakes live in single-detached houses, while 62% of respondents in Southport live in medium to high density housing units. This is reflective of the overall statistics for both suburbs where the dominant dwelling structures are high-density dwellings for Southport, and single-detached houses for Varsity Lakes (Australian Bureau of Statistics, 2011). The average years lived in their neighbourhood is 9.1 for Southport, and 4.3 for Varsity Lakes.

The average household size of Southport respondents is 2.20, while that of Varsity Lakes respondents is 3.30. Among Southport respondent households, only 19% have school-aged children (5-19 yrs old); while those in Varsity Lakes, 43% of households have school-aged children. These figures also echo the overall statistics for both suburbs (ABS, 2011).

As far as mobility is concerned, Varsity Lakes respondents report more vehicles per household with an average of 2.10, while Southport respondents' households average only 1.50. Multi-modal travel is markedly more in Southport, where 10 respondents engage in more than one mode of travel in everyday life (private vehicle, public transport, push bike and walking). In Varsity Lakes, only one respondent reported using public and private means of transport, and the rest used only their cars.

4.2. Dimensions of neighbourhood

The interviews for both study areas yielded a total of 620 statements (Southport: 308; Varsity Lakes: 312), culled from the responses to the five basic questions. These statements were sorted and classified into 22 dimensions, which in turn fall into 4 themes. The dimensions are defined in Table 1 below. The personal theme deals with general impressions and memories of a respondent about their place. The physical theme covers dimensions about the physical setting. The social theme pertains to lifestyles and relationships with other people. And the political theme deals with issues that are affected by governance such as traffic, crime, drugs, rent control and other economic issues.
Table 1: Themes and dimensions of neighbourhood

<table>
<thead>
<tr>
<th>THEME</th>
<th>DIMENSION</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>PERSONAL</td>
<td>Feelings</td>
<td>Expressions of feelings or evaluations about their neighbourhood, or a particular place. Examples: <em>good, enjoyable, happy, nice, beautiful, lovely, cozy</em></td>
</tr>
<tr>
<td></td>
<td>Memory</td>
<td>The area's history, such as changes that have occurred, or significant events.</td>
</tr>
<tr>
<td>PHYSICAL</td>
<td>Accessibility</td>
<td>Accessibility of their place to places of work, school, shops and amenities. Examples: <em>convenient, convenient place, handy, close to shops, etc.</em></td>
</tr>
<tr>
<td></td>
<td>Built features</td>
<td>Pertaining to the built features of their place, from buildings to roads, including the quality and type of built facilities. Examples: <em>new buildings, suburban, compact, built-up, one-way street, parking</em></td>
</tr>
<tr>
<td></td>
<td>Crowding</td>
<td>Perceptions of how crowded or cramped their place is.</td>
</tr>
<tr>
<td></td>
<td>House and lot</td>
<td>Features of their own house and/or lot.</td>
</tr>
<tr>
<td></td>
<td>Leisure</td>
<td>Leisure activities done by the respondent in the area.</td>
</tr>
<tr>
<td></td>
<td>Natural features</td>
<td>The natural features of their place from flora and fauna, to bodies of water, and parks.</td>
</tr>
<tr>
<td></td>
<td>Tenure</td>
<td>Comments regarding residential tenure.</td>
</tr>
<tr>
<td></td>
<td>Walkability</td>
<td>Comments on how they walk to and from destinations in the neighbourhood.</td>
</tr>
<tr>
<td>SOCIAL</td>
<td>Friendliness / Harmony</td>
<td>A general assessment of the residents of the neighbourhood, not just about specific neighbours, as being friendly or amiable.</td>
</tr>
<tr>
<td></td>
<td>Lifestyle</td>
<td>Perceived lifestyle of people in the area. Examples: <em>busy, fast-paced, easy going</em></td>
</tr>
<tr>
<td></td>
<td>Neighbours</td>
<td>Description of who lived in their place, including socio-economic statuses, ages, tenure type, transients, as well as nationalities or ethnicities.</td>
</tr>
<tr>
<td></td>
<td>Neighbours' behavior</td>
<td>Comments about their neighbours' behavior from descriptive to evaluative reports. Examples: <em>good neighbours, quiet neighbors, nice &amp; tight-knit, nice people, feral, on drugs, a lot of violence</em></td>
</tr>
<tr>
<td></td>
<td>Peaceful</td>
<td>Description of their place as “peaceful” and/or “calm”, or to the absence of strife.</td>
</tr>
<tr>
<td></td>
<td>Pedestrians</td>
<td>Pedestrian traffic on the street.</td>
</tr>
<tr>
<td></td>
<td>Quiet / Noisy</td>
<td>Auditory description of their place: how quiet or noisy their place is.</td>
</tr>
<tr>
<td>POLITICAL</td>
<td>Council / organization</td>
<td>Comments on city council, body corporate or neighbourhood organization, including decisions or policies.</td>
</tr>
<tr>
<td></td>
<td>Crime &amp; drugs</td>
<td>Perception of crime in the area, usually associated with drug and substance abuse.</td>
</tr>
<tr>
<td></td>
<td>Economics</td>
<td>Comments on economic conditions, availability of jobs and business opportunities in the area; as well as rental rates.</td>
</tr>
<tr>
<td></td>
<td>Safety</td>
<td>Assessments of how safe they feel in their neighbourhood.</td>
</tr>
<tr>
<td></td>
<td>Traffic</td>
<td>Vehicular traffic in their area.</td>
</tr>
</tbody>
</table>
Figure 2 below shows the spread of dimensions of neighbourhood descriptions for each neighbourhood. The frequency patterns of the dimensions exhibit a pattern of salience. Although the frequency values differ between neighbourhoods, the dimensions' ranks are almost all the same. For the Physical Theme, built features, accessibility and natural features are the most mentioned aspects. For the Social Theme, the top dimensions are: neighbours' behavior, quiet/noisy, neighbours, friendliness and peaceful/calm. In the Physical Theme, both Southport and Varsity Lakes respondents describe their neighbourhood in terms of its built features (e.g., buildings, road conditions, etc.) and its accessibility to the places they frequent.

Grouped into neighbourhood themes (Figure 3 below) the respondents' perception of neighbourhood is dominated by the Social Theme, with the Physical Theme taking only secondary salience in their estimation of their neighbourhoods. Bear in mind that the statements are responses to open-ended questions, meaning, respondents were free to define what they understood to be their neighbourhood, and to describe it in their own terms. Figures 2 & 3 not only point to the multidimensional idea of "neighbourhood", but also how the social dimensions are important aspects of this idea.
4.3 Evaluations of neighbourhood

The evaluations of neighbourhood are gleaned from respondents' answers to what they like and what they do not like about their neighbourhood; and how they rate their satisfaction living in it (with a 5-point Likert scale). The respondents' descriptions of their ideal and un-ideal (or problem) neighbourhood reveal the conceptual valuations of neighbourhood.

The average neighbourhood satisfaction for Southport respondents is 4.02, while those in Varsity Lakes have an average of 4.24. Among the Southport respondents, 7 (one-third) considered their neighbourhood to be their ideal. While in Varsity Lakes, 14 (two-thirds) considered theirs to be ideal. The average neighbourhood satisfaction of those who consider their neighbourhood to be ideal is 4.52, while the other group has an average of 3.95. Combining the responses of those who consider their neighbourhood ideal (Figure 4) and comparing them with the responses of those who do not consider theirs to be ideal (Figure 5), give us a further enhanced picture of what residents value about their neighbourhoods.

It has to be reiterated that Figures 4 & 5 depict responses of two groups classified by their ideal neighbourhoods and not by geography. The patterns of the themes across neighbourhood evaluations for the two groups are very similar, hinting at a common set of values for neighbourhoods. While the responses for "Dislikes" and "Ideal" are considerably less for the group who already live in their ideal neighbourhood, the pattern of values remain the same.

The physical dimensions of neighbourhood are of primary importance to both groups, and the dimensions often mentioned are: (1) how accessible it is to places of work, school and leisure; (2) the natural features of a neighbourhood; (3) the preference for walking and (4) pleasing built features. The social dimensions are considerably higher in frequency in the group that does not consider their neighbourhoods to be ideal. Of particular interest to both groups are: (1) who they would be living with – their neighbours; (2) the behaviors of these neighbours in consideration of their preference for (3) a quiet environment and (4) a peaceful, harmonious co-existence with their neighbours.

The presence of illegal drugs users and high crime incidence (under political theme) is also a prominent consideration for both groups when they talk about what they do not like about their
neighbourhoods and the neighbourhoods they do not want to live in. These dimensions can be closely tied to the social dimensions of undesirable neighbours and behaviors in their depictions of their Problem neighbourhood (Figures 4 & 5).

The spike in frequencies of the Social and Political themes of their Problem neighbourhood and aspects they dislike in their neighbourhood is intriguing, particularly in the group that does not see theirs as an ideal neighbourhood (Figure 5). Comparing Figures 4 & 5 with the geographic-based evaluations in Figures 6 & 7 below, reveal an interesting pattern of response frequencies.

Varsity Lakes responses (Fig. 7) show a fairly similar pattern with Figure 4. This is so because the group in Figure 4 is dominated by Varsity Lakes residents. However, this cannot be said for Figures 5 & 6, even if the group in Figure 5 is dominated by Southport respondents. In both Figures, the Social and Political themes are relatively high in the Disliked aspects of neighbourhood, and the average neighbourhood satisfaction ratings are 3.95 (for the group in Figure 5) and 4.02 (for Southport respondents, Fig. 6). In Varsity Lakes, despite respondents having high frequencies of disliked physical aspects of their neighbourhood (narrow roads), two-thirds of them deem their neighbourhood to be ideal, and overall, their neighbourhood satisfaction rating is above satisfactory (4.24 out of 5). Southport may boast of better accessibility, mobility and leisure options than Varsity Lakes. However, only a third of the respondents view it as an ideal place to live in on account of the perception of crime, illegal drugs and unsavory characters within their vicinity. This seems to indicate that the social and political dimensions are what affect neighbourhood dissatisfaction.

5. Conclusion and recommendations

This paper proposed to frame the liveability question for Gold Coast from the residents' perspective. Although the results shown here are but part of a bigger study that includes comparing people's evaluations of their neighbourhood with their actual physical and socio-political processes, the results allow a preliminary working explanation of what constitutes liveability for residents of Southport and Varsity Lakes in Gold Coast City. Foremost is that neighbourhood is perceived multi-dimensionally. The dimensions of neighbourhood fall into four themes – Personal, composed of feelings and memories about the neighbourhood; Physical, comprised of the sizes and qualities of the built and natural features; Social, where the perception of other people and effects of their behaviours fall in; and Political, where
the dimensions related to neighbourhood governance are concerned. Secondly, the Social aspects of neighbourhood life have to be highlighted as a co-equal factor of neighbourhood liveability, and not just as an effect of the built environment. Who and how people live and share their neighbourhood space with are outside the usual domain of architectural and urban design, yet are crucial aspects of liveability as these dimensions seem to significantly affect dissatisfaction in neighbourhoods.

The results also find affinity with the findings of Bonauito, Fornara, & Bonnes, (2003) and Howley, Scott, & Redmond, (2009) where their studies in Rome and Ireland, respectively, uncover multidimensional aspects of neighbourhood and how these relate to neighbourhood satisfaction.

The bigger study to which this paper belongs will compare and analyse the derived dimensions of neighbourhood with the physical and political conditions of the neighbourhood. The study will also be replicated for neighbourhoods in Wellington, New Zealand and Quezon City, Philippines to contextualize liveability in different cultural and climatic conditions. These preliminary results, however, already suggest a number of trajectories such as: (1) a more in-depth, statistical investigation of the dimensions derived here and how they correlate with neighbourhood satisfaction; (2) how neighbourly interaction may be encouraged or improved through urban design; (3) social homogeneity and neighbourhood satisfaction; (4) liveable urban environments and change.

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References


The UNESCO Chair: Australasia architecture studio at Mantua

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Abstract: A UNESCO Chair is a long-term program, set up in accordance with a resolution adopted by the General Conference of UNESCO in 1992, for educational and research activities at international level. The UNESCO Chair program pursues the strategic objective of fostering the creation of new educational programs, generating innovation in the areas of design, scientific research and facilitating exchanges between Universities on specific themes. For the UNESCO Chair in Mantua (Mantova), the severe financial crises that have recently hit western economies reinforce calls for rethinking of strategies for territorial development. With this in mind, knowledge and cultural heritage take on a central role in facilitating economic development and recovery. The Australasia Architecture Studio at Mantua delivers both, traditional and emerging approaches to architectural training. Adding to a traditional design practice this postgraduate master studio investigates architectural programming, briefing of institutional clients and management techniques including (1) value management, (2) stakeholder management, (3) building information modelling and (4) reflective practice. Six projects from the Master’s program are used to provide insights on the value of applying the above methods and techniques for educational and real-world significance, together with implications for, and applications to, the practice of architecture.

Keywords: Architecture Practice; Design Brief; Value Creation; Stakeholder Management

1. The UNESCO Chair at Mantua

The Master of Architecture and Urban Preservation at Politecnico di Milano in Italy sits within the UNESCO Chair for educational, research and scientific enquiry to maintain, preserve and regenerate world heritage sites including the repurposing of listed buildings and structures with cultural significance. Integrated design studios and lectures cover topics and workshops ranging from international policy to emerging digital design tools and technologies, in the context of architecture and heritage preservation. The studios aim to vertically integrate strategic management, together with tactical and technical approaches, to the design and management of heritage sites. Each studio is formed of postgraduate students and professional architects aiming to tackle real-world problems.

The studio provides the unique advantage of engaging with research students, academics and practicing architects from across the globe, thus providing case studies, examples and insights. The studio starts with a foundation section on cultural and natural heritage legislation including:
1. Definitions of Cultural and Natural Heritage
2. National, international and European law concerning cultural heritage;
3. Cultural heritage conventions and other instruments: in particular, the 1972 UNESCO (Colombo, 2013).

The teaching curriculum also introduces project management (PM) techniques with a particular focus on dealing with heritage and project life-cycle, innovation and economic appraisal. One aim is to achieve value for money (VfM) expectations (McCully 2014). The Australasia studio presents case examples for students to identify and discuss issues in complex financing and procurement systems in the context of heritage, economic appraisal and procurement of projects in the built environment (Aranda-Mena et.al, 2013).

Once policy and theoretical foundations are established, examples are provided including the protection of heritage at urban and landscape level. Case studies including protection and promotion of landscape heritage are presented and discussed in the context of the 2000 European Landscape Convention including the case of Florence in which the actual landscape (and “cityscape”) of the old and new city including neighbouring suburbs are protected from uncontrolled urban spraw development and inappropriate building forms and heights (Duxbury 2012; Pereira, 2014). Italian case studies are often starkly contrasted with Australian cases in Melbourne, Sydney and Brisbane, where little or no consideration is given to the preservation of the cityscape and examples are provided where greed seemingly takes over the heritage and protection agenda. Cases in which the character of the city might be under threat are of particular interest to the studio, as sensibilities go beyond a specific site or building and escalate into the urban realm (Aranda-Mena 2014; Robson 2014; Outhred 2014).

As a second stage in a studio, an architectural challenge, including design competitions with a heritage component, is presented to the studio by entering into a call for Expressions of Interest (EOIs). The process of thinking about architectural competitions is explained, using Skype communication technology to the class by Silbergerger (2012) and Volker (2010). Generally projects with heritage, cultural and social interest are of particular interest as they usually need a careful evaluation and tactful consideration on the trade-off between heritage protection and new building works. The second stage includes worked examples of adaptation such as modifying a place to suit proposed compatible uses; and maintenance as the continuous protective care of the building fabric, as distinct from repair involving restoration or reconstruction as to what might make an old structure gain new life. Careful consideration is also established if building intervention is necessarily (Smith et.al, 2011).

In the third stage, after having established ‘what is heritage’ and relating it to project identification, an introduction to project management and the tools for project delivery are presented including (1) planning, (2) design and (3) project operations/lifecycle adopting a project-based approach in order to develop a design proposal for a real-world case intervention. The competition entry or architectural brief for the project assignment is either directly adopted from a government call for EOIs or from an international design competition. This ensures that genuine real-world contexts are experienced by studio participants.

Six studio examples are described here; comprising three Masters design studios and three Masters theses projects:

- Karosta, Latvia (2014): integrating urban mobility and heritage in the War-Port City of Karosta.
- St Kilda & Palais (2015): intervention to the Palais Theatre and development proposal for the adjacent St Kilda triangle site, Melbourne, Australia.
- Lambrate, Milano: Urban intervention and regeneration project in Milano Lambrate (Kuzilenkova 2016).
- Poznan and Verona: an investigation of alternative approaches to architecture and heritage conservation in Poland and Italy (Stevanella, 2016).
- Japan-Italy: an investigation of alternative approaches to architecture and heritage conservation (Auber 2016).

All of the above follow under a principle of sustainable urban development and although all six projects are about built-form they also with notions of non-tangible heritage. Pereira, A (2013) discusses the need to increase domain knowledge exchange and procedural transparency as well as enhancing the quality of decision-making in planning processes towards sustainable development of WH cities. The UNESCO Chair at Mantua presents the opportunity to bring together the right audience with the right learning context. In doing this, well-established definitions of cultural significance such as aesthetic, historic, scientific and social “values” are discussed. Architecture and planning projects and field studies across five continents are presented and explored (Aranda-Mena 2010). This also brings into play the acquisition of skills in academic research using a wide range of field and empirical data. The case projects and case studies are presented in a provocative way such that research students see and learn about using sources of information, both quantitative and qualitative; including documentary evidence, government reports, photographs, maps, published material, paintings, sketches and word of mouth testimony (UNESCO, 2012). The following section describes the reflective practice technique which is used as pedagogy to consolidating lessons learnt, thus knowledge (Mann et. al, 2009).

2. Innovation: new techniques into practice

A number of projects have been set up in Melbourne in which the UNESCO Masters students can participate. Each project goes through a full briefing and presents lecture notes on the schematic and documentation stages of the project. Design activities take place after the foundation course on Preservation Law and Management/Project Appraisal modules are delivered. Aspects of adopting management and BIM modelling techniques are considered in a less prescriptive way to that proposed by Legris (2016) but as natural (nearly optional) part of the studio. The action part of the studio takes place over two intensive weeks. It is so intense that end of the studio a ‘reflective practice’ exercise important and much appreciated to have clarity on both the proposal itself and lessons learnt. For this students are required to go back to day one of the action studio when preliminary information and the project brief were discussed. Also, there is a smaller component to the reflective practice on a daily basis when at the end of each full-day students are requested to reflect on 5 keywords learnt on the day and to write an report as part of a shared wiki discussion. At the end of semester there is also a discussion on lessons learnt and reflective practice after they have presented their projects in the form of an Government call for expressions of interest (EOIs).EOIs would have to carefully consider client’s requirements, external requirements, requirements for retention of significance and the actual physical condition. An initial brief/report is submitted on day one of the workshops including an (1) explanation of basis of assessment, (2) general summary of significance, (3) significance of individual or discretionary components from landscape (or cityscape) to architectural elements and building parts and, (4) the more recent drive to catalogue and protect the non-tangible heritage which often takes the form of activities such as a wet-market (aka as farmers market) or traditions, such as the “Speakers Corner” in
London or Hoi An’s fish and wet market square in Vietnam, where the empty spaces and the activities that happen in them are what is to be protected (O’Keefe and Prott 2011).

The following section briefly describes each of the studios with the intent to provide not just, useful information but also insights and experiences from the class.

2.1. Karosta: Urban Mobility and Revitalisation and Identity

Karosta, Liepaja, Latvia presents a unique, challenging and exciting set of attributes that attracted the studio to enter to this competition. The proposal concerns the methods of achieving practical and ethical results via participatory design and collective action. The Value Management workshop established strategic and economical solutions for Karosta’s urban renewal while carefully considering the local sustainability, the arts and the local societal values and anti-Soviet sentiment. As a primary objective the aim was to increase the sense of identity and belonging by improving streetscape and public infrastructure in particular public transportation. The final proposal provides design solutions for street furniture, playgrounds, benches, information kiosks, signage, performance stages, art installations and in particular a system for bus-stops/shelters.

Six teams worked on the competition entry, totalling 18 architecture graduates from various national and cultural background presenting a case to exercising Minsk (1990) process model for cultural integration and Hofstede’s (2010) model of management and cultural dimensions. Each team developed urban responses to connect three disjointed sections of Karosta’s including the old Heritage town, the Water Front and residential areas, in particular derelict zones. For this a system of bus routes, bus-stops, signage, information kiosks and shelters were of particular attention to the studio. The Value Management workshop assisted in establishing and prioritising objectives.

The resulting proposal aims at re-vitalising a run-down residential zone by reconnecting it with is past including the cathedral, the old water tower, and an old riveted iron-bridge. Although Karosta attracts many tourists to visit such sites, the current local residents are disengaged with the heritage cultural side of the town because of negative connotations with Soviet occupation. The master challenge with the project was to bringing a new life as to refashion the Soviet housing blocks. In the first half of the intensive, a two-week studio undertook strategic planning and design exercises and workshops starting with the value management, stakeholder and project management (IPMA 2011). BIM modelling sessions began during the second half / week of the workshop. The resulting project outcomes proposed a bus-stop system and a strategically planned route around key points across the old and the new parts of Karosta. The design was presented via a crit and the proposal was submitted to an international competition.

2.2. The Palais Theatre and the St Kilda Triangle

A second Mantua Australasia Architecture Studio aimed to create a development proposal for a highly politicised site in a bay-side suburb of Melbourne, Australia. The site is known as the St Kilda “Triangle” which adjoins (but separated from it by a divided highway) the waterfront of Port Philip Bay in the suburb of St Kilda, south of Melbourne’s Central Business District. The brief to the assignment requested teams of four students to provide concept designs for a development proposal in the form of an Expression of Interest (EOI). A key issue is the sensitivity of the site, listed as Crown Land and as such can only be leased to a private developer for up to 99-years. For the same reason the site is perceived by the local residents as public rather than private and therefore the resulting development should first and foremost provide value to the community and local residents. Not surprisingly, most development
proposals actually submitted by developer-led architects have been rejected on these grounds. Since the studio took place a master plan has now been developed, approved and adopted by the responsible authority. The site is protected and explained using Kerr’s conservation guide (1985).

Just as in real-life, the Mantua studio approached the project with a collaborative mind-set in which teams undertook a close look to project stakeholders and governance mechanisms and applied the stakeholder circle technique (Bourne and Walker 2005; Bourne 2016). The studio concluded with a master plan, development strategies and recommendations for planning, advocacy and project staging.

Again, BIM and project visualisation and representation techniques such as ‘infographs’ (graphics displaying rich-data) were an important aspect of the studio. Much of the computer modelling took place during the second-half of the studio after a number of concepts were investigated and information and data collected. Architects teamed in groups of four to develop a planning, design and preservation proposal. The presentations at the crit had to incorporate the Value Management, Stakeholder management and Economic appraisal; all embedded in the architectural design presentations with summary diagrams.

2.3. National Gallery of Victoria: Aboriginal Arts Centre

Melbourne’s Central Business District has seen much transformation over recent years. Over 30 years a large part of the old city centre has become residential through the re-purposing of old office blocks and other commercial buildings. The success of this is due to a steering group set up to interpret regulations applicable to converting offices and warehouses into residential apartments. Currently, with the explosion of high-rise flat development in Melbourne CBD, and similar residential development in the adjoining former docklands area, the focus is being re-directed towards the arts, culture and conservation of heritage and listed buildings.

Teams of four students analysed the project from the four project perspectives project primary, secondary and desirable objectives via de value management sessions, secondly developed the stakeholder circle via de stakeholder management workshop (Missonier & Loufrani-Fedida 2014), BIM modelling and representation techniques for the design proposal and finally an life-cycle and economic appraisal. As with previous Mantua studios, a project briefing on a new Aboriginal Art Gallery and Cultural Centre for the NGV was introduced at the studio and followed by practical workshops including design-brief review, and project proposal development. At the early project stages, an in-depth study of the NGV as an institutional client was conducted, including a presentation put together by the NGV capital works operations manager. The resulting project submissions are well-balanced design proposals with strategic economic and lifecycle built into them including project management considerations for three dominant axes, the project, the process and the people involved. To redefine the project at two-staged Value Management workshop was conducted. To identify stakeholders and governance, the stakeholder circle proven to be an excellent method. Incorporating all into a project timeline, as to analysing whole-of-life-cycle including project appraisal and project operations.

2.4. Urban regeneration Lambrate, Milano

A social approach to urban regeneration in Milano, Lambrate. The project investigates a method for transforming a ghetto/derelict zone into a sustainable living community. As part of the experience of being in Manatova, the author of this paper agreed to supervise three Master Thesis. The first of them developed an urban regeneration proposal for Lambrate suburb zone, north of Milano. Lambrate originated as a Roman vicus as they conquered the area in 222BC and developed for agriculture and
navigation along the rivers Po and Lambro. After the WWII, the Innocenti machine factory began production of the famous Labretta motorcylce in Lambrate. The factory closed in 1996, six years after a takeover by Fiat and the factory facilities have been abandoned since. The site had become derelict and a meeting point for homeless people. The thesis proposal looks at various aspects to re-fashion the abandoned facilities as proposing a value generation scheme in which microbusiness and start-ups could take place. The scheme seeks sponsorship and financing from a number of private, public and NGOs. The urban design intervention also caters for adjacent surroundings providing leisure spaces and green areas including urban furnishing, lighting and signage. Measures to increasing safety and security concerns are also proposed (Kuzilenkova 2016). The overall result was very well received by the crit and supervisory panel.

2.5. Heritage Conservation: Poznan and Verona

Stevanella’s Thesis (2016) looked at the implementation of Heritage conservation policies at the Urban scale comparing the cities of Poznan in Poland with Verona in Italy. The topic of ‘delivering’ policy intent and governance management was central to his thesis. As part of the case study investigation Stavenella spent an academic semester in Poznan and the author himself resides in Verona. In this way he was able to collect field notes and relevant data and documentation to inform his comparative study. The resulting contribution of his thesis is a set of management tools and methods to effectively protect and deliver heritage projects. It was found that formal management tools and techniques are much needed for the protection of heritage. Guidance at various levels was established, from higher, policy visionary level, to managerial and to tactical/operative levels. Each level would need a level of leadership which is often lacking in government and planning departments. Capacity building in the private sector is also needed. Another contribution was the demonstration stakeholder analyses in specific the demonstration of conflicting values, agendas and project expectations. A gap analysis was created for each location which is to assist to solve differences and achieve a common vision, goal and objective. During the Laurea examination whit was put as a risk-management strategy.

2.6. Heritage Conservation: Japan and Italy

A third thesis project investigated approximations to architectural heritage by the public. Establishing a social value system and comparing it against two contrasting cultures and nations with different value systems. The resulting project highlighted that national culture and identity is a complex social construct in which highly heterogeneous groups co-exist. The appreciation and engagement with the past, including heritage architecture, by the millennia generation is a problem in both nations. Although inconclusive, the thesis opens up key questions of youth’s disengagement with history and lack of pride with the built environment, especially from two nations that traditionally take so much pride in their cultural heritage. Perhaps more than never we have a generation that is fully immersed in the digital world and would not be surprising as the millennia generation already see email accounts as a thing of the past (Auber 2016).

Each of the above projects or studios is then individually assessed via “Reflective Practice” (RP). RP is a generic term, which explains a method by which professionals engage to explore their projects, jobs and life-experiences in order to lead to a new understanding and appreciation. Reflection involves a number of skills (such as observation, self-awareness, critical thinking, self-evaluation and taking others’ perspectives) and has the intended outcome of integrating this understanding into future planning and goal setting (Mann et al., 2009). Different models of reflection described in the literature are usually
iterative (a particular experience triggers reflection and results in a new understanding or decision to act differently in the future); or vertical (describing depth of reflection), or some combination of both.

What is the evidence base for reflective practice? How do students engage in the process of reflection? In addressing the final question, four methods of facilitating reflection will be outlined: journal reflection, reflection on a critical incident, reflection following professional development, and reflection on a clinical encounter. As early as the 1930s, the educator Dewey stated ‘there can be no true growth by mere experience alone, but only by reflecting on experience’. However, it was only much later in the 1980s that reflective practice (RP) started to be widely discussed following Schön’s seminal work (Schön, 1983). There is now a growing body of literature supporting the importance of reflective practice (RP) across professional fields including architecture. The Mantua studio investigates the different ways in which students and practitioners can facilitate their own reflections in short, intensive sessions. Reflection on the Theses is over a longer period and it is even more effective time after graduation. Overall, the important aspect is to commit and allow adequate reflection time as a routine in such a way that becomes a habit of professional practice and for life-long learning.

4. Summary and discussion

To summarise the Mantua Architecture Studios and in particular the international aspect to it, the design experience and management and technological lessons and experiences have been incredibly well received by graduate architects, not only for bringing more digital tools into what is a traditional architecture program but to also bringing an emphasis on business and managerial methods, obviously, valorising at a higher level the sensibilities that architects need to rightly intervene heritage and the built form of our cities. The studios have been most appreciated for including aspects such as life-cycle thinking and value creation as for using BIM to demonstrate ways to forecast and improve building performance. Overall, BIM was found to be relevant beyond building shape, and to facilitate better understanding of stakeholder dynamics, life-cycle costing as to investigating building materials technologies and operations. Exercises with the stakeholder circle method has proving highly interesting, engaging and in interactive for not just for mapping out stakeholder dynamics and value using but to better understand the project process and risks associated with completing projects. The use of infographics in creative ways is an excellent way to introducing management techniques to designers a bi-product of the studio is the emergence of interesting way to visualise information by using architects’ own imagination and skillset.

The focus on developing reflective practice (RP) has been much supported across Melbourne’s RMIT University architecture and management programs since the 1990’s (E.g. Walker 2002) increasing reflective learning in both architecture and project management. During this time, the practices of architecture and construction and project management have become more complex and RP enables practitioners to clarify confusion and project problems which defy technical solution’ (Schön, 1987). Once in the workforce, a practitioner receiving appropriate supervision and professional support will continue to develop knowledge, skills and attitudes beyond entry-level first and then competencies leading into significant domain expertise (Mann et.al, 2009).

For instance, interesting reflections emerged on Australian versus European approaches to heritage and property development such as the tension between heritage protection and greedy development. This usually involves a compromise whereby the historical building façade, or a part of the building is retained and restored and a new high-rise building emerges, usually behind it.
A case study is provided by Robson (2014) in which historic Windsor Hotel in Spring Street, Melbourne, is presented as a developers proposal with the aim to replacing the 1960s renovation, now in disrepair, with a high-rise tower, but still retaining the original heritage building in Spring Street and stark difference with the recent Mayer shop project in Melbourne where only the façade was preserved. The proposal went before the Victorian Heritage Council and, despite strong community protests, the development has been approved. The original hotel was built during the Victorian Gold Rush boom in the 1880s. The proposal is to retain the original façade, to re-furbish the building interior to modern standards, and to construct a 25 level tower behind the heritage hotel. This type of compromise is very common for heritage developments in Australia.

Other reflective aspects of student experience included (1) explanation of basis of assessment, (2) general summary of significance, (3) significance of individual or discretionary components from landscape (or cityscape) to components, (4) the more recent drive to catalogue and protect the non-tangible heritage. Reflective feedback from studio participants includes:

• I enjoyed the engaging interaction. The course is very well organised - every day we had a clear idea what is expected from us as to what to do. Very interesting lectures and case studies on relevant subjects. Intensive, as we had to learn a lot in a short period of time. It is well organised, I would say, it is one of the best. Even if we had only two weeks to work I didn’t feel stressed and I enjoy every stage of it.

• Through this course, I get to know the procedure of a project management and learn to do an interesting project. It is hard to learn from other courses/studios. This studio is really intensive and demanding, students have to digest lot of information from each day’s lecture and I have to think about a project (design) at the same time.

• As well as the feedback about 'keywords' we wrote every day, it really helps me to recognize what I have got from the course. The teacher participates with every team/group work which is really great! It’s like we do a revision as a team, but still everyone has chance to communicate with professor.

• The Skype-call/lecture. It was interesting while being in Europe, having live lectures from Australia and elsewhere.

• As for the subject of the class, it was the first time, in this course in general, that we had to deal with real-world procedures than the (design) project itself. The good organization and the step-by-step procedure the direct application of the theory into practice, a microphone and more practical examples would have been good.

The abovementioned studios and Theses projects will be presented in a detailed book expected to be published as part of the PoliMI SpringerBriefs in 2017 and are hereafter briefly described together with insights form the class experience including info-graphs, architectural drawings and 3D models.

6. Conclusion

This paper shows the work done with the UNESCO Chair, Australasia Studio as to the importance of working concurrently across three axes: the policy as governance, design sensibilities as architectural creative response; and the use of management techniques and digital technologies to effectively and efficiently deliver projects as to operations. Providing a strong competency foundation to students for developing an integrated practice studio with specific aims of increasing architects’ competencies, skill
sets as to exposing them to a number of emerging software tools and techniques that bring a competitive edge. The nature of chosen projects and design challenges within particular cultural, social and economic contexts are highly valuable (and engaging) to the studio. Often located internationally or establishing comparative discussions in structured ways provides a rich learning experience. Follow-up UNESCO Master of Architecture studios will be scheduled for 2017 and beyond in locations such as Milano, Mantua, Melbourne, Hoi-An and Barcelona.

The UNESCO Chair has recently been renewed. New research topics and activities will soon follow including an Australasian architectural exhibition, with projects carried out in Australasia and Italy. Overall, the UNESCO Chair, Australasia studio should continue to bring a rewarding learning and teaching experience across all involved including students, architects, academic staff and researchers.

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Translating architectural research into construction practice: A case study of introducing new construction techniques into building practice

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Abstract: Significant tension can exist between the goals of architectural research and those of architectural and building practice. Worthwhile research involves generating risks as the benefits from its outcomes are uncertain and they require interpretation in practice as new design approaches or construction methods. In contrast, architectural and construction practice generally involve managing building procurement risk. This can encourage the practitioner and construction team to resist changes to their methods to enhance solution reliability, even if the method delivers less than optimal performance. Practitioners can be innovative but often only by incremental development: each step within the bounds of risk acceptable to others in the design and construction team. This paper continues discussion of the complexities of translating architecture research into innovative construction practice as observed in a case study first reported in Nolan, Shanks and Clark (2014). The focus project applied research results into local practice through the design, prototyping, and construction during 2015-16 of a 120-unit development in northern Tasmania. The solution was based on prefabricated timber-framed apartment modules and other innovative timber construction techniques. This paper explores the themes of innovation and risk as the case study building moved from the design phase through prototype development and into tendering, construction and completion.

Keywords: Prefabrication, innovation, project risk management, timber construction.

1. Introduction

This paper continues discussion of the complexities of translating architecture research into innovative design practice as observed in a building case study first reported in Nolan, Shanks and Clark (2014). Significant tension can exist between the goals of architectural research and those seeking to deliver innovation in architectural and building practice due to differing perceptions of risk in solution development and delivery. Worthwhile research involves risk through uncertainty in the outcomes of systematic investigation. Successful outcomes then require realization in practice as innovative design approaches or construction methods. In contrast, architectural and construction practice generally
involves managing building procurement risk. This often encourages the practitioner and construction team to resist changing successful methods, even if the result delivers less than optimal performance. Unlike the researcher, the professional pursuing innovation needs to balance potential benefit against the realities of the project budget, supply chain capability, and partner professional preference, and client comfort. Practitioners can be innovative but often only by incremental development. To see benefits from their work, the researcher can be an adoption catalyst. Innovation in the built environment through the effective adoption of research outcomes often needs to be a collaborative and educative process between researchers and practitioners where risk is to be expected and managed to realise potential benefits.

2. Risk, research, innovation and the building procurement process

Risk is an uncertain event or condition that, if it occurs, has positive or negative effects on a project’s objective (Weaver 2008). The potential level of risk is assessed by comparing the likelihood of an event occurring against the consequences of its occurrence. Risks can occur at several scales. In architectural practice, project scale risks include events such as failure in material delivery or weather damage during construction. Strategic scale risks are more varied and can apply to a building sector or all buildings of a type. These include reliance on a single construction system to poor licensing procedures for builders or tradespeople. The building procurement process can generate significant risk through: the need for the completed building to satisfy its performance requirements; the quality of action of those involved in the delivery process; and the performance of building materials, equipment and system supply chains. As the likelihood of adverse events in the building procurement chain is high and events occur regularly, supply chain participants: clients; design professionals; and builders, are sensitive to risks and act to mitigate them through deliberate and structured risk management processes in their practice. These inevitably encourage a preference for proven solutions over potentially innovative but unproven ones.

2.1. Innovation in the built environment

Research is the creation of new knowledge or the use of existing knowledge in a new and creative way to generate new concepts, methodologies and understandings (Australian Department of Education 2014). Innovation is different. It is the process by which organizations successfully transform the products of research, new concepts and ideas, into improved products, services or processes, in order to advance, compete and differentiate themselves (Baregheh et al. 2009). Research, particularly scientific research, often limits the number of variables addressed to reinforce the validity and reproducibility of results. However, due to the number of unique project variables, building design innovation - the translation of research results into improved built solutions - is far from predictable but is messy, uncontrollable, unpredictable and difficult to define (Loosemore 2014).

Creative research and innovation processes invariably involve and generate risk. Technically-focused architectural research necessarily involves outcome uncertainty as the researcher seeks to enhance building or material performance through focused and systematic investigation. If successful, the researcher’s conclusions require interpretation through innovation in the design and construction process: change in practitioner behaviour, or adoption of new design approaches or construction methods. However, innovation through the adoption of new methods generates risk in its application. Something can go wrong and adverse events occur. As a result, innovative methods inevitably face resistance to adoption. This is a normal reaction and results from the real and imagined risks perceived in procurement process change. The level of resistance at key decision points in the procurement process is critical to adoption. If the perceived risk of innovation is felt to be higher than identifiable benefit at any
given decision point, it will generally be abandoned. The novelty of innovation can also undermine confidence in its delivery and generate caution. The standard response to caution in building is consultants over-specification or builders over-pricing. Both can kill off effective innovation.

The researcher seeking to realise the finding of their work should expect and, if possible, help manage these reactions. Collaboration with the design team can not only create the broad knowledge and skills-base needed to convert new ideas into reality but also spreads the significant risk associated with innovation (Loosemore 2014). Collaborative engagement between the researcher and the design and construction team can assist participants adjust their perceived risk/reward ratio, develop innovation adoption approaches, or identify means of risks mitigation. This is an educative phase where the researcher can become an intelligent innovation broker between the parties, training and building confidence in the design team, cost consultants and the risk managers in innovation’s delivery and benefits. Separating this phase from the standard procurement process and prototyping the solution can significantly reduce perceived risks. With better knowledge gained during this separate, prototyping stage, practitioners can take informed decisions and confidence in solutions increases (European Commission 2010 p.97). Acceptance of innovation and confidence in its use is often incremental. The first application of innovation regularly involves excess discretionary tolerances until experience with the system generates confidence and increases efficiency (Edgerton 2006).

Open, competitive tendering processes can preclude collaborative approaches and limit the benefits of innovation brokerage. Open tendering requires contract requirements to be fixed, documented and available equally to all tenderers. While early integration with building contractors may be possible, a preferred contractor’s eventual appointment is not guaranteed. The alternative is for a nominated subcontract to supply the innovative components. This reduces innovation risk but increases the risk of excessive costs. This is another constraint on innovative: to be accepted, a range of potential contractors has to be able to supply the solution.

3. NRAS Inveresk – A case study

In November 2013, a consortium of Tasmanian architects invited academic researchers to join a tender to the University of Tasmania for the role of principal design consultants in a National Rental Affordability Scheme (NRAS) project at the University’s Inveresk campus in northern Tasmania. The tender called for proposals for a student accommodation building of 120 discrete apartments and associated common and services spaces to be built adjacent to the North Esk River. While strict cost and time constraints applied, the call for proposals specifically encouraged innovation. The successful tenderers were to be appointed in early 2014, construction start in early 2015, and building hand-over to occur in February 2016.

The NRAS Inveresk project was the last of the University of Tasmania’s four NRAS-funded projects to be tendered. The first in the series set the acceptable default solution for this project type. It used tilt slab concrete panels as the base structure with internal joinery, fit-out and services installed on site. The Inveresk site challenged this default solution’s adoption. Located on a flood plain, ground conditions were known to be very poor with a thick layer of sludge occurring between the effective ground level and a solid foundation. A workable solution had to either accept the cost of piling through this sludge or be light and resilient enough to make a raft slab a viable option. The invited researchers had research and practice experience in prefabricated module construction and advanced timber engineering with wood, and exposure to European design and construction practice. As part of the design team, they proposed that the preferred innovative approach for the project be based on the construction of factory-built apartment modules, assembled from readily available timber systems by local building contractors offsite. Complete
with lining, joinery and services, these modules could then be transported to site, stacked and connected in position. Other innovative approaches were proposed, such as the inclusion of cross laminated timber (CLT) panel as floor plates and stairs.

3.1. NRAS Inveresk Design Scheme and Technical Innovation

In shaping their proposal, the project team embraced the client’s call for innovation and the need to avoid costly foundation works if possible. They developed a three storey solution on top of a concrete podium based on prefabricated, load-bearing timber apartment modules. The proposed modules would be finished in a factory, complete with internal finishes and joinery and external façade elements, arrive at site in protective wrapping and be lifted into their final position by crane. In addition, CLT panels were to be used as floor plates in the central common spaces, external walkways, and as prefabricated stair units.

The use of largely complete, prefabricated timber modules was novel in Australia. Multi-level timber framed residential buildings are built, but are invariably site assembled solutions, usually combining prefabricated timber wall and roof frames with commodity joist or trusses products for the intermediate floor plates. Advanced timber prefabrication for multi-residential building is rare. Wall frame and truss (F&T) manufacturers provide the principal timber prefabrication capacity in Australia but their production is usually optimised to produce house lots (Nolan 2011). They are wary of involvement in larger projects.

The CLT use was also novel. There is no indigenous CLT production and in 2014, Australian CLT use was limited to two major buildings and series of display structures constructed by major developer Lend Lease. The major buildings were on sites with poor soil conditions but considerable market potential. While these examples supported CLT's use at Inveresk, the delivery conditions for these buildings were considerably different. Lend Lease was the client, developer and builder in these projects, and having had experience with CLT in Europe, could make a strategic decision to innovate and introduce the technology. In contrast, the NRAS project had multiple decision makers, none with CLT experience: an institutional client, an innovative but conventionally structured consultant team, and a builder selected through public tender.
3.2. Managing the risk of innovation

Though prefabricated modules and CLT construction are increasingly commonplace in Europe and the solution suited the client’s call for innovation, securing the project with an innovative but locally untried solution and satisfactorily delivering that solution required the core design team to develop explicit risk-reduction strategies, using tacit research-in-action approaches (Schon 1983). The team sought to systematically identify and provide solutions to the potential technical and non-technical risks to the project’s successful completion (Manley, K. 2006). Identified risks included client acceptance, consultant skill, builder confidence and with the structure of relationships along the procurement chain.

Risks to client acceptance were generated by understandable doubts about the structural capacity and rigidity of the modules, and the capacity of the Tasmanian building supply chain to successfully deliver a timely and cost-effective timber solution. For its part, the consultant team had to recognize and address the additional technical challenges presented by novel construction approaches, such as identifying reasonable element to element tolerances and delivering the required fire separation. Builder confidence largely influences competitiveness of pricing before contracting and acceptance of the documented solution once the contract has been awarded. The proposed systems’ novelty and the tenderers’ limited involvement to the design process, a feature of competitive tendering, complicated this confidence.

Specific actions were proposed to address these risk and reinforce the proposition that the proposed innovation was simply a manageable refinement of accepted local building solutions for a project of this size. To remove any perceived material performance or availability risk, the consultants proposing the modules be constructed from readily available timber sections and engineered wood products. These were products the client, consultant team and local builder’s understood. Further, a major builder and three F&T fabricators were consulted to confirm the supply chain’s capacity to provide the necessary module components. Lastly, they recommended that a prototype module be built during design development to resolve module construction, prefabrication logistics, detailing and tolerances.

The University of Tasmania’s selection committee listed the team’s proposal as the preferred option citing its evident innovation, but retained the ‘default’ concrete framed solution as a fall-back option. To confirm their risk exposure, they requested supplementary tender information, and commissioning independent cost and engineering analyses. This was a time-consuming process but when positive assessments were returned, the client finally accepted the design team’s proposal, and appointed them as principal consultants in mid-June 2014. With the project secured, the design team had to ensure that the solution could be delivered through the supply chain in a timely and cost-effective manner. To achieve this, project development was split into three distinct architectural design phases. The first two, schematic design, and detailed design development of the modules through prototyping ran in parallel. The last phase, design documentation, integrated the outcomes of the first two phases into an information set for tendering. In doing this, the higher-risk module development phase was effectively separated from the more low-risk design development activities.

To minimise the chances of adverse events, the client accepted the team’s recommendation to prototype a standard accommodation module. This aimed to generate designer and builder knowledge, information and confidence in each module’s components; test the module’s performance and resilience; clarify fabric and services detailing; allow the module fabricator to confirm supply chain capacity; provide tenderers with sufficient three-dimensional information to allow them to price the project competitively and significantly address the logistical tolerances associated with timber modular construction. To achieve these aims, the prototype’s construction was planned to include the structural frame insulated, wrapped,
plasterboard lined and stopped, with full services rough-in, and doors and windows and portions of the external cladding fitted. To test acoustic separation between floors, an additional floor frame was also constructed and installed on the prototype. The prototype and its components were documented for manufacture and construction began in August 2014. See Figure 2 and Figure 3. Prefab Lab was the prototype’s builder and responsible for testing material detailing and supply during the construction process and documenting assembly and coordination issues for tenders.

**Figure 2**: Computer model of the prototype structure.

**Figure 3**: Cut-away scale model of a module.

Images credit: Morrison & Breytenbach Architects

**Figure 4**: Prototype frame under construction.

**Figure 5**: Clarifying assembly detailing.

The design team interacted face-to-face with the prototype construction at the Prefab Lab to address key structural details, refining servicing, and clarify assembly issues. See Figure 4 and Figure 5. To demonstrate the module’s robustness in transport, the lined and wrapped unit was lifted from the workshop, loaded on a truck, driven about 20km and unloaded in the workshop’s yard. See Figure 6 and Figure 7. This external storage was to demonstrate water-tightness and facilitate tenderer inspection. The returned module was accessed for transport movement and the client’s risk managers inspected the plasterwork and fixings to identify damage. As the module proved robust and no damage was found, the client formally approved construction of the prefabricated timber option for the project.

As submitted for tender, the solution comprised 114 prefabricated timber-framed apartment modules, 6 conventionally-framed high-accessibility units, and CLT floor plates in the connecting walkways and common areas. These elements, in combination, were considered a manageable balance
between existing builder knowledge and experience in prefabrication with timber and innovation in material and construction approaches for Tasmania. The authors believe this to be the first building in Australia procured through a conventional tendering processes to use CLT as an integral part of the project. The prototype remained available throughout the tendering process for builders to assess the construction methodology and understand the scope of the project.

At the end of the tender period, submitted prices were within the client’s expectations and the project was awarded. At this point, the risk management processes adopted to support innovation appeared justified. Innovation had been adopted and adverse events has been avoided.

Figure 6: Wrapped and lined prototype with test floor over.

Figure 7: Wrapped and clad prototype lifted off after road testing.

3.3. Realising innovation through construction

While the design team’s innovation adoption approaches could directly influence behaviour and decision-making prior to tender, they could only influence action during construction indirectly. Construction is the builder’s domain. In pre-contract negotiations, the preferred tenderer approached the architects and client asking to remove the CLT from the project and its replacement with a traditional solution. The builder had experience with module construction for the mining sector and was confident that they could deliver these satisfactorily. However, they doubted the reliability of imported CLT supply and wanted to avoid the risk of delivery failure. The prevailing site conditions precluded the use of precast concrete due to weight and the cost of fire protection precluded the use of traditional timber or steel framing. As a result, CLT was retained in the design. As a key intent of the project was to enable the use of locally available products and materials, with the exception of the CLT components, a local hardware store and frame and truss manufacturer were contracted to supply the majority of the project materials.

As work commenced, the builder engaged the prototype maker to inform the manufacturing and logistical aspects of the project and configured a warehouse close to the building site as a temporary module production facility. Using their previous experience, the builder established two rolling assembly lines in the shed, each with five work stations. See Figure 8. One line accommodated two modules at each work station while the other held one. Standing time at each station was three days, and subcontractors were required to complete work to a tight schedule. See Figure 9. With 15 modules under construction at any one time, one full module was produced on average per day. Each module was finished with all services, insulation, cabinetry, internal and external linings and floor coverings. Labour was subcontracted from local trades and inducted into the off-site construction philosophy specifically for this
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project. The work force’s transitioning from traditional on-site sequential construction was initially slow, but improved as workflow management techniques developed and the workers’ familiarity with the project and tasks increased. This resulted in a marked increase in productivity over the term of the build.

Figure 8: Modules under construction in the prefabrication factory.

Figure 9: Trade prefabrication schedule.

Site construction processes

Site construction processes differed significantly from traditional building sites. A group of 10 completed modules arrived by truck over a day and were craned into position and fixed into place. See Figure 10. This process allowed for a quiet, clean build with one floor per wing taking only one day. Once the three levels of modules were installed, prefabricated roof assemblies were craned and fixed into place. These were made of prefabricated timber trusses assembled into as a modular unit at ground level, with the sarking, roof cover and safety anchors fitted prior to being craned into place. See Figure 11. The central common space structure connected the four wings and featured CLT floor plates fitted between prefabricated steel columns and beam. Prefabricated CLT stairs were also assembled. Contrary to the builder’s initial concerns, the CLT arrived on schedule and went together faster than expected. Once all four wings were completed, installation of fire and weather proofing began using traditional processes.

3.4. Outcomes and observations

While module manufacture proceeded relatively smoothly, site complications generated delays. The ‘two sites’ structure generated increased and unexpected management complexity in scheduling and resource allocation. Waterproofing prefabricated modules against the Tasmanian winter during storage and after installation proved problematic. While this issue had been discussed during the design phase, the design team could not instruct the builder on preventative practice. Several top floor apartments suffered water ingress resulting in significant post-installation rectification. Connection detailing between the CLT panels and the surrounding structure caused installation difficulties. Tradesman unfamiliar with large-scale timber panels struggled to install the interlocking detail designed by the engineer. This was compounded by inaccuracies in the prefabricated steel work. The CLT’s precise sizing was not matched by the steel work’s looser tolerances. In discussion, the contractor suggested that in future projects the use of CLT in a steel frame, shown in Figure 13, might be abandoned in preference for CLT only. This would potentially simplify the supply chain, limit dimensional conflicts and reduce scheduling risks. Unpublished cost comparisons between the as-built timber and the default tilt-slab solution, adjusted to provide a like-
for-like comparison, indicated that only a minor premium was paid for the innovative wood solution, mostly in preliminaries. For their part, the client regarded the project and its innovation as a success.

4. Conclusions

Risk and approaches to its management influence the effective adoption of research outcomes through innovation in architectural and building practice. Worthwhile research involves generating risks as the benefits from its outcomes are uncertain and require interpretation in practice as new design approaches or construction methods. However, the number of variables addressed can be limited. In contrast, architectural practice generally involves managing the risk of innovation in the building procurement process: a process far from predictable, messy, and unpredictable. While this uncertainty can encourage practitioner caution, collaborative engagement between the researcher and the professional can assist participants adjust their perceived risk/reward ratio, develop innovation adoption approaches, or identify means of risks mitigation. As each project is unique, the form of this collaboration will vary with the type of project, the level of innovation proposed, and the skill of the project participants.

For the NRAS Inveresk project, the researchers and design team sought to respond to the client’s call for innovation by adapting and transferring solutions successfully developed elsewhere to the local building industry. In this, they sought to introduce novel building materials and construction techniques,
CLT and factory-built modules respectively, to the construction of a 120-unit development in northern Tasmania. Securing the project and satisfactorily delivering the solution required explicit risk identification and reduction strategies. The project team sought to convince the client that the Tasmanian building supply chain could successfully deliver the solution and to reduce in the client’s mind the perceived risk of the innovation being attempted. They proposed and the client accepted the construction of a full-scale prototype. This allowed the significant systems development required for effective technology transfer and was successful in building client and tenderer confidence in the solution. Notwithstanding these strategies, the successful tenderer still attempted to remove one innovative component of the project, CLT, due to supply concerns. Fortunately, these concerns proved unwarranted.

Overall, the innovation approaches and risk management procedures adopted appear to have been successful. Innovation was adopted, potential adverse events did not eventuate, and problems that did arise proved manageable. The project was completed in January 2016 on budget, on time and met or exceeded the client’s expectations (Jordan T., pers. comm. April 2016). Initial occupant feedback is positive.

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References


Net regenerative regional development: implementation in the master planning stage of a 680 hectares case study

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Abstract: A positive vision for the future of humanity can be the basis for a needed change, a vision of opportunity, abundance and the potential for thriving. Regenerative development can provide a pathway towards this vision. Case studies are beginning to show that when applied, the concepts underpinning regenerative development can accelerate a transition to more equitable, sustainable, post fossil carbon societies. Net Regenerative Regional Development (NRRD) is development that supports the health and vitality of a region through mutually beneficial relationships between all the stakeholders and flows of the system. Though in its infancy in application, NRRD is based on the accumulation of millennia of human knowledge and provides us an opportunity to positively change the often negative future predicted. The potential of NRRD is being investigated using a large project called Seacombe West in Gippsland, Victoria and its masterplanning process. The masterplanning process is being informed by regenerative development theory and the facilitation process by the Living Environments in Natural, Social and Economic Systems (LENSES) framework. This study shows that planning NRRD through the use of LENSES supported the emergence of more holistic and systemic guidelines which informed a masterplan that has greater regenerative potential.

Keywords: Regenerative development; Design process; Large scale project; cross-disciplinary.

1. Introduction

There has been a call from many areas of research and practice for a different approach to sustainable development in the built environment, because many of the social and ecological indicators that underpin our civilisation are being rapidly eroded; that is we are failing at our current approach to sustainability. Led by thinkers in the built environment such as McDonough and Braungart (2002), du Plessis (2011; 2013), Mang and Reed (2012), Lyle (1994), Plaut et al. 2011 and Cole (2012b) the call has gone out to approaches that facilitate built environment outcomes that move beyond marginal improvements and shift our focus towards creating vitality. Projects that begin to heal the damage done in the past and create vital relationships that lead to resilience, adaptive and thriving outcomes. As argued by Mang and Reed (2012), Cole (2012a), du Plessis (2012), Hes and du Plessis (2015), Robinson and Cole (2014) and Beer (2016), regenerative development is the leading theoretical framework to facilitate contributive development approaches.
Regenerative development has been defined as ‘the process of cultivating the capacity and capability in people, communities, and other natural systems to renew, sustain, and thrive. It is not about maintaining what is, or restoring something to what it was.’ (Plaut et al., 2016). Regenerative development focuses on supporting a system to: (1) identify and reach its full potential; and (2) support the system to change and evolve towards states of increasing health and abundance.

There are examples of the application of regenerative development ideas internationally, but these often tend to be reflections on projects and their outcomes (e.g. Mang and Reed (2012), and case studies found on practitioners’ pages such as Regenesis and the Institute for the Built Environment (IBE), Colorado State University). While these provide insights into the outputs of regenerative development projects, there is a further need to better understand the process that supports regenerative thinking by contrasting it to business as usual.

The aim of this paper is to evaluate if adopting regenerative thinking from the onset of a project does support regenerative opportunities in developing the masterplan. This is achieved by evaluating the use of a creative facilitation tool called LENSES in the Seacombe West large scale development project (see Section 3.1) in Gippsland, Victoria, Australia. This analysis will assess both the design guidelines emerging from the design charrette facilitated by LENSES, as well as the translation of these guidelines into the masterplan. The latter will be done through a comparison with an earlier masterplanning attempt from 2003, which did not rely on regenerative thinking.

2. Existing regenerative development projects

To date there are very few built projects that have implemented a regenerative development approach throughout the design and construction process. The existing examples tend to reflect on the outcomes as opposed to analysing the process of applying regenerative thinking and contrasting it to business as usual. Moreover, very few studies provide insights for designers, engineers and planners on implementing regenerative approaches across multiple scales—from the building scale to ecosystems.

One project that tested the potential of regenerative development at a large scale is the Villages at Loreto Bay; a 6,000-unit mixed-use community development and eco-resort located south of the town of Loreto in Baja California Sur, Mexico (Steinitz et al., 2005; Buntin, 2008; Benne and Mang, 2015). However, it faced economic downturns following the economic crisis in Mexico in 2008, and construction did not go further. According to Benne and Mang (2015) the project had great regenerative potential, however, there were several gaps in the thinking and approach, including following a project-centric approach that disconnected the site from its broader community and context. It lacked a long-term vision of a regenerative future for the site, and had limited context ‘for seeing and targeting what was strategically more important for enabling the larger community to grow a healthier more prosperous future’ (Benne and Mang, 2015, p. 49).

The involvement of the interdisciplinary team from Regenesis helped grounding the project’s aspirations towards being the world’s largest green development through proposing a unique project concept that reflected the greater potential of the place. The aim of the regenerative approach was to build a stewardship culture among the community to protect the health of Sea of Cortez. Through the regenerative process in Loreto Bay, new potential for the Greater Loreto region emerged and the emphasis on the role of the site in its broader context led to positive outcomes such as informing new policies governing the protection of estuaries in the region, and bringing the community back together.

Other projects which follow regenerative thinking include the Omega Center for Sustainable Living (OCSL) in New York, the Willow School in New Jersey, and the Sustainable Boutique Hotel at Playa Viva,
Net regenerative regional development: implementation in the master planning stage of a 680 hectares case study

Mexico. These projects particularly show the potential of applying regenerative thinking at the building scale. While they do lay ground for dialogues on the adoption of regenerative approaches in the design process, their scope limits their potential to engage with the broader system as decisions falling outside the site boundaries can be restrained. The Seacombe West project provides significant scope for documenting the regenerative thinking process of a large scale development.

3. Method

This section describes the case study project, the regenerative development framework used to facilitate the workshops (LENSES) and the overall research strategy. The assessment process used to evaluate the impact of using LENSES is then subsequently discussed.

3.1. Description of the case study: Seacombe West

Seacombe West, located 217 km South-East of Melbourne in Victoria, Australia, is a proposed 680 hectares (6.8 km²) development on Lake Wellington (*Murla* in the Gunai aboriginal language), one of the three interconnected lakes that form the Gippsland lakes. These lakes cover 340 km², are separated from the Bass Strait by a thin sand shore that forms the ninety miles beach, and are fed by seven rivers that carry water from a catchment area of 20,000 km² (Roberts et al., 2012). In addition, many areas along the lakes are protected under the Ramsar convention (Ramsar, 2016) and other wetland and birds protection agreements. The Gippsland lakes are therefore a significant natural feature of the State of Victoria and generate a large economic activity, mainly in terms of agriculture, fishing and tourism. However, these lakes were artificially connected to the sea at Lakes Entrance in 1889 (a connection that requires regular dredging) and since then the entire ecosystem has been affected by increased salinity. Even though Lake Wellington is the least saline of the three lakes (Webster et al., 2001), its biodiversity has rapidly declined over the last decades (Parks Victoria, 2008). The salinity at Seacombe West has also increased after each flood evaporates, leavings a layer of salt on the land. As such the site can no longer serve its past ecological or farming functions. The proposed development intends to work with the changed saline conditions, providing stable habitats while also regenerating the ecological functions of the lost ecosystems of the site. It also aims to enhance its socio-economic activity.

![Figure 1: The Gippsland Lakes catchment area and the location of the site on the south-eastern shores of Lake Wellington (Lake *Murla*). Adapted from Love Our Lakes (2016) and Google Maps®.](image-url)
3.2. Overall research strategy

The authors have led and organised a series of workshops with the key stakeholders of the project in order to facilitate regenerative thinking from the early stages of design. The results of each workshop were carried forward to the next as depicted in Figure 2. The fourth and final workshop organised consisted of a design charrette over 2 days, with 40 participating experts in water management, engineering, landscape architecture, architecture, construction, governance, biology, sociology, economics, arts and other fields. Aboriginal, government and local community representatives were also present. This workshop, which was facilitated mainly by Professor Brian Dunbar, one of the creators of LENSES, generated a number of design guidelines that were provided to the design team for consideration in developing the masterplan.

As shown in Figure 2, this paper focuses on (1) the transfer of regenerative thinking from Workshop 4 to design guidelines; and (2) discussing the translation of these guidelines into the masterplan. This will evaluate whether using a regenerative thinking framework to facilitate the workshops (see Section 3.3) supports guidelines that match the systems thinking. Discussing if these guidelines are in turn reflected in the final masterplan can help reveal if outputs from the workshops are taken on board by the design team or if a business-as-usual mentality prevails. The LENSES framework was used to facilitate the workshops and is also used to analyse the design guidelines that emerged from Workshop 4. This is further described in Section 3.3. It is important to note that the project is still at the masterplanning stage and whether this will lead to a regenerative built outcome is currently unclear. An analysis of a built project would provide a more robust analysis but this is not possible at this stage.

3.3. Description of the LENSES framework

LENSES stands for Living Environments in Natural, Social and Economic Systems. The aim of this framework is ‘to facilitate tangible, actionable and contextually based solutions that support and create healthy, natural, social and economic systems’ (Plaut et al., 2012, p. 113). As depicted in Figure 3, LENSES is represented by a circular disk that consists of a series of overlaid lenses, each representing a certain set of information. The outermost lens (the Foundation Lens) outlines the guiding principles of the project. The intermediate lens (in blue) is the Flow Lens and represents the range of flows across the project. These can be physical or abstract. Both the flows and the guiding principles of the project have
been defined by the stakeholders during Workshops 1-3 (see Figure 2), and there is always a blank space left for additional flows/guiding to be added. In the centre of the framework lays the Vitality Lens, which contains the two spheres of degenerative and regenerative design and prompts the workshop participant to think about how to create benefit or regenerative opportunities for each flow. Artefacts of this model are printed or made for workshops and each lens can rotate around its centre, allowing stakeholders to test how each flow relates to each guiding principle and if it is regenerative or degenerative. This visual representation is a tool that helps structure the thinking during the workshops and allows the stakeholders to have all the key flows and principles in an organised manner.

Beyond its visual representation, facilitating workshops using LENSES focuses on systems thinking, allowing regenerative outcomes to emerge, and cross-disciplinary knowledge exchanges. Stakeholders build their own lens during the initial workshops and then use the resulting model to guide the design charrette. In this project, the aim of LENSES was strictly to facilitate workshops that enable the emergence of regenerative thinking. The outcomes of the charrettes rather than the artefact were then used by the design team to devise the masterplan. In other projects LENSES has been used to drive regenerative outcomes in projects as diverse as town planning, building design, education, personal growth, organisational development and others. This demonstrates its polyvalence. More information on LENSES can be found in Plaut et al. (2012) and Plaut et al. (2016). Some of its limitations are discussed in Section 5.2. In this paper, the authors have also used the LENSES framework to qualitatively assess the design guidelines that emerged from Workshop 4, as presented in Section 3.4.

Figure 3: Visual representation of the LENSES framework, adapted to the Seacombe West project and highlighting hypothetic flows (in green) that are addressed in a design guideline from Workshop 4

### 3.4. Evaluating if using LENSES helps support regenerative design outcomes

As described in Section 3.2, this paper focuses on assessing the design guidelines resulting from Workshop 4 and on the masterplan provided by the Design team. The combination of these two assessments will help inform if LENSES does support regenerative design options.

During Workshop 4, the participants were divided into six multidisciplinary teams, each focusing on a different aspect of the project. These teams were organised around themes of: (1) land and water, (2) ecosystems, (3) built environment planning, (4) built environment systems, (5) governance, people, money and culture, and (6) vision and inspiration. Each team produced an A0-sized landscape poster...
(see Figure 4) summarising their ideas and presented these to the audience. This paper analyses these design guidelines based on both the posters and the video recordings of the presentations and identifies which of the flows are covered (see Figure 3 for an example). This analysis does not trace back the design guidelines to the use of LENSES directly (correlation does not imply causation). However, it can be considered that potentially regenerative outcomes that cover multiple flows and use a systems-based approach have been encouraged by the use of LENSES. In order to verify this, the authors have conducted an online survey of ten questions which has been completed by 28 (out of 40) participants (70%). While presenting and discussing the results of this survey are beyond the scope of this paper, some of its findings will be used to support the results.

The second part of the study focuses on the comparison of the proposed masterplan for Seacombe West, which has been produced by the design team. That is, comparing the masterplan of 2016 to the 2003 version would help investigate if using LENSES does help lead to regenerative alternatives. This was done by identifying a regenerative approach based on the definition of Net Regenerative Regional Development as: development that supports the health and vitality of a region through mutually beneficial relationships between all the stakeholders and flows of the system. Key aspects were identified according to Robinson and Cole (2014), Plaut et al. (2012) and du Plessis (2012): Humans as co-evolutionary and co-creators of their environment with nature; looking at how nature works and using this to inform the design; the world is ever changing so design for adaptability and impermanence; creating regenerative potential physically and mentally; looking at nested system; not setting goals but processes that will help the place adapt; and looking at what is unique to a place and what it can contribute to the greater whole. This analysis will be based on the documents available for the two masterplans including the proposed program, project phasing, goals, layout and particular design strategies. Results are presented and discussed in Section 4.

Figure 4: Posters from the built environment planning (left) and ecosystems (right) teams, Workshop 4.

4. Results and discussion

Table 1 presents the analysis of the design guidelines proposed by the six different groups from Workshop 4. Results show a broad coverage of flows in almost every group. The identified flows that were covered ranged from a minimum of 5/15 (33%) to a maximum of 13/15 (87%) with an average of 9.6 flows (64%) covered across the six teams. It is important to note that these flows are not generally considered together, e.g. knowledge, money, ecosystems, people, transport and water.
### Table 1: Analysis of the design guidelines of different working groups during Workshop 4

<table>
<thead>
<tr>
<th>Group</th>
<th>Main design guidelines</th>
<th>Considered flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land and Water</td>
<td>Improve the quality of the entire site through land works, including elevating land for development, creating waterways and separating fresh from saline water and stabilising edges with landscaping elements to prevent erosion. Inland fresh water bodies (see also Ecosystems) would support local ecosystems and biodiversity. Potential solar power desalination plants with excess freshwater fed back into the lake to help reduce salinity. A thriving boating community.</td>
<td></td>
</tr>
<tr>
<td>Ecosystems</td>
<td>Enhancing and regenerating the current ecosystem by generating a range of microclimates through different wind exposures and land masses (e.g. islands, secluded spaces, elevated red gums and others), creating fresh water lakes and billabongs within the site, minimising salt intrusions through micro-barrages with fish gates and creating isolated islands as refuge for fauna and flora. This is done in conjunction with producing food through submerged algae and aquaponics as well as enhancing knowledge transfer through living labs, interactive workshops and nature interpretation trails.</td>
<td></td>
</tr>
<tr>
<td>Built Environment</td>
<td>A fractal design that is centred around a common house and space where public amenities are provided. Modular prefabricated, carbon positive (if achievable) homes that are made locally from local materials where possible to encourage job creation and local industries. A car-free environment with cycling lanes, boat sharing, public buses and solar-powered boats. Buildings as catalysts for the ecosystem.</td>
<td></td>
</tr>
<tr>
<td>Built Environment</td>
<td>A modular and scalable centralised plant that simultaneously treats energy, waste, water, greenhouse gas emissions and other environmental flows. Processes include recycling, composting, urine diversion, a range of renewable energy technologies, waste carbon dioxide and heat used to grow food in greenhouses. Share all data openly to enhance knowledge sharing.</td>
<td></td>
</tr>
<tr>
<td>People Governance</td>
<td>A spiral of innovation including equity in the community, innovative investment modelling focused on experience and crowdfunding, teaching through events, video games and an annual festival of ideas all within a bottom-up participatory governance approach.</td>
<td></td>
</tr>
<tr>
<td>Money Culture</td>
<td>Developing a sense of stewardship within the community with a main focus on contributing to the place, caring for the land, family and for life as well as fostering a collective sense of responsibility. This will be supplemented by an experiential learning, a living academy and transdisciplinary collaborations including the community and a range of stakeholders, such as universities, art centres, government, local industries and others. A particular emphasis is made on inclusivity, championing aboriginal culture and developing tolerance of all cultures. Exports would be knowledge, experience and local products.</td>
<td></td>
</tr>
</tbody>
</table>
The breadth of aspects covered by each team and the proposed guidelines do reveal a strong tendency for systems thinking. Moreover, the presented guidelines tend to improve the overall performance of the system in terms of flows by minimising waste (in a broad sense) and simultaneously improving the livelihood of the community. This type of thinking is characteristic of regenerative development. This observation is supported by the survey results on the question ‘On a scale from 1 to 5, can you score how well you felt LENSES developed a shared understanding of the potential of regenerative development?’, to which the average response score of participants was 4/5. From these observations, it seems that LENSES can fulfil its aim of facilitating regenerative design workshops by supporting the emergence of regenerative and systems thinking.

Table 2 compares the 2003 masterplan of the site with its 2016 counterpart, delivered by the design team which received the design guidelines emerging from Workshop 4.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>2003 Masterplan</th>
<th>2016 Masterplan</th>
</tr>
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<tbody>
<tr>
<td>Layout</td>
<td><a href="https://dx.doi.org/10.6084/m9.figshare.4197903">https://dx.doi.org/10.6084/m9.figshare.4197903</a></td>
<td><a href="https://dx.doi.org/10.6084/m9.figshare.4197918">https://dx.doi.org/10.6084/m9.figshare.4197918</a></td>
</tr>
<tr>
<td>Staging</td>
<td><strong>Stage 1</strong>: The island between the eastern entrance and the new town centre. “Best blocks first in best dressed” thinking <strong>Stage 2 &amp; subsequent stages</strong>: to steadily move away from Stage 1 dependent largely on rate of sales. <strong>Stage 3</strong>: including the resort and golf course will then follow</td>
<td>Start with one aspect, the safe harbour and 200 non-permanent homes, initial civil work for safe harbour and ability to test the concept of raising the land to support restoration of past ecosystem. This will inform how the site can evolve.</td>
</tr>
<tr>
<td>Goals</td>
<td>Create a boating-led development, similar to the kind of developments at the eastern end of the Lakes system such as Paynesville. Out of 11 goals the last one was to provide wildlife refuges.</td>
<td>Ecological restoration, ecological reserve, staging to allow ongoing learning, fresh and saline water areas. Innovation in finance, ownership and community. Increasing investment of nutrients and soil building throughout the site. Washing away the salt over time. Design of more resilient ecosystems.</td>
</tr>
<tr>
<td>Underpinning thinking</td>
<td>Farm land which was of poor quality for agriculture or environment but was suitable for a canal development to meet boating demand in early 2000s. Redress the salinity issue resulting from Lake water inundation, as well as using funds to provide Wildlife Reserve to preserve endangered small marsupials. Creating employment and investment into financially depressed Wellington Shire.</td>
<td>Asking what can the development do to help the whole region achieve a higher level of resilience. Asking if restoration is enough, looking instead to create vital viable systems. Looking at all the flows across the site and where they go beyond its boundaries as well as asking how to create benefit. Looking at ecological systems as a model – such as creating niches.</td>
</tr>
<tr>
<td>Housing strategy</td>
<td>Environmentally sustainable design – passive, resource efficient.</td>
<td>Modular prefabricated transportable houses, carbon positive</td>
</tr>
</tbody>
</table>
The comparison in Table 2 shows significant differences in the staging, goals and underpinning thinking of the project. The regenerative development thinking seems to have permeated the staging and goals and some of the guidelines provided from Workshop 4 seem to be taken into account, notably in terms of enhancing ecosystems. Another aspect is the similarity in the housing strategy: the current masterplan proposes ‘carbon positive’ buildings which are on level above the 2003 proposition. Technological solutions do not seem to be significantly affected by a regenerative approach.

5. Discussion and conclusion

This study supports the findings of the integrated design literature (Reed and 7group (Organization), 2009), which shows that bringing many experts around the table at the beginning of a project often leads to a more robust, thorough, inclusive and well thought-out project. In this case it is expected that the outcome of the masterplan has the potential to be a more regenerative one compared to the 2003 version, as it focusses on identifying the flows and how the design can enable critical relationships that give a place vitality, viability and evolutionary potential (Mang and Haggard, 2016).

Using the LENSES framework reveals that the benefits of the integrated process were achieved. The workshop outcomes also created the potential for rich socio-ecological systems to emerge and evolve. The masterplan has evolved considerably from 2003. However, it is critical to highlight that the masterplan is not fixed. After phase 1 (the safe harbour and 200 houses) the project may change because the best research, professional advice and assumptions of what could work at Seacombe West may not unfold as expected. Yet, the underpinning thinking is specifically about adaptation in time: unpredicted outcomes will be integrated in the site management and future development. The creative input from experts regarding critical flows could help support the resilience of the project over time.

As any research work, this study suffers from a number of limitations, including the small sample size of participants (40) and the preliminary stage of the project. Also, the results are based on the case study project of Seacombe West and are valid only for this project. Other projects might result in different findings in terms of the effectiveness of the LENSES framework and the translation of the design guidelines into the masterplan. It is also important to note the potential significant role of the actual workshop facilitator in delivering a regenerative alternative. The bias resulting from the composition of participating stakeholders should also be further evaluated. For example, the strong presence of academics in Workshop 4 might have supported the systematic inclusion of knowledge transfer propositions across all groups. In addition, the differences observed between the 2003 and 2016 masterplans could be due to a range of factors other than the design guidelines proposed at the end of the workshops. These factors include the composition of the design team, the questions asked and the general design culture at that time. Yet, despite these limitations this study is one of the first to analyse the process underpinning the emergence of a regenerative design and it provides insights for future similar projects.

Acknowledgements

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