The 51st International Conference of Architectural Science Association (ANZAScA)
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Victoria University of Wellington, New Zealand

MARC AUREL SCHNABEL (Ed.)
Back to the Future: The Next 50 Years

51st International Conference of the Architectural Science Association (ANZAScA)

Edited by
Marc Aurel Schnabel
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 about teaching and research in institutions of higher education.

In 2017, ASA embarks into the future – again. 54 years ago, Prof Henry (Jack) Cowan, Mr Derrick Kendrick and other architectural science academics held the first meeting to start the formation of the association. Since then, nearly every year, the ASA is holding an annual international conference, drawing on not only architectural scientists but also researchers and practitioners outside tertiary educational institutions. Papers discuss cutting-edge research across Architectural Science as well as areas dealing with architectural (science) education, digital design, historic preservation of buildings, landscape architecture and urban design. The annual conferences draw top academics, researchers and practitioners from all continents around the world. Standing on the shoulders of our work of the past 50 years, the 51st instalment of the conference explores avenues that will have the significant impact on in the development of Architectural Science in the next 50 years. Hence, it is timely to ask, What are the future trajectories in our field?, What are the visionary researchers and practices that will influence our built environment over the next 50 years?, and more importantly, Do we now have a better-built environment, more responsible architecture, and more environmentally sustainable design, than we did 50 years ago? The theme of this 51st International Conference of the Architectural Science Association (ANZAScA) is, therefore: “Back to the Future: The Next 50 Years”. This publication presents 79 accepted papers presented at the Conference, hosted by the School of Architecture, Victoria University of Wellington, Wellington, New Zealand, 29 November – 2 December 2017. Details of the Conference are currently at https://www.asa2017.victoria.ac.nz, and each paper is archived at ASA’s website: www.anzasca.net.

Each paper in these proceedings has undergone a rigorous peer review process. Following the call for abstracts in March 2017, a total of 193 abstracts were submitted for review. Each abstract was blind peer reviewed by two members of our International Scientific Committee, made up of 82 experts from ten countries, across four continents. Of these, 159 abstracts were accepted for development into a full paper. Following this, 141 full papers were submitted, each of which was again blind peer reviewed by two to three members of our International Scientific Committee. Based on the reviewers’ recommendations, 85 papers were accepted for presentation at the conference, and 79 are included in this publication.

On behalf of the Organising Committee, I would like to sincerely thank all of the people who have contributed to realising this Conference. Thanks go to all the authors for working hard on the papers and presentations. I am 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. I am deeply grateful for those who have worked behind the scenes: from the School of Architecture, particularly Shuva Chowdhury, who went several extra lengths, Yingyi Zhang, and Selena Shaw; my colleagues at the Office of Faculty of Architecture and Design, various people around Victoria University of Wellington, and members of ASA Exco, in particular Guy Marriage, who came up with the conference theme. We hope that the papers presented in this publication reflect on the theme and the role that Architectural Science has played and will continue to play for the betterment of our built environment.

Marc Aurel Schnabel, Wellington, 2017
Conference Theme

In celebrating the 51st International Conference of Architectural Science Association (ANZAScA), we look forward into the future and seek the presentation of visionary research and practice that will influence our built environment over the next 50 years. Standing on the shoulders of our colleagues and our works of the past 50 years, the conference explores avenues that will have the significant impact on in the development of Architectural Science. The theme calls for relevant ideas from a variety of domains reflecting and speculating on future trajectories of architectural science to reveal possible phenomena, factors and forces that will influence these trajectories with an exploratory perspective.

The 51st International Conference of the Architectural Science Association (ANZAScA) is hosted by the School of Architecture, Victoria University of Wellington, New Zealand. We cordially have been inviting architectural science and design researchers, educators, design professionals, stakeholders, and students to present their critical thoughts, discuss new ideas, and engage in our debate:

“Back to the Future: The Next 50 Years”

The Conference Proceedings are grouped into nine chapters:

- Vision (trajectories, speculations & phenomena)
- Theory (philosophy, methodology, culture & society, history)
- Context (landscape, urban design, heritage)
- Design (buildings, details, (digital) design)
- Simulation (calibration & validation, virtual, augmented & mixed environments, climate change)
- Architectural Science (environmental quality, well-being, health)
- Modes of production (construction technology, productivity, BIM, CIM, robotics, innovative technology, automation)
- Practice, Education & Profession (building code, professionalism, development, safety, pedagogy)
- Culture (culture, indigenous, tradition)

Contributions to the above groupings of research-areas have been sought to cover relevant content relating to the architectural science of the disciplines of architecture, engineering, building science, design, urban- & landscape design, computer science, philosophy, psychology, mathematics, humanities, and other relevant disciplines, who can contribute to the discussion. Researchers and doctoral students have been invited to submit research papers and critical essays and to attend the conference to widen our discussion about the future trajectories of architectural science.
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Keynotes
Diving into Potential

*Architecture taking Care and Responsibility for our Living System and the Future*

Jerome Partington
*Sustainability Manager*
*Jasmax Design, Auckland, NZ*

**Abstract:** A brief dive into Jasmax’s sustainability journey, to reflect on the evolution of our sustainable design vision from green buildings to regenerative development. By embracing the unique potential of bountiful Aotearoa NZ, Jasmax has learnt to challenge ourselves to be better and do our best as we encourage others to do the same. Jerome describes Jasmax’s Auckland Office roots: the high-performance Green Star + NABERSNZ Certified NZI Centre, projects that provided the foundation to embrace and pilot the international Living Building Challenge for Tuhoe’s Te Kura Whare, now the first Living Certified project outside the USA, and how this inspiration and client collaboration became the impetus for both Ara’s Kahukura, engineering and architecture school, and the new flagship living education centre in Auckland – project proof, that challenges all of us to look deep for our own potential and the value of consciously working together for the health of our living system.
Towards a Digital Building Culture

Russell Loveridge
Managing DirectorSenior
Swiss National Centre of Competence in Research (NCCR) in Digital Fabrication, Zurich, CFH

Abstract: Digital tools and numerically controlled fabrication processes are already redefining manufacturing in many industrial sectors. However, architecture and construction is the single largest industrial sector focused on production, and yet it is also one of the most resistant to the adoption of new technology. Initiated in 2014, the Swiss National Centre of Competence in Research (NCCR) Digital Fabrication aims to foster a revolution in construction through the seamless combination of digital technologies with material and physical building processes. Researchers across academic disciplines collaborate to develop ground-breaking technologies while concurrently remaining aware of the issues of economy, ecology, societal impact and the critical role that architecture plays in defining place and culture. This keynote presentation will highlight research being undertaken within the NCCR Digital Fabrication and will discuss the innovative and collaborative approaches needed to tackle such programmatic, economic, and social challenges of digitally augmenting the construction of our built environment.
Stories of Resilience

Anica Landreneau
Principal and Director of Sustainable Design
HOK, Washington DC, USA

Abstract: An exploration of projects past, present and future that are designed to adapt to shifts in climate while transforming the economic, social, cultural and urban fabric of the cities we live in. Case Studies include: Pearl Harbor, HI; Los Angeles, CA; Houston, TX; Washington, DC; Cartagena, Colombia; and Jeddah and Riyadh, Saudi Arabia
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‘Primitive Attitudes’ and Traditional Practices

Looking Back For Sustainable Solutions to Future Flood Disasters

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Abstract: Global warming, even with a 2°C rise in temperature as per the Paris agreement, will mean more flooding events, as warmer air holding more moisture leads to greater rainfall. Human settlements have grown up by water, whether sea or river, as this gives access for trading. Such settlements in both the developed and developing world will have to learn to cope with more and greater flood events. Many poor communities are already forced to live on flood prone land that those with more money avoid. The global increase in flood disasters related to natural hazards, and the massive economic costs of these, gives the opportunity for a deeper interrogation of the issue. This paper summarises the link between global warming and flooding and then uses two empirical case studies of vernacular communities to contrast their ways of living with flooding with western attitudes of trying to avoid it. As it becomes more obvious that rapid urbanisation and the vast infrastructure developments that support urban lifestyles play a major role in these disasters, there is no better time to look back in time and beyond westernised worldviews for future solutions that are favourable to both people and environment.

Keywords: Floods; traditional practices; living with inundation; learning from the vernacular.

1. Introduction

In 2005 an article (Kundzewicz et al., 2005) originally accepted for publication in 2004, argued that there was a link between climate change and increased risk of flooding from high precipitation events in central and eastern Europe. In August 2005 high precipitation caused severe flooding in South Germany, Austria, Switzerland, Slovenia, Bulgaria, Romania and Moldova (BBC News, 2005). It has been argued that this event was not necessarily the result of climate change (Beniston, 2006). Nevertheless it still did a great deal of damage (Dankwa, 2006).

Min et al. (2011) used a mixture of observation and modelling to conclude that anthropomorphic...

...increases in greenhouse gases have contributed to the observed intensification of heavy precipitation events found over approximately two-thirds of data-covered parts of Northern Hemisphere land areas.” Another modelling study of the 2000 floods in England and Wales
also found that greenhouse gases from human activity increased the risk of these floods occurring (Pall et al., 2011).

In the southern hemisphere Brisbane is an example of a city with a long history of flooding which led to the construction of the Wivenhoe Dam upstream of the city. This dam, built as a result of the 1974 flood, ameliorated but did not prevent the January 2011 flood (Smith and McAlpine, 2014). Earlier links had been made between climate change and an increase in how often high rainfall events would occur in Australia, coupled with a decrease in the frequency of low rainfall events (Whetton et al., 1993). This same study noted the link between high rainfall events and probable increase in flooding. In New Zealand climate change is “…expected to lead to increases in extreme rainfall, especially in places where mean rainfall is expected to increase (Ministry for the Environment, 2010, p.vi).

Barredo (2007) argued that even without climate change there would be more floods in Europe as population increase moves wealthy people into flood prone areas, and the urbanisation that comes with this (loss of natural drainage, more impervious surfaces) poses a flood risk. In the past it was the poor who were forced to live in these less than desirable areas. However, it is also the poor who have thus learned to live with flooding. Looking forward 50 years to a probable warmer climate and greater risk of high precipitation events this paper looks at how a number of poor societies have learned to live on flood prone ‘land’. Without the resources to keep the floods away through building stop banks and costly barrages, these societies may have much to teach about living with risk.

2. Method

This paper beings by looking at westernized attitudes to dealing with floods and the increased risk of flooding from climate change. It then looks at two empirical case studies of how communities have adapted to living with floods. Both case studies are places familiar to the authors. The discussion draws on this familiarity and the opportunity to talk to local people, as well as the writings and observations of others. The purpose is to draw out principles of how those living in New Zealand and Australia might approach living with an increased risk of flooding by learning to live with water rather than seeking to keep it out.

3. Westernised Attitudes to Flooding

In the developed world floods are generally something to be avoided, either by prevention, which usually involves large scale measures such as sea walls, or through mitigation which can happen at both the large scale and the scale of the household. Additionally avoidance is a third strategy, whereby land prone to flooding is abandoned. Each of these strategies is briefly discussed with examples.

3.1. Keeping the Water out at large and small Scales

The Dutch have long recognised that if you want to keep water out you build dykes to protect the land. The sea wall has been used for centuries to protect human settlement from coastal erosion. Modern sea walls are one way to avoid the effects of sea level rise but building and maintaining such sea walls can be expensive. Examples of such an approach are the Thames Barrier in London, built as a result of east coast and Thames estuary floods in 1953 (Met Office, 2017) and the Oosterscheldekering storm surge barrier in Rotterdam (Fagan, 2013, p.219). However, not every community wants such barriers although they also want to avoid flooding.
Tai O on the eastern side of Lantau Island, Hong Kong is a traditional fishing village where houses are built on stilts above the sea water that has become a tourist attraction (Hong Kong Tourism Board, 2017). The old sea wall that protected the village had earlier fallen into disrepair and in 1989 a flood destroyed half of the village (Loh and Civic Exchange, 2002, pp.3-4). Since then various storm surges have flooded the small town. A new sea wall has been constructed to preserve the town centre but only from the annual flooding rather than storm surges. The wall was to have been taller but residents objected because they felt it would interfere with tourism, an important source of livelihood (Chan et al., 2013). However, the village is under threat from climate change linked sea level rise that will “…affect their traditional production and lifestyle…” (Zhang et al., 2011; He et al., 2015). It seems inevitable that Tai O, with its elderly population and very high insurance premiums following recent storm surge floods (Chan et al., 2013), will not survive in its present form.

Another large scale strategic approach is to lower flood plains so as to make room for more water when rivers flood (Rijkswaterstaat, n.d.). This is akin to the traditional flooding of water meadows, or irrigated grass pasture, that has been a feature of southern England since 1600 AD (Cook et al., 2015). Thus rural areas are flooded to prevent the water reaching populated urban areas. This traditional strategy was recently used in the Taieri Plains area in New Zealand. In July 2017 dairy farms were flooded to avoid the water reaching settlements. This is an area where the danger of flooding has been “…modified (but not eliminated) through engineering works over the past 150 years” (Otago Regional Council, 2012).

Mitigation strategies can also occur at the small scale, such as the installation of concrete walls and rubber sealed flood gates in houses along the banks of the River Ouse in York, UK and bolting down manhole covers (Dhonau et al., 2017). Other advice is to adapt to flooding by not storing valuables or having expensive furnishings at low level (Osberghaus, 2015), and this behavioural approach comes closest to communities that have traditionally lived with floods.

3.2. Avoidance through Relocation

Increasingly the option to relocate to a safer site of similar or better value than the one destroyed is impossible due to urbanisation, high property values, and the effects of climate change that reduce the number of non flood prone sites. In addition, the successful reestablishment of communities into new locations is complex, costly, and has negative environmental, social and economic implications (Cernea, 2000; Oliver-Smith, 2010). Nevertheless, after disasters governments can force communities to relocate through the imposition of no build zones and development policies (Cernea, 2000; Oliver-Smith, 2010). Following the devastating effects of the 2004 Asian Tsunami the traditional coastal fishers of Sri Lanka were further affected by the subsequent imposition of a shortsighted coastal no-build zone policy (Schilderman, 2011). Some 50,000 families were relocated inland, sometimes by as much as 10km, and settled into new housing developments with no public amenities. Isolated by distance and lack of private and public transport not only from livelihood and food sources but also from traditional social environments, their new situation proved a second displacement. Traditional social structures and support systems essential for recovery from a traumatic disaster and continuity of community based livelihoods were here severely undermined by relocation. An immediate outcome of this was the contest for and exploitation of the fishers’ traditional territorial waters by outsiders with no prior fishing experience who falsely claimed donated boats. Previously these waters were safeguarded for generations by proximity, undocumented mutual agreements and traditional, sustainable fishing practices. Another disastrous consequence of relocation was undermining of the capacity of traditional communities to rebuild their homes in a manner suited to their needs (Schilderman, 2011). Westernised understandings
of house and community differ significantly from those of traditional, tropical communities. In the latter living environments extend across several thresholds in response to day to day needs, livelihood practices, social structures and temperature fluctuations. The extensive donor support was mostly in the form of complete houses rather than technical or material assistance. Seen as a commodity removed from the owner builder (Oliver, 1992) these houses fitted well within western concepts of a basic home contained within four walls and set in a gridiron layout. The inadequacy of houses and relocation sites and the widespread contest of the no-build zone prompted several communities to return to their original coastal settlements. They then rebuilt their destroyed communities and attempted to re-engage in their traditional livelihoods.

The situation of the fishers of Sri Lanka is not unusual. It is estimated that every year since 2008 on average over 22 million people are displaced by disaster, 60% more than the figures from four decades ago (IDMC, 2015). Poor communities are the most vulnerable to disaster and subsequent government relocation policies (Cernea, 2000; Oliver-Smith, 2009; Schilderman, 2011). While relocation to avoid future inundation either from the sea or river flooding seems logical and the excessive cost of repair and restoration of infrastructure is sometimes used to justify relocation, increasingly it is post disaster development policies and the perceived economic benefits of these that force communities out of their living environments (Cernea, 2000; Oliver-Smith, 2009; Ferris, 2011; Schilderman, 2011).

Examples of government forced relocations after disaster can be found in both the developed and developing world. A small community of 154 homes in Eferdinger Becken, Upper Austria sits in the floodplains of the Danube, which floods regularly. As part of its passive flood prevention strategy the Austrian government offered the community 80% of their property values if they agreed to relocate by mid-2016, while the 20% balance was allocated for demolition and re-cultivation of the land (EEA, 2017). The buyout was estimated to cost 325 million Euros. Eighty homeowners accepted the offer and were relocated to a designated site claimed from forest and semi natural areas within the region (EEA, 2017). Those who stayed, mostly the elderly, opted to live in the upper levels of their homes and were allowed to renovate only for this purpose (EEA, 2017). In 1996 following the failure of the US$20 billion engineering flood prevention projects on the Yangtze River and ongoing devastating flooding, in 1998 the Chinese government decided to relocate 2.4 million people from its flood plains (RAM, 2012). The aim was to free the latter from development, reduce river pollution, revive river ecology, and allow the river to flood with less human disruption (RAM, 2012). Communities engaged in rice cultivation, aquaculture, fishing and farming were resettled into newly built towns at huge costs and provided with new livelihoods (RAM, 2012). However, the Yangtze River continues to flood leading to bad social, economic, and environmental outcomes as a consequence of China’s extensive development and dam building projects, such as the Three Gorges Dam, and millions of affected people continue to be relocated (Jing, 2016). Recent reports and studies emerging from Japan highlight the pressure imposed by the Japanese government on evacuees from the 2011 Fukushima nuclear disaster (caused by the Tohoku earthquake and tsunami) to return to their former living environments even though they are unsafe for human inhabitation (Hirano, 2017; McCurry, 2017). This is apparently being driven by massive economic loss from the inevitable death of local industries, towns and regions if entire communities fail to return (Hirano, 2017; Yamakawa, 2017).

These situations demonstrate the increasing social and economic consequences not only of relocating communities but also of abandoning disaster prone sites and infrastructure. The negative consequences of forced relocation on the health, social and economic wellbeing of both the dispossessed and host communities is also widely known (Cernea, 2000; Ferris, 2011; Oliver-Smith, 2009, 2010). All these issues demonstrate the complexity of relocation and the inadequacy of government processes for successful resettlement of communities. The numerous efforts of the UNISDR and the World Bank focused on
disaster and poverty risk reduction and resettlement demonstrate the gravity of these issues. The inevitable outcome of more climate change flood events is that relocation may seem the easy option.

4. Case Studies

The two Asian case studies show how communities in Indonesia and Cambodia have adjusted to live with periodic flooding. Living with floods is not ideal but is possible. These communities, especially in the case of Cambodia, have come to rely on the periodic floods for the livelihoods. It is the attitude to floods that is of particular interest for this paper.

4.1. The rob—tidal flooding in Semarang, Indonesia

The port city of Semarang, located on the northern coast at the mid-point of the Indonesian island of Java, is the capital of the province of Central Java and the fifth largest city in Indonesia. Since 1957 it has suffered from tidal flooding caused by land subsidence and worsened by climate change related sea level rise. It has estimated that by 2015 the land was subsiding by 13cm per year (Semarang City Government, 2016, pp.37, 56). This subsidence is believed to be caused by a combination of factors, the principal ones being the consolidation of the alluvial soil under the loads placed on it from the construction of buildings and roads resulting from urbanisation, plus the effect of increasing groundwater extraction (Abidin et al., 2012, p.71). The tidal flooding, known locally as rob, affects seven of the city's sixteen districts, covering an area of nearly four million hectares (Hadi, 2017, p.1). Apart from the physical damage caused by the water the rob also has negative effects on health not least because it affects the septic tanks used by households for sewage treatment (Hadi, 2017, p.2).

Research carried out by Harwitasari and Van Ast (2011) in some of the most flood-prone areas of Semarang found half the residents of these areas experienced flooding between four and nine times a month, with the water depth being between 500mm and 1m while ten percent of the population suffered daily flooding. In spite of this, people did not choose to relocate from the areas that were studied. This is not only due to their inability to afford to move elsewhere, but is also related to local services, accessibility to the city centre, employment and ancestral property ownership. Local social contacts were also found to be very important (Brus, 2012, p.37). Because they want, or need, to stay, people have found ways to adapt to the regular flooding. A study of Genuk District, one of the areas suffering from regular floods, found that generally people wished to remain there as the economic benefits of being there outweighed the problems caused by flooding. In order to remain people adopted a range of strategies, from building up the level of the ground round the house, then raising the floor of the living room to, ultimately, building a second storey on the house (Khadiyanta and Dewantari, 2016). Another study of six flood-prone districts found that the most common strategy was to raise the house higher above the ground, and that at the neighbourhood scale it was common to increase the height of the streets (Harwitasari, 2009).

While these responses demonstrate the ability of people to use their own skills and resources to adapt to extreme conditions rather than abandoning the places where they live, in the case of the rob floods some people cannot afford to adapt and this is not a problem that will go away over time. It is also likely to get worse. An article in The Jakarta Post describes a 56 year old man who "lives in his flooded house in a space just under his roof, perched like a bird on beams" because he cannot afford to raise the floor or build an upper level (Zavoil, 2014). As sea level rise increases there may be many more people perching on the roof beams.
4.2. The Reversal—Tonle Sap’s Annual Flood Pulse

Southeast Asia’s largest wetland, the Tonle Sap in Cambodia, expands and contracts annually changing from a lake of 2600sq.km to 15000sq.km, with its water levels rising from a low of 1.5m to a height of 9m (Arias, 2014). This annual flood pulse is a natural and essential phenomenon for the sustenance of the region around the Tonle Sap and the lower reaches of the Meekong River, which originates in the north of China and weaves its way through Laos, Thailand, Cambodia and Vietnam before releasing its life giving waters to the sea (Kummu, 2008). The flooding of the Tonle Sap Lake is caused by a phenomenon known as the reversal flow (Airas, 2014). With the significant increase of water in the Meekong due to annual monsoon rains and ice melting in the Himalayas, the Tonle Sap River, which usually carries water from the Tonle Sap Lake to the Meekong, changes course bringing back to the lake not just the waters that passed through it but also 60% of the waters flowing down the Meekong (Kummu, 2004). This mixing of waters rich with nutritious sediment and the inundation of the gallery forests for several months each year produces rich benefits for the biodiversity of the region and the people of Cambodia (Kummu, 2008) and contributes 60% of Cambodia’s fish production (Evans, 2004).

Recognising the invaluable benefits of the reversal flow and the annual flood pulse and the rich food sources it produced, several centuries back people settled around the Tonle Sap in two types of architecture, floating and elevated (Evans, 2004; Grundy-Warr, 2016). The driving concept of this architecture is finding harmony with natural environmental conditions through adaptation. The floating architecture in the form of house and shop boats and ancillary structures on rafts rises vertically with the waters and moves horizontally as the water body expands and contracts (Evans, 2004; Grundy-Warr, 2016). The elevated architecture in the form of stilt houses located 6-8m above ground level sits beyond the gallery forests and along the Tonle Sap’s feeder rivers and waterways (Au Morris, 2014). In the dry season access to the community is from a wide central spine road, also used for drying fish, and each elevated home is accessed via ladders, stairs and multi-purpose platforms (Au Morris, 2014; Grundy-Warr, 2016). As the waters of the lake rise and boats replace modes of land transportation ground level functions gradually move upwards and the elevated platforms and rafts begin to serve as access points, fish drying and production platforms, shops, markets and social gathering and recreational space (Au Morris, 2014). At the height of the flood when the entire Lake region is transformed into a water world and communities are completely isolated from land, boats and rafts are adapted for all types of use and life around the Tonle Sap Lake continues without disruption (Au Morris, 2014). Using timber, bamboo, palm thatch and other vernacular materials communities have developed suitable construction systems for stilt houses and ancillary structures, including aquaculture pens under floating homes and sheltered pens for livestock built on rafts. These architectures have been developed and located on their watery sites to withstand both the fluctuations of the lake waters and environmental conditions, including winds and tropical storms (Au Morris, 2014; Evans, 2004; Grundy-Warr, 2016).

However, since the 1990s the equilibrium and adaptive living practices maintained for generations by the traditional lake communities have increasingly been under threat. The predominant culprits are modernisation, industrialisation and the increase in human settlements within the Meekong river basin (Dugan, 2010; Evans, 2004; Kummu, 2008). A community elder from Kampong Phluk, a traditional community on the Tonle Sap has been leading the fight for the sustainable management of the lake environment and resources. Interviewed in relation to a study on local resource management he states, ‘Old people knew. They knew a lot. Old people knew that fish lived in the forest... and that the forest helps to protect the village, especially in the flood season, from water, waves and storms. Protecting the forest meant that they were protecting the fish breeding grounds. This meant that there was enough food’
‘Primitive Attitudes’ and Traditional Practices

(Evans, 2004, p.13). The passing of traditional knowledge from generation to generation ensured the maintenance of sustainable practices by community members. Now the largest threats to have emerged in the last 30 years come from development activities taking place beyond these communities in the upper reaches of the Meekong, particularly in China. Since the 1990s, the numerous large scale hydropower dams, reservoirs and irrigation schemes built all along the upper reaches of the Meekong not only cause flow alterations of the Meekong and increase the silt it carries but also affect the flood pulse of the Tonle Sap. The potential negative effects of this are increases in the Tonle Sap’s dry season water levels (Kummu, 2008). The result is restricted ground accessibility for communities, shrinking of land based dry season food production areas, and consequent loss of vital nutrition in the diets of the lake communities (Evans, 2004). In addition to the hydropower projects, industrial and agricultural pollutants and human waste entering the Meekong and subsequently the Tonle Sap pollute its waters, causing detrimental damage to fish species and populations and the livelihoods of communities (Dugan, 2010, Kummu, 2008). Further aggravating the situation are the more localized unsustainable practices such as modernized exploitative fishing and fish production methods, deforestation, land clearance for commercial developments, increased production of garbage, and the lack of environment friendly garbage and human waste disposal methods. These unsustainable practices and pollutants are severely compromising the health of the lake, the gallery forest, biodiversity and communities (Evans, 2004; Kummu, 2008).

While the traditional communities of the Tonle Sap have devised a unique way of occupying an unstable environment through considered adaptation and have benefited from the hydrological and ecological fluctuations of natural systems, it is the interventions of modernized societies aimed at controlling and exploiting these natural resources that now threaten their living environment, health and livelihoods. As the effects of climate change becomes more obvious and the shortcomings of conventional static living environments and modern infrastructure become apparent, the Tonle Sap’s traditional amphibious and dynamic communities offer potential solutions for future housing and community developments in coastal, riverine and low lying areas prone to flood.

5. Learning from the Vernacular

The first thing the two case studies show is that communities can live with regular flooding. This runs counter to the westernised view of floods as something to avoid, whether through engineering works or by deeming land prone to flooding as unsuitable for human habitation. Given climate change is leading to more severe weather events and more flooding, in 50 years living with flooding may be more common place. In some situations traditional or vernacular infrastructure solutions and non-westernised attitudes to occupying an environment are proving to be far more effective and sustainable, and dismissing them as primitive or temporary could be detrimental (Oliver, 1992; Schilderman, 2011). This is increasingly important as it becomes obvious that modern infrastructure developments, including widespread urbanisation and inappropriate construction methods, are together now making the largest contribution to the disastrous outcomes of unusual weather events (Berman, 2010; Cernea, 2000; Ferris, 2011; Oliver-Smith, 2009 & 2010; RAM, 2012). The highly acclaimed nationwide flood prevention programme in the Netherlands, ‘Room for the River’ completed in 2015, is admirable for its intention to make room for rivers and restore flood plains (Zevenbergen, 2013). However, the programme estimated to cost 2.3 billion euro not only displaced communities but also destroyed ecosystems and natural environments through its extensive excavation, earth moving, dyke relocation and building of earth mounds or safe islands for relocated, new homes.
Reflecting on westernised attitudes to water and land and the infrastructure controls devised to hold them apart Berman (2010), following the disastrous outcomes of Hurricane Katrina, states “we have come to realize that our highly orchestrated, static levee flood control systems, intent on constraining and neutralizing the environmental fluctuation impacting our cities, have also been partially responsible for unintentionally amplifying urban and ecological risks.” In this context “partially” is perhaps an understatement considering how widespread the problems are that arise from decreasing permeable ground and the increasing quantities of water channelled into urban areas for human consumption and away from them in the form of ‘waste.’ This puts immense strain on waterways, rivers and the environment in the effort to ensure seamless and constant supplies of water services. The vernacular examples show how it is possible to adjust living to cope with fluctuating water services. This is in line with the ecological resilience rather than engineering resilience approach to the built environment (Garcia and Vale, 2017). The latter assumes it is possible to return to the same state as previously after an event like a major flood. The ecological approach sees the system change adapt to the event without moving into a new state. The vernacular examples of the rob and Tonle Sap have the characteristics of ecological resilience as ways have been found of adapting to changes in water levels. It is now urgent that developed societies devise more fluid geographical approaches to living with water than the familiar static systems and controls of the engineering resilience approach.

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Reclaiming Heritage by Retelling 'The Thing' in Virtual Reality

Decoding Walled City of Lahore

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Abstract: The focus of this work is on representing the surrounding of Masjid Wazir Khan in Lahore. It is explored how the computational tools and translations can promote a participatory process to build up a digital archive. The concern for abandoned spaces in heritage sites is examined by observing user interaction with heritage displays through different media. The paper presents two stages of a digital heritage work. Providing the details of an exhibition, the initial stage informs the reader about the background of the project. Explaining the necessity of the shift from analog interaction tested in the exhibition to the digital, the paper elaborates on the deployed workflow. Primarily, the front façade of Masjid Wazir Khan and the square at its entrance are visually surveyed by photography. Secondly, the photographic survey is used to build a 3D virtual model of the site by using a photogrammetry 3D modelling software. Thirdly, the 3D model is imported into an immersive virtual reality system through which users are teleported to the site in Lahore. The paper demonstrates the qualitative findings of the deployed digital workflow that links the heritage context to distant users, providing technical details of the deployed modelling process.

Keywords: Photogrammetry; digital heritage; user experience; virtual reality; Walled City Lahore.

1. Introduction

It is human nature that our senses of sight, smell, touch; taste and hearing are driven towards the uncommon attributes of our surroundings (Abid, 2012). There are lost spaces, nooks and corners in admired heritage, monuments, sites and cities. The project emphasizes such spots that are ‘reclaimed’ by the people for either their living, daily use, businesses or trifle. The aim of this research is to delve in the complex surroundings of forlorn spaces; to ‘retell’ its usage and function. At this stage of the research, an immersive, interactive and inclusive workflow is designed to enable the viewer in an embodying virtual reality (VR) environment to use various senses from sound, sight and cognition to contribute to the retelling of the reclaimed heritage in the context of Masjid Wazir Khan located in the historical Walled City of Lahore. The focus of this research is on representing thoughtfully chosen spaces occupied by
various activities. The research brings together the notion of ability of inhabitants to transform the spaces they are in (Heidegger, 1962) and the immersive technique of VR that enables the user to bring forth their own understanding.

This paper encapsulates the discussion of spaces that have been selected from the site located in the historical part of Lahore. It covers how these spaces were documented and disseminated to remote visitors. It involves frisky-positive conduct and awareness of psych geographical effects (Debord, 1958), and are thus quite different from the classic notions of journey or stroll that Heidegger had indicated in his famous essay of A Mountain Walk (Sharr, 2007). Research probes in the idea of necessity of VR for enhancing the user experience from remote distance. Methodology of the research is discussed alongside the methods employed to reach the conclusions. Later, the 3D modelling process is demonstrated in conjunction with elaboration of how the stories can be retold in virtual reality (VR).

2. Background

2.1. Walled City of Lahore

The scope of the whole project covers the old architecture and narrow road in the walled city of Lahore called Shahi Guzargaah. The project is largely envisioned to consider designated area of Masjid Wazir khan and surrounding spaces. The project is interested in the crossing between architectural and urban scales. Interaction between these two scales happen through two ways; one through different functions mixed by users and another via the formal and spatial qualities. The former is examined in the first stage of this research where three sites are selected to evaluate interactively disseminated stories of their real users.

The novel methodology includes the field trips to the site that are driven through the notion of derive that literally means drifting to document the nature and characteristics in a systematic manner. Hence it is employed where one or more persons during a certain period drop their relations, their work and leisure activities, and all their other usual motives for movement and action, and let themselves be drawn by the attractions of the terrain and the encounters on the way (Debord, 1958).

The latter about the spatial aspects is focused in this paper based on digital documentation and display techniques. Yet, this section introduces the first stage to understand the background of a novel methodology based on digital technologies.

2.2. Nooks and corners ‘reclaimed’

Three spaces were selected based on their relationship, scale and usage alongside the narrow roads of the Walled City. The first one depicts story of a repair man. It encapsulates his nostalgia and immense attachment to his spot of livelihood (Figure 1, left). It is the exterior of the Government Rang Mahal Christian High school and represents its ability to hold the source of revenue of the user (Abid, 2017). It elaborates on the “sustaining” character of the Walled City. The second space is a small whole sale store in the vault next to Masjid Wazir Khan (Figure 1, middle). The surrounding of the second space is documented through photogrammetry which will be explained later. The third selected alcove is an occupied vault situated in Government Rang Mahal Christian High School where the occupant has set up a shop for antiques (Figure 1, right). It is on the same route (Shahi-Guzargaah) to Masjid Wazir Khan and part of a heritage site. All these selected nooks and corners are reclaimed by public from heritage sites with whom they deeply associate themselves.
2.3. First Stage: Digitally Restored Manually Interacted

The three spots that are documented were exhibited at ICA (Institute of Culture & Art) in collaboration with ICOMOS (International council on monuments and sites) on IDMS (international day for monuments and sites), 2017 and at Makerfest (2017) that were held in Lahore in April and in July, respectively (Figure 2). Both exhibitions aimed to inform how various spots of a heritage site are used by their occupant in relation to their surroundings. These exhibitions laid a foundation for the idea that it is people who make places and contribute to the upkeep and use of heritage sites. The conception behind the venture roots deeply in the philosophical thought that the details of the building can be read for the inspirations and ideas of its inhabitants. This is an examination of Heidegger’s concept, “The Thing”, which explores the quality of sustaining in which he suggested the ability of the jug to pour; its intentional feature (Heidegger, 1962).
2.3.1. Exhibition setup

The interactive art pieces were envisioned to engage the viewer, to ignite awareness and to build a sense of consciousness towards heritage and context (Figure 3). The inclusive character of each piece enabled the viewer to use various senses from sound, sight and cognition. Each piece had an MP3 designed for it especially that mapped the sounds of that space, stories of the inhabitants with overlay of music and expression to make it engaging for the public. Smaller activities were embedded such as miniature bricks and origami birds that viewers were requested to place as per their liking.

The research behind the exhibitions dwelled upon the role of the participation through different media. Interactive technologies were arrayed. Photographs, sound and video recordings were combined to present the endemic spatial features of Shahi Guzargaah located inside the Walled City of Lahore. Retelling the individual stories of their real users. Installations provided visitors digital means to interact with the site audio-visually.

Figure 3: Exhibition Space and installation of the project at Maker Fest, Lahore, Pakistan ©M Abid, 2017

2.3.2. Overview of the exhibitions

We found that there is a strong connection between the theories that McLuhan and Heidegger presented. Both explored how mind works different from information technology (Heim, 2005). McLuhan clarifies the significant role that technology plays in defining the reality whereas the Heidegger’s work suggests the concept of “being in the world” (Heidegger, 1962). Following theoretical research expressed “being in the world” as one’s own daily encounters in, with and through the world (Heim, 2005) which is extended on the sensory perception that stimuli cognition to change social and psychic environment (Ralon and Vieta, 2011). From this theoretical basis, we moved to question how to reclaim heritage through virtual reality.

One of the reasons for taking the idea into the VR is to increase user participation with state-of-the-arts applications. In terms of participation, the exhibitions filtered a certain type of crowd in the venues. Although both events attracted a varied audience, demand for more interactive engagement remained missing. Our intention shifted towards various avenues where digital heritage could be made available for a wider audience and where it is accessible, cost and time effective.

2.4. Second Stage: Necessity of User Experience in VR

Today, urban designers and planners apply to 3D modelling techniques to address the issues of cities during decision-making (Kunze et al., 2012; Fukuda et al., 2017). When a city has important historical quarters, these techniques are given more priority for better planning decisions regarding the development of citizens, life and preserving their collective historical identity through participatory means of public engagement (Fregonese et al., 2016). To respond these contemporary demands, new and
powerful photogrammetry software offer low-cost options for computationally expensive digital processes. ReCap 360 and Remake (formerly Memento Project) are the photogrammetry software provided by Autodesk using the same algorithm to generate 3D models from photographs. Recordings techniques are advanced in the second stage of the research which is explained next section. The new techniques include photogrammetry and immersive virtual reality (VR) technologies.

2.4.1. Photogrammetric modelling

It is necessary to document the cultural heritage especially built environment that is vulnerable to air pollution, traffic and climate. It is significant for the future preservation of monuments and sites. The 3d photogrammetric model helps in understanding the complex spatial settings of age old structures. The information can be further linked with the sounds and other information to enhance the user experience (Dorffner and Forkert, 1998).

Imaging photogrammetry is about measurement. It focuses on measuring the subject. The procedure demands a certain protocol from the user in terms of orientation, light, camera specs for the model to be accurate. The detail of the photographed content is important for the quality of model produced (Lievendag, 2017). With time and progression in technology it has become a powerful tool for 3D model making especially with sensitive camera lenses, advanced computers and even software such as Autodesk Remake.

2.4.2. Immersive-ness via virtual reality

Virtual reality (VR) is widely used since it connects virtual spaces from various times be it present/ past or future. The virtual realities use computer graphics (CG) and are to make interactive moves by real-time rendering of large scale projects that encapsulates urban and architectural scale usually are documented and users experience it as walk through. The virtual environment made by 3D CG is not immersive and not inclusive hence, it divorces the user of experience (Fukuda et al., 2017). Full scale design projects on a planned construction site can be visualized by augmented reality. It over lays on real world images. 3D virtual objects with computer generated data by using videos of photographic displays (Fukuda et al., 2017).

A spherical curtain defines the physical space (5x5m) of the immersive and embodying setup of the VR environment used in this research. Users with mobile tablet devices are able draw sketches on reference planes that are three-dimensionally navigable inside the 3D virtual environment. The 3D model of Masjid Wazir Khan is imported in this virtual space to visualise as well as annotate drawings through tablets in an immersive way. 3D sketches and annotations are exported in DXF format. These drawings are then compared to the 3D model of the site to show the deviation of lines drawn in VR. Deviation colour maps visualise the level of accuracy in the immersive and embodying environment.

2.4.3. Site: Masjid Wazir Khan

Since, the research had catered installations, photography, mp3s making it a multidisciplinary art form; it became clear that if the research is directed toward bringing these spaces in virtual reality than it may provide more academic conclusions and findings. Hence, Masjid Wazir Khan was selected to be mapped and documented that encapsulated (2) as a sample.

Masjid Wazir Khan is present at the heart of the complex of walled city of Lahore, Pakistan. It was built by Hakim Aliuddin (also referred as Ilmuddin) in 1634 (1054 AH) (Muhammad, 2011). The mosque sets
well in its surrounding of the neighboring bazaar. It is directly linked to it. The bazar opens into the courtyard of mosque. The northern and eastern sides are occupied by encroachments like branches of the structure. There are residential areas on the southern side. These residences share their structural load with the walls of the mosque (Muhammad, 2011).

3. Methodology

The methodology for the research of the conceptual phenomenon and technical aspects is mainly through the historical literature available and its critique. The methodology above explained venture for understanding the user immersive-ness. The second stage includes photogrammetric model. The outer square is documented and the surrounding area is also documented via an iPhone for the immersive and inclusive 3D model. The method that researchers have employed for documenting the Masjid Wazir Khan is SFM, or called in this research is photogrammetry. The Structure from Motion (SFM) method is employed into VR to overcome the challenges that VR and AR provide for documentation of the urban scale projects. It has become increasingly popular and convenient for 3D modelling since the equipment used for it is very basic such as point and shoot cameras/digital cameras and smart phones. It uses free or very cost-effective softwares. The SFM studies are not based on real time calculations such as virtual and augmented reality (Fukuda et al., 2017).

3.1. Procedure

Shahi Guzargaah opens into the Masjid Wazir Khan. It is about 260 meters from Delhi-gate. It is around 550 meters away from Rang Mahal Government high school on the Shahi Guzargaah. The organisation of the process includes various steps. First, the front facade of Wazir Khan Mosque and the square at its entrance are visually surveyed and documented through photographs.

The seven red dots in this Figure 4 show the points from where the pictures are taken from personal mobile “iPhone – 6”. The time of the photographs is in between 8:30 am-10:30 am. The pictures were deliberately taken in horizontal orientation in 360 dial. The three different points were selected from the outer circle to document the pictures and then four different points were selected from the inner circle and documented the inner circle of the mosque (Figure 5). The photographs are on a sunny day and in one go. This brightens the white surfaces excessively which in result causes the parts of geometry to be in a hotchpotch format. Hence, it creates random black holes (Aydin et al., 2017).
The important parameters for the photography for SFM for virtual reality are light, noise elements, locations from which pictures are taken and weather. The early day time was selected to avoid crowd and sun. If the object is not possible to shoot all at once, then the noise elements such as electric wires, people, and traffic are omitted (Fukuda et al., 2017). As a result 650 photos were shot. Regarding this study, the details about the used camera and photos are in the below Table 1.

Table 1: Specification of mobile camera and pictures

<table>
<thead>
<tr>
<th>Camera Specifications</th>
<th>Model: iPhone 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-megapixel iSight camera with 1.5µ pixels</td>
<td></td>
</tr>
<tr>
<td>Autofocus with Focus Pixels</td>
<td>f/2.2 aperture</td>
</tr>
<tr>
<td>True Tone flash</td>
<td>Five-element lens</td>
</tr>
<tr>
<td>Hybrid IR filter</td>
<td>Backside illumination sensor</td>
</tr>
<tr>
<td>Sapphire crystal lens cover</td>
<td>Auto image stabilization</td>
</tr>
<tr>
<td>Auto HDR for photos</td>
<td>Face detection</td>
</tr>
<tr>
<td>Face detection</td>
<td>Exposure control</td>
</tr>
<tr>
<td>Panorama (up to 43 megapixels)</td>
<td>Photo geotagging</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Image Specifications</th>
<th>W: 3267 pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>H: 2448 pixels</td>
<td>Resolution: 72 dpi</td>
</tr>
<tr>
<td>Bit depth: 24</td>
<td>Colour representation: sRGB</td>
</tr>
<tr>
<td>F-stop: f/2.2</td>
<td>ISO-32</td>
</tr>
</tbody>
</table>

This photographic survey is used to build a 3D virtual model of the site by using a photogrammetry tool, Autodesk Remake (Figure 6). The photogrammetric model of the site is a mesh geometry made of polygons. One of the factors that affect the level of detail on such a 3D geometry is the number of polygons. The photogrammetric software allows the repopulation of triangles on a model. The user can usually decrease the number of polygons up to 95 per cent. This would not make any significant negative impact on the end-user’s viewing experience in virtual reality. This paper drives a conclusion through a
comparison between different levels of details in photogrammetric models used in the immersive environment (Table 2).

![Figure 6: 3D model of the site made with ReCap 360. Wireframe (left) and textured views (right).](image)

<table>
<thead>
<tr>
<th>Model Name</th>
<th>General file specifics (in numbers)</th>
<th>Geometry/model specifics (in numbers)</th>
<th>Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>WKhan-40</td>
<td>Uploaded photos: 40 Generated textures: 1 Generated cameras: 28 Discarded photos: 12</td>
<td>Faces: 913,614 UVs: 500,566 Vertices: 457,822 Edges: 1,371,429</td>
<td>V/F: 0.50111 V/E: 0.33382</td>
</tr>
<tr>
<td>WKhan-120</td>
<td>Uploaded photos: 118 Generated textures: 3 Generated cameras: 103 Discarded photos: 15</td>
<td>Faces: 3,066,310 UVs: 1,683,330 Vertices: 1,535,590 Edges: 4,601,885</td>
<td>V/F: 0.50079 V/E: 0.33369</td>
</tr>
<tr>
<td>WKhan-250</td>
<td>Uploaded photos: 250 Generated textures: 3 Generated cameras: 200 Discarded photos: 50</td>
<td>Faces: 3,704,432 UVs: 2,025,818 Vertices: 1,854,504 Edges: 5,558,995</td>
<td>V/F: 0.50062 V/E: 0.33360</td>
</tr>
</tbody>
</table>

In Autodesk Recap, it is observed that the higher number of uploaded photos does not necessarily result in greater details in the model. However, the geometry covers larger space with higher number of geometrical features. The model with higher number uploaded photos, e.g. WKhan-25, can be less desired depending on what areas of the real environment are targeted (Table 2). Our examination continued with the third model in the list, i.e. WKhan-200. Firstly, the number of polygons is decreased by more than 90 percent so that the model’s file size is not too large to run a session in the VR facility (Figure 7). The 3D model (WKhan-200) is then imported into a 3D hybrid virtual environment through which the users are teleported to the site with different view options such as top, side and perspective. Hyve-3D encourages collective immersive experience and aids remote discussions via remote annotations (Aydin et al., 2017).
3.2. Assessment

Users with wholly different cultural background can engage with a realistic visionary experience of the site in Lahore, Pakistan. Our observation and the user feedback provided us a qualitative assessment of the models that the VR facility can compensate lower resolution 3D models with its immersive features. This means that immersive-ness happens between two channels: embodiment and embedded-ness. Another conclusion can be that lower resolution models provide space for users to cast their own understanding to communicate with the displayed realistic environment. Observing user interaction with realistic virtual models allowed us to imagine the living unity in a stream of experiences. The human body, all senses are far heightened through communication technologies (Ralon and Vieta, 2011).

If we attempt to have a comparison between the two agencies then the feedback of the users included comments such as ‘thought-provoking work’, ‘surprising’ and ‘innovative effort’; demonstrates the research has attracted people and left them with positive impression and inspiration for participatory art and digital heritage installations. Virtual reality induced the memory or familiarity with them through materiality and environment. The viewers were from New Zealand hence, it was their first-hand introduction to the area documented. They did 3D sketching on the Hyve-3D, also moved about from their attached tablets. It is important to understand the difference from the previous methods since, it engaged their cognitive senses, along with other mentioned above were expected. This had increased the levels of immersion; state of deep engagement (Sherman and Craig, 2003).

4. Conclusion

It is important to use 3D modelling for planning purposes, mapping the usage of spaces by the people, future preservation of heritage and cities. The project included multiple stages such as installations, sound recordings, and mapping the experiences of users via their story telling. The SFM method employed to produce VR which is cost effective, takes less time and can be much more prolific in terms of user experience & engagement in comparison to prior methods. However, most notably it is significant to make people part of the process, it highlights the phenomenon of “the thing” and enables the user to mould it accordingly. The data of the pictures can be used to study the sites in detail and can help built a database for future projects. Not only large-scale projects, but the similar techniques can also be used in renovation projects and the process can be employed in making the user’s part of the project. The approach of bridging philosophy and technology behind spaces can be further harnessed by taking forth the argument.
and aiming at better results for SFM processes for cultural heritage sites and cities. It highlights the potentialities of surveying heritage sites, its present usage by the people and virtual tourism; doesn’t only respond to the space but also its essence. It will also be beneficial to address queries such as how do we share this information with the audience for its awareness, how can cities be mapped alongside their crux to be discovered by a distant/wider public.

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References

Between Architecture and Construction

A Site of Integrated Learning

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Abstract: In 1994 the School of Architecture and Construction at Unitec Institute of Technology received its first intake for a new Bachelor of Architecture programme. The co-location of this architecture degree within a school that contained construction programmes (Bachelors of Building and Quantity Surveying) was seen to be of collaborative benefit. However, within three years, this new theoretically beneficial formulation had split. Contemporaneously, the University of Newcastle, Australia had adopted a one hundred per cent Problem Based Learning (PBL) model to facilitate stronger relationships for learning with the local profession and construction industry that ran for 10 years. Recently Unitec MARCP students engaged in an integrated design and technology studio project for a comparatively short period of six weeks. In a contemporary education world where collaboration and cross-disciplinarity are the language of currency this examination of the processes of growth and decay in these three events at Unitec and Newcastle provide insights into the potentials and pitfalls of such constructions. This paper will discuss upon these events to draw out issues that might illuminate future attempts to develop integrated learning practices for architecture and construction.

Keywords: Pedagogy; integration; design; technology.

1. Introduction

The work of the best pupils leaving the school shows patently, and every day that the school’s construction course fails to meet the needs of our time. (Saint, 2007,435)

It is a quote that I use every year in my introductory lecture to first year architecture students in technology. That this is a quote from a series of polemical articles on architectural education by Eugene Viollet-le-Duc and Louis Vitet from Paris 1862 demonstrates that the tension between employer expectations and graduate construction knowledge has persisted for some time. Viollet and Vitet continue;

Both the idealism and the instability persistent in architectural education feed off obscurities attending the subjects aims and the public utility of its practitioners. With engineers there is less uncertainty. They are thoroughly trained because they are found useful. (2007, 435)
The distinction, these statements identify, is founded on the oppositions of obscurity and clarity and the subsequent conclusion that the discipline with clarity is, ipso facto, the most useful. The last sentence of the quote seems awkwardly constructed and might almost be construed as; they are found useful because they are thoroughly trained. That construction points to a paradigmatic difference between of methods for learning for and about these different fields where construction knowledge is seen to be gained from training and design knowledge from some other obscurity.

These tensions, as I have noted, have been with us for some time. They are a manifestation of differing perceptions and expectations in the fields of design and construction. It is into the space of these tensions that this paper will delve. It will examine events at the Unitec Institute of Technology, Auckland, Aotearoa, NZ and the University of Newcastle, New South Wales, Australia that demonstrate different pedagogical responses to this tension. This examination will attempt to draw out some principles for a sustainable model that integrates design and construction learning into a holistic view of architectural production. How, in the future, might we design constructive relationships within learning processes that might be models for conduct outside of the place of formal learning?

2. Unitec

In 1994 the School of Architecture and Construction at Unitec Institute of Technology in the Auckland suburb of Mount Albert received its first intake for the Bachelor of Architecture programme. This new programme had been developed by a cohort of staff who had originally taught in the architectural technicians course, the New Zealand Certificate of Architectural Drafting (NZCAD). The Education Amendment Act 1989 opened the way for Polytechnics to offer degree programmes and Carrington Polytechnic (as Unitec was then known) began development of a suite of programmes designed to position it as the premier place of integrated learning for design and construction practice. The Bachelor of Building and Quantity Surveying were started in 1992 followed by the Bachelor of Architecture in 1994. The co-location of this architecture degree within a school that contained construction programmes was seen to be of collaborative benefit. However, within three years this new, theoretically beneficial formulation had split and architecture and construction had reverted to predominantly separate programme structures located at opposite ends of the campus.

There are several strands that might inform this split. In a contemporary world the differences (and one might also mean divisions) between design and construction are embedded in conventional contractual arrangements. They are also deeply embedded in personal attitudes of the disciplines towards their other disciplinary collaborators and counterparts. One experienced construction educator remarked that it often takes only a summer holiday job to inculcate these attitudes. (Birchmore, 2002) The contractual and personal are interwoven and mutually reinforcing. The history of the split at Unitec is illustrative of these tensions and might serve as an object lesson on how not to conduct business and so provide useful insights for the future.

The Bachelor programme in Architecture began in 1994. It was developed under the leadership an architect and educator who subscribed to an idea that buildings were produced by groups of people with contributing skills and abilities. In the original proposal for the new architecture programme this was described as a “building team” approach and a

...reaffirmation of an approach to design that is both broad (technical, practical, spatial, contextual etc) and long (from problem setting to post occupancy evaluation and beyond. (Matthew, 1991).
This lead programme developer was supported by staff members from the then Department of Architecture and Construction comprising architects, draughts-persons, engineers, quantity surveyors and building construction managers. The Department was headed by an architect who was also a member of Commonwealth and NZ Institutes of Building. He was recognized across both fields - design and construction. In 1994 Carrington Polytechnic became Unitec Institute of Technology and with that new name came a new Faculty of Architecture and Design headed by this architect as Dean. The faculty moved into new premises at the north end of the campus and into the two-storey, brick building designed for the Whau Lunatic Asylum and originally opened in 1867.

Once Carrington had approval for the degree programme from NZQA in late 1993 a permanent Head of School was appointed. The new Head of School was a Scot who had spent 5 years at Victoria University in Wellington and the last six years in charge of the technology stream in the School of Architecture at the University of Western Australia (Miller, 1994, 79) Anecdotal evidence suggests that this new appointment was not the ideal or even preferred candidate. He was seen by the construction faction as having little local construction knowledge and viewed with suspicion by the architecture faction because of his construction experience. As a result, he was undermined and marginalized by both groups leaving him no choice but to resign before the year was out.

A Quantity Surveyor was the Programme Director for the other two Bachelor programmes [Building and Quantity Surveying] under the School of Architecture and Construction umbrella. When the Head of School resigned the Quantity Surveyor took over as acting Head of the Architecture Programme. This heightened the tensions. In the view of the architecture staff, his attitude towards architecture reflected his profession’s instrumentalist views. The prospect of his appointment having permanency galvanized the architecture staff. They discussed and collated their views in a staff briefing document in July 1995 and arranged an after-work meeting with two senior members of the Advisory Panel set up to help develop and later support the degree. Shortly after that meeting these two senior architects visited the Dean of the Faculty of Architecture and Design to convey the staff views. The Dean, also a pragmatist, made the decision to split the School into Architecture and Construction.

The separation was difficult and painful. One former staff member when asked for an interview for this paper, refused stating “it still hurts”. The lead programme developer elected to go with the “new” Construction programme. He believed that he had conducted an inclusive and exhaustive consultation process in the development of the bachelor programme with processes for regular review. He was frustrated by the separatist disciplinary manoeuvering that had, without inclusive consultation, dismantled the integrating trajectory of the original idea/configuration. But it happened and what is more important to us now; is why?

We can identify certain belief systems that are held by architects and the other major disciplines (engineers, quantity surveyors and construction managers) in the field of design and construction. They are largely related to chronology or sequencing of processes and have implications in contractual arrangements as discussed earlier. Out of this conventional separation in sequence comes a separation of skills. The argument is that because the skills are different we need specialist teachers and specialized programmes and the best way to impart the knowledge is to concentrate the students into their disciplinary groups to impart the deep knowledge required for each specific discipline. Critics might describe this as a silo. The 1994 Unitec model had proposed to co-educate architects, quantity surveyors and Construction managers with the intention of sharing some base knowledge and facilitating personal and professional mixing by getting them to ‘rub shoulders’. (Wood, 2016)
While the initial physical separation was fast [construction returned to the other end of the campus shortly after the split was announced in late 1995] the curricular separation was still being debated in 2002 as a letter from a senior Construction staff member to the Head of the School of Architecture confirms. The Head of the School of Architecture, had called for a review of the combined courses and the Construction staff member was responding, articulating reasons for the Construction Department’s desire to maintain these combined courses. He described the cross-disciplinary tension that he saw.

It usually takes the form that architects think the others don’t have a creative bone in their body, no appreciation of design and only an interest in things that can be counted or making things simple. The counter criticism usually hangs around observations that architects aren’t interested in the practical things like ‘will it stand up, can it be built’ or ‘can it be afforded?’.

(Birchmore 2002)

He goes on to add.

I believe one of the sources for this ‘tension’ which I’m not sure is creative is the lack of respect for the challenges that need to be faced by each of the team members. I think this lack of respect grows from ignorance of these challenges. (2002)

We seem to be getting in this correspondence an alliance of creativity with design and a denial of such with construction. It could also be characterized as a play(creativity)/work(construction) dichotomy. It is a dichotomy identified by Peggy Deamer in her recent book ‘The Architect as Worker: Immaterial Labor, the Creative Class and the Politics of Design.’ (2015) Deamer claims first, that as architects “we do not believe we do work. We fail to conceptualise our work as work” (2015,61) and secondly “We have a pathetic notion of design that isolates it from work. Architects design, constructors build; we do art, they do work” (2015,61)

These positions parallel the sentiments articulated by the Construction staff member. In “Work” (her chapter in the book) Deamer discusses the group of artists that have conceptualised art as work.

Just as the tradition of art-as-labour suggests that architecture as a profession should consider ‘labor value’ the tradition that sees human work as inherently imaginative, creative and self-realising should be equally embraced by architects. Creativity in architecture rests not on an ever-expanding categorical inclusion of form making but rather on an imaginative approach to problem solving. (2015, 67).

Deamer is arguing that architects need to have a more inclusive view of the design and construction process, one that has respect for the contribution of all participants.

Architecture has always strongly defended its disciplinary boundaries. There is an argument that maintains that secure disciplinary identity is precisely what allows an architect [and here you could substitute Engineer, Quantity Surveyor, Construction Manager or any other discipline] to engage with confidence with other disciplines. If this is a valid argument, then the pedagogical questions that follow are; how do you construct a method of learning to act within this discipline while at the same time being a participant in the broader field of construction? How do you learn behaviours that are both exclusive and inclusive?
3. Problem Based Learning (PBL)

During the same period of development and implementation of the new Unitec Bachelor of Architecture programme there was a pedagogical movement termed Problem Based Learning (PBL) that was being introduced, trialled and developed in professional studies programs in North America, Europe and Australia. (de Graaff and Cowdroy, 1997) The most significant local example of PBL was at the School of Architecture, University of Newcastle, Australia where they ran a 100% integrated architecture program for about 10 years (1984-94), then a partially integrated program for another 6 or 7 years (History, theory and research methods were removed from the core integrated component).

The program was highly innovative and for motivated students, it was incredibly successful. The architectural profession loved it. (Ostwald, 2017)

De Graff and Cowdroy (1997, 168-169) identify some basic principles shared by most PBL versions:

Didactic principles
Students are responsible for their own learning
Cooperation rather than competition
Active acquisition of knowledge and skills
Professional orientation
Holistic orientation towards professional practice
Integration of knowledge from different domains
Integration of knowledge skills and attitudes

The Newcastle programme faltered for several reasons. Ostwald (2017) identifies them as; (i) cost factors (time and staffing) (ii) lack of compliance with university systems, (iii) lack of flexibility, (iv) some student retention problems. All, I suspect, are related and intrinsic to the formulation. The undefined nature of the PBL process means that curricular requirements, those requirements valued by the institution, are often hard to manage. The research nature of PBL identified in the didactic and professional principles noted above stretch and contract student and staff time in unexpected ways making time allocation complex and difficult to sustain. This in turn generates a planning instability that could be described as inflexibility. The student centered orientation requires staff to play a more facilitative role rather their traditional role as design master – a role they may not be good at or enjoy. The PBL model adopted at Newcastle came not from comment about the lack of construction knowledge of its graduates but, ironically, from a threat to become part of the much larger Engineering Faculty. However, in response, the local profession lobbied the university to retain the school and develop a new approach. The architecture programme then adapted the PBL model from the Medical School that had recently been established on the same campus.

4. Comparisons

Although the reconfiguration of the Newcastle programme was generated by different circumstances from the new Unitec degree they do share similarities in aims. Both were recipients of active local professional support. In the Unitec case it was because of a perceived lack of professional and constructional orientation in the adjacent Auckland University programme. For Newcastle the initial imperative was to maintain independence from a threatened merger with the Engineering faculty. The adoption of a pedagogical approach strongly aligned with local professional agenda was a perfect fit. For
both this outreach to the profession and the subsequent validation of the role of the profession in learning was important.

The significant difference appears to be in the make up of the student cohort. While the Unitec architecture programme was originally located within a School of Architecture and Construction and course and classes co-taught, the Newcastle programme was exclusively a single discipline (architecture) one. The thesis that core knowledge and the experience of architecture students rubbing shoulders with students from associated disciplines does not appear to have been part of the Newcastle agenda in the same way.

5. Integrating Design Studio and Technology: Utopia Waiouru

The Unitec architecture programme, at both undergraduate and post graduate levels has, for several years, been actively responding to the persistent calls by external examination bodies for integration of technology teaching/learning and design studio. (IRP, 2017) Traditionally, in Schools of Architecture, the Design Studio has been identified as the course in which the integration of all lecture subject material occurs. Empirically however, we know that the opposite is the case. In most programmes, this traditional structuring functions is a dis-integrating mechanism unless active agency is applied.

During the last two years a six-week design studio project in the first semester of the first year of the MARCP Design Studio has been aligned with the technology lecture course. The activating impetus for the integration, in this case, comes about because of shared interest and belief in the importance of construction knowledge for design by the two course leaders, both of whom are tenured staff members and Registered Architects.

The project aims were specifically directed towards construction technology as the driver. The generic Design Studio project needs to engage issues of programme, site, technology and theory. In this project technology, as structure and envelope, was prioritized. The necessary context (Programme, site and theory) had been generated by the initial six weeks of study that had involved analysis of a three utopian cities/settlements and the application of these learnings to the design of a contemporary utopian city for 75,000 refugees in Waiouru. Design development of programme and site was deliberately subordinated. Space planning and site planning were simply “taken” from the earlier project. Theory was carried over from the earlier section of the project (the first six weeks) in the form of the question; What is a utopian tectonic? Theory was supplemented by a series of readings that examined the performance of structure and envelope technology.

Other elements of project design were subject to an integrating approach. The Design Studio course for the six weeks of the project was co-written with the Technology lecturer. The majority of the presentation requirements were the same in each course with Design Studio requiring only some additional contextualizing material.

The integration of performance of the two courses took place at a number of levels:

1. The whole of the lecture course was attended last year by the Design Studio leader.
2. Selected lectures this year were attended by the Design Studio leader.
3. Site visits in the lecture course to a precast factory, a façade manufacturing factory and timber laminating factory were all attended by both course leaders.
4. A curated Trade Fair showcasing cladding/facade materials was attended by both course leaders.
5. The Technology course leader was a member of the interim and final review panels for Design Studio.
6. Both Course Leaders were participants in the post review marking and moderation processes for both courses.

And, there was an additional layer of technical support. A Structural Engineer was embedded in the studio. He attended every studio session and interim and final reviews. His opinion was seen to be valued. He was given the first response to a project in all reviews. His assessment mark was an identified component of the final grade.

Anecdotally, the outcomes have delighted students and staff. Students remark upon the presence of the engineer in the studio as being particularly valuable. A recent visit by the Interim Review Panel (IRP, 2017) remarked upon the high quality of the work being done within the programme to maintain and extend the integrated teaching of design and construction technology.

6. Discussion

The three examples, described above, were all attempts to integrate a series of strands into a cohesive body of knowledge to enable a graduate to begin performing effectively as an architect. The original Unitec Bachelor of Architecture programme in 1994 was predicated upon the idea of the “building team” and sought to co-teach groups of students in design and construction. It foundered because the architecture staff felt that the course content required by co-teaching was a poor compromise for both architecture and construction. There was not enough design in the course for the architects and not enough construction for the construction students. (Birchmore, 2002) There were other contributing issues that have been anecdotally identified; the possibility that the head of the architecture programme could be a Quantity Surveyor and the experience of the enmity between architecture and construction being played out in the lecture theatre. There is also the argument that there were significant differences between academic cultures within the two areas that exacerbated the tensions.

The Newcastle programme configuration was generated by the threat of disciplinary subordination; the prospect that it might be subsumed under an Engineering Faculty. (de Graaff and Cowdroy, 1997). Like the establishment of the Unitec new programme, the Newcastle programme had originally also grown out of a technicians course at a Technical College. They both received strong support from the local profession. Whereas the Unitec model might be seen as internalized integration around the student cohort (students rubbing shoulders and sharing base knowledge) the Newcastle problem based model (PBL) could be seen as externalized around knowledge. The foci for integration were different. They both push stress during the performance of the course to different areas. The Newcastle model exerted temporal organizational pressures due to the fluid nature of the problem/research process. The Unitec model exerted pressure on the organisation/provision of content that satisfied both parties without compromise. This is obviously an oversimplification of the issues but I think it is useful as it highlights some issues that might be capable of re-design. The significant impression is that both models both placed enormous pressure on staffing. These new configurations required for their success; the role of the architectural educator as a facilitator rather than the master design tutor at Newcastle and for staff at Unitec the need to model the product of architect/constructor with equal respect for and appropriate knowledge of both fields.

The final example described, Utopia Waipoua, is of a different scale and took place within an existing programme with a conventional lecture/design studio dis-integration model. The important thing identified is that it required enormous effort beyond the normal institutional rationing of time to organize and perform. It required a consistency of purpose [to focus only on structure and envelope], project
design [to reinforce this with complementary timetabling, assessment/grading schedules and readings] and performance [complementary lecture content and consistent, focused studio discourse with students]. For a Design Studio project to have focus within the short timeframes designated something has to give, to take back seat. To integrate lecture subject material, that which is discriminated against by its location elsewhere, requires affirmative action. To integrate requires that element, in this case technology, to be elevated to the same status as design. Design is applied to technology and technology is applied to design in equal measure. This has to be a focused act and other architectural design issues of programme and site must be marginalized. We must also face the pressure of conventional paradigms of technical training and creative design. To achieve this staff must be skilled at articulating the focus of this issue, generating an atmosphere of creative work and be equally able to critique its products. These are tall orders.

7. Conclusions

This is not a new insight. The first two stories happened thirty to forty years ago. They illustrate the need for a collective vision for success. Both of these configurations, Newcastle 1984-1994 and the new Unitec programme 1994-1996 required particular values to be shared and particular skills to be performed. They required what might be termed a culture. They existed for different periods of time but faltered and changed because the necessary components for sustained success, a shared vision and appropriate skills, evaporated. The Waiouru project can be seen as a success because the time frame was short and the staff involved had established a vision based on shared experience, shared values and mutual respect. They had established a culture to sustain that project – but they only had to do it for a short time. There are a number of conditions that need to come together for the effective and creative integration of design and construction. Maybe these conditions can occur only occasionally, they are like sunspots, brilliant explosions and by their nature short-lived. We must acknowledge these conditions and during the next fifty years organize our places of learning to provide capacity to encourage and provoke such explosions.

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A Visual Consultation Method for Understanding Spatial Use in Remote Aboriginal Housing

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Abstract: Appropriate housing within remote Aboriginal communities is a chronic issue. With government funded, public housing projects aiming to procure maximum housing units for minimum cost, in the shortest period, cultural aspects of housing provision are often neglected. Insufficient and ineffective consultation is a significant factor in the deficiencies found in the procurement of public housing situated in remote Aboriginal communities. The paper proposes that addressing spatial use patterns through community consultation in housing has the potential to enhance housing quality. Due to the time and the expense associated, individual client consultation in current procurement strategies is limited, at best, generally resulting in housing which inhibits social function and cultural expression. This paper reports on a visual consultation method to overcome the economic and time restitution of typical housing procurement in remote Aboriginal communities. The paper presents “The House Game” an interactive consultation method that facilitates the understanding of spatial use patterns. The paper demonstrates how these patterns can be used for post-occupancy evaluation and the formulation of architectural briefs for appropriate housing.

Keywords: Visual consultation method; spatial use patterns; remote aboriginal housing.

1. Introduction

The provision of culturally and environmentally appropriate housing is a chronic issue within remote Aboriginal communities. Current procurement strategies are failing to meet the required benchmarks to alleviate the inequities of remote Aboriginal housing. Insufficient and ineffective consultation is a significant factor in the deficiencies found in the procurement of public housing situated in remote Aboriginal communities. In addressing this situation, many procurement approaches have been implemented over the past sixty years, Document Design, Design Development and Construct, Design and Construct, and Guaranteed Maximum Price, just to name a few (Davidson et al., 2011). With the current strategy of government funded, public housing projects to produce maximum housing units for minimum cost, in the shortest period. However, it has been shown that providing large quantities of housing quickly without consultation, rarely result in healthy outcomes (Memmott, 2008)(Pholeros and Phibbs, 2012). Inherent to the procurement method is the consultation methodology, which has been identified as a key contributor to the success of a housing project (Lee and Morris, 2004). This paper presents the results of
a research project aimed at developing a visual consultation methodology for understanding spatial use in remote Aboriginal Housing.

2. Consultation Methods

Typical methods of architectural consultation in time poor environments consist of, semi-structured interviews with individuals or community focus groups, which have a set of open questions, contextualised within study theme, which is open to a slight deviation. Or, questionnaires that present a ridge set of, questions in which the participant must indicate an answer. Both semi-structured interviews and questionnaires have significant barriers when working within remote Aboriginal communities. Often English is a secondary language; literacy level can be low, a combination, which makes comprehending question and articulating, answers difficult, with miss-understanding or miss-communications often (Lee and Morris, 2004, Memmott, 2008). Furthermore, the power inequity between participant and research can result in responses which the participant is pre-empting the answer the researcher wants. In general terms, the data resulting from questionnaires and semi-structured interview do not lend themselves to the interpretation of more complex aspects of sociocultural spatial use. Not all research questions require an understanding of the rules and principles governing everyday life, but most architectural research relies on at least a limited gathering of the data necessary to discern the rules and principles of sociocultural use in a given setting. In the current political and economic climate, due to the time and the expense associated, individual client consultation is limited, at best, generally resulting in public housing which inhibits social function and cultural expression. This has a detrimental effect on the sociocultural spatial use and overall physical and mental health of the occupants (Bailie and Wayte, 2006).

Overwhelmingly, research into remote Aboriginal housing procurement presents a similar outcome; involve the residents and community,(Lee and Morris, 2005, McGrath et al., 2005). Memmott (2008) specifically outlined the consultation process should support both the traditional owners and the residents who use and own the housing. Ideally, the best method suited to producing a comprehensive understanding of the community and the particular use of the domiciliary environment is participant observation and in-depth interviews conducted over an extended period. However, due to economic and time constraints, it is often difficult to carry out this type of extensive consultation. Subsequently, it’s becoming more apparent the method in which people are asked ‘what they require?’ is just as important as the question itself. Typically, visual consultation methodologies are seen as effective methods of communication when working with non-Aboriginal participant/clients though rarely used by planning or housing agencies (Lee and Morris, 2004).

The House Game is a consultation methodology which has been developed to facilitate a better understanding of how sociocultural modifiers affect the spatial use and sort to overcome the economic and interpretive limitation of traditional consultation methods. The House Game as a visual consultation method used to facilitate post occupancy evaluation (hereafter POE) of the participants existing house and establish the spatial planning and sociocultural use of the participant’s ideal dwelling. Visual thematic analysis is utilised to determine spatial requirement and sociocultural use. With a comparative study of results used to identify and highlight discrepancies in sociocultural spatial use.
3. The House Game Method

The House Game method is typically conducted in two parts; initial conducting POE on the participants existing dwelling, while collaboratively building a common visual and spoken language. Then discussing the participant’s ideal dwelling, considering both the spatial planning and sociocultural use, while simultaneously establishing patterns of spatial use and developing an architectural brief.

The House Game is designed around the format of a board game. Participants are asked to draw a floor plan of their existing dwelling. The drawing of their existing house plan constitutes the game board (Figure 1 right). They are then presented with a variety of gaming pieces which, included Parcheesi, Battleship, and Checkers (Figure 1 left). Providing a collection of pieces with a variety of colours and shapes, used to represent the various statuses of household members and visiting kinfolk.

![Game Pieces and Game Board Example](source: H. Farley)

A wide variety of shapes and colours is needed to represent the full range of kin relations recognised in Aboriginal society. These include, for example, the developmental differences among children of varying ages according to whether or not they are socially independent enough to sleep without their mothers, the respect that must be accorded to older kinfolk according to status acquired (or not) in service to the family, men and women who travelled singly as opposed to conjugal partners, and so on.

Once the representation of the range of kinfolk is settled, the participant is asked to use the game pieces to represent the existing household membership according to sleeping space. From the arrangement of people, in relation to the dwelling, the researcher poses a number of hypothetical scenarios, all contextually specific and designed to elucidate the pattern of spatial use that reveals design requirements which, are culturally unique to Aboriginal people. Beginning with occasions that might result in a small number of visitors; the regular exchange of visits between mothers and daughters for example; progressing to the occasion which results in the greatest number of visiting kinfolk, for instance, a funeral. Knowing the rules governing the full range of association of kinfolk by age, gender and status reveal the nature of the use of domiciliary space and explains why, for example, one bedroom holds only one conjugal couple and another bedroom is occupied by as many women and children as physically possible.
4. The House Game Method Example

The example discusses (LAVH01) the spatial investigation conducted with middle aged, Noongar women living in Laverton, Western Australia (Figure 2 left). LAVH01 is a double brick, four bedroom house with a single carport, which exhibits no design response to either the environmental conditions or Aboriginal culture (Figure 2 right). The participant shared the dwelling with two young boys, two adolescent girls and a young mother and infant, totalling seven permanent occupants.

4.1. The House Game – establishing a spatial map

To start the POE process, the participant drew her spatial understanding of the dwelling in the form of a ‘floor plan’ as shown in Figure 3. The proportion of spaces and furniture were not measured and therefore not proportionally correct. However, this activity is a spatial mapping exercise which enables the participant to gain confidence in generating a plan and discussing the building in which she lived. Facilitating the development of the common visual and spoken language between researcher and participant.

Figure 2: Map of Australia – Laverton marked by red dot (left) (Source: Melbourne University Library – University of Melbourne) Field sketch of LAVH01 (right) (Source: H. Farley)

Figure 3: LAVH01 - Participant drawn spatial mapping – floor plan. (Source: H.Farley)
4.2. Mapping residents

The participant then populated the floor plan with all permanent residents using her choice of the game pieces (Figure 4). All residents were represented in what was termed their private space, areas typically classified as bedrooms, individual private spaces' were allocated by age, gender and family group. With each area generally accommodating more than one person (Figure 4).

![Figure 4: Existing dwelling showing current residents (Source: H.Farley)](image)

The participant, who was the primary resident, grandmother and guardian to the younger children occupied the ‘master bedroom’, also culturally the most senior member of the household which therefore entitled her to the most significant space within the dwelling. The two young boys occupied a single room, as did two adolescent girls, with the last bedroom space assigned to a young mother and her baby daughter (Figure 4).

From the placement of current residents, it is evident the bedroom space are used as private space. Specific cultural rules also govern the sentiment of private space. A private space within Aboriginal culture is not considered an individual private space for just one resident. The agreed residents occupy assigned private spaces. In this case, the two teenaged girls have an agreement that the bedroom space they occupy, is their private space; this space is not considered the private space for any of the other residents.

The private spaces accommodate a number of uses, private gathering, private sleeping, secure storage of goods and function like a house within a house (Figure 6 left). Occupants then shared bathing, cleaning and cooking facilities (Figure 5 centre), with the kitchen, dining and living spaces used as communal, gathering areas (Figure 5 right) where general socialising occurred.
4.3. Mapping scenarios

Once the spatial allocation of the permanent residents was established and mapped, a number of hypothetical scenarios are posed. The scenarios are used as a generative tool, creating conversational points designed to elicit the spatial use of the dwelling. The first scenario posed to the participant was; “if there was a funeral where would your brother, his wife and their three children camp?”, slowly increasing the number of visiting kin. As seen in figure 6 each family group is allocated a private space (bedroom), with some younger permanent residents being re-allocated within culturally excepted norms. In light of the increased numbers of residents, the already established private spaces were maintained.

At this point the participant stressed there was no drinking or camping (staying for an extended period) at her house and if people wanted to cook outside they “go bush” (Interview one, 6/2014, Laverton). An important statement, regarding spatial use, allocation of space and the overall functioning of the dwelling. No cooking outside has an influence on the external use of the dwelling, external gathering areas would be reduced or removed. Additionally, no camping or staying for an extended period also changes the occupancy of communal spaces as these spaces are typically used to accommodate kin, who can not be allocated a private space of their own.

Concluding the POE, it was evident the residents occupied the house in what could be considered a conventional manner. That is, the family occupied the spaces defined by the design intent of the house, living spaces were used for social gathering as was the dining area, the kitchen was used to store and prepare food. The only spaces which had been manipulated to suit the sociocultural requirement of the family were the bedroom spaces, each being used by a number of individuals or family for private sleeping, gathering and storage. It is evident that the occupant can undertake all daily activities within the current bounds of the dwelling, however in doing so increasing the physical demands of the dwelling and increasing the potential for mental and physical health implication linked to overcrowding.

Furthermore, the participant and researcher had developed a common language in which spatial allocation and use could be discussed. The House Game created a platform, which allowed the participant
to discuss sociocultural aspects of the participant's life and how this modified the spatial use of the dwelling.

**4.4. Mapping the ideal dwelling**

The House Game method is then conducted again to establish the spatial planning of participant's ideal house (Figure 7 left). Mapping the ideal dwelling was where the participant's creative imaginations flourished; the participant was asked to draw what they considered their 'ideal' house, considering interior and exterior relationships, private and communal spaces.

*Figure 7: Ideal house plan (left), summer occupancy (centre), winter occupancy (right). (Source: H. Farley)*

*Figure 8: covered central space (left), fire placement (centre), fire placement in elevation (right). (Source: H. Farley)*
The participant perceived some benefits from this type of planning, particularly the breezeway which runs through the centre of the dwelling (Figure 8 left). As evident in the comparison of summer spatial allocation (Figure 7 centre) and winter spatial allocation (Figure 7 right), this space is key to the healthy functioning of the family group. With men and young boys sleeping outside of the private space in summer and moving into the private space in winter.

This dividing space facilitated the separation of spatial uses allowing everyone (generally term refereeing to individuals or individual families) to have their ‘own space’ (interview one, 06/2014), facilitating privacy in regards to life stages, gender and birth family groups. The participant outline the left side of the dwelling would be used for private activities (private sleeping, private gathering and private secure storage of goods) (Figure 9 left) while the right side for communal activities such as cooking, gathering and depending on accommodation requirements semi-private sleeping (Figure 9 centre). It was explicitly expressed verbally and supported by the visual data, these types of spaces (communal and private) were best kept separate, providing the occupants with enough space to adhere to established sociocultural rules. The provision of two bathroom facilities was also required to allow the residents to adhere to the sociocultural rule, such as the mother in-law, son in-law avoidance relationship.

The participant specified the roof covering the breezeway would be higher than the other roof, with mesh covering the side, which allowed the occupant/s to have a fire in a covered area, as a ‘fire is always needed, but needs to be covered’ (Figure 8 centre, right). The fire, in this case, would primarily be used for heating, with a secondary function of cooking.

5. Conclusion

The paper presents the results of The House Game as a consultation methodology that can elicit patterns of sociocultural spatial use, while overcome economic and interpretive limitation of traditional consultation methods. Using The House Game as a catalyst to discuss what the participant is doing opposed to what they have done provides more dependable and insightful than interview or questionnaires. As what people say they do is often different, to a greater or lesser extent, from what they actually do. This is evident, through analytical comparison of the existing and ideal dwelling, discrepancies in sociocultural spatial use can be highlighted, for example; through POE the participant stated “if people wanted to cook outside they go bush”, however when considered the ideal house, the participant decisively included spaces (Figure 8 centre & right and Figure 9 centre) which would support cooking outside and camping for longer periods of time irrespective of climatic conditions. It can also be
inferred, although the existing dwelling provides the basic necessities, shelter, cooking and bathing facilities and spatial opportunities for gatherings, the design does not support cultural expression. Furthermore, the House Game supports the identification of design modifications that are informed by sociocultural modifiers. Subsequently, the objective results of visual consultation methods, like The House Game, can be used to reduce the time required in the field whilst maintaining the validity of results. Providing concise information to help overcome the systemic cultural preferences of the house provider over the recipient (Lee, 2004)

6. Future Work

Transitioning from paper to digital interface is the next step in developing The House Game consultation method. Current parametric models have been applied to address adaptation to climate, change building fabric or optimizing planning (Yifeng. L and Shanshan, 2012, Chronis and Liapi, 2010, Donath and Bohme, 2007). However few studies exist of parametric, digital adaptation in response to sociocultural use patterns. The House Game method as outlined in this paper can also be extended to establish sociocultural patterns of spatial use as parameters within a digital housing model (Woodbury et al., 2007, Madkour et al., 2009). This could facilitate the live adaptation of a digital model through The House Game process. Through the consultation process, the building model could respond to a specific context and sociocultural spatial use patterns within in hours if not minutes.

Acknowledgements

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References

Bailie, R. S. & Wayte, K. J. (2006) Housing And Health In Indigenous Communities: Key Issues For Housing And Health Improvement In Remote Aboriginal And Torres Strait Islander Communities. The Australian Journal Of Rural Health, 178-183.


Abstract: Crowding is a pressing issue in New Zealand residential housing. Over the next thirty years, our population is expected to grow to 6 million, up from its current 4.6 million. With this, it becomes increasingly important to provide guidance to designers on how to best design spaces so our burgeoning population can thrive. Crowding in New Zealand is particularly a problem when multi-generational families increase loads on internal amenities, with homes often stretched to accommodate more than they were designed for. Spatial standards have been introduced in New Zealand that help to mitigate the issue, but do little to address the unique spatial needs of our culturally diverse population. This paper assumes the need for a universal standard to guide building in this country, and asks: How can New Zealand determine a spatial standard for minimum dwelling size that considers the needs of our culturally diverse population? It examines existing spatial standards, assessing how they address the spatial requirements of various cultures, and, a set of design guidelines that articulate spatial relationships for culturally sensitive dwellings. This paper outlines an approach for amalgamating these documents, making recommendations for the development of a universal standard appropriate for New Zealand.

Keywords: Housing; standards; appropriateness; culture.

1. Introduction

In “Maximum vs. Minimum: size and the New Zealand House”, Guy Marriage (2010) questioned whether New Zealand should follow the lead of international policymakers in legislating a minimum standard for dwelling sizes, or whether it should leave this regulation to the market. The paper took as a case study Auckland’s shoebox apartments, which at one stage were being produced as small as 18m². Clinton Bird’s 2005 work on sizing standards for Auckland City Council saw this increase to a minimum of 35sm², almost doubling the original floor area and vastly improving the quality of living in new developments. However, cultural design principles were outside of the scope of the Bird’s considerations.
“Maximum vs Minimum” covered important areas including average dwelling sizes, apartment living and existing housing regulations in New Zealand. It also looked to international housing regulations, specifically focused on the *Parker Morris report (1961)* and the *2010 Housing Design Guide in London*. Marriage argued the importance of considering a legislated standard for minimum dwelling size in New Zealand, noting the following consequence of an unregulated market:

There is an argument that good design can compensate for smaller size and that therefore the market should remain unregulated; that good quality, well-designed, small housing units will make their way onto the market at affordable prices. This appears to be an unlikely outcome - there is no practical way to legislate for good design, and while high quality and good design may be often found together in more expensive developments, it must be recognized that without financial or legislative imperatives there is little incentive for developers to spend up large on either good design or an adequate area of dwelling (Marriage, 2010).

“Maximum vs Minimum: size and the New Zealand House” set the foundations for understanding why we need a set of regulations for determining minimum spatial standards in our country.

In the seven years since this paper was published, a number of much-needed cultural guidelines have been released addressing the unique spatial needs of some of New Zealand’s diverse population. For example, Housing New Zealand (HNZ) published both “Ki te Hau Kainga – New Perspectives on Maori Housing Solutions” (2002) and the “Pacific Housing Design Guide – Guidelines for Designing Pacific Housing Solutions” (2002).

This paper builds on the foundations set by these documents in order to address how New Zealand might go about determining a set of spatial standards for dwelling sizes that considers the adaptable needs of its culturally diverse population. It looks to international spatial standards in order to identify whether or not a comparison can be made for the recommended, adequate area of living between international case studies and New Zealand. It sets out to establish a method for developing a stronger relationship between existing standards for dwelling sizes and cultural design guidelines in New Zealand, in order to establish a methodology for how such a culturally sensitive, universal standard for New Zealand’s population could be determined.

2. Methodology

The research for this paper was initiated through a survey of international spatial standards – specifically those further developed as seen in Ireland and England – to assess their relevance to New Zealand, and then focused on New Zealand standards. This paper identifies existing, non-legislative standards from around the country based on a set of specific variables and examines their relevance to our developing, culturally diverse population. It identifies the strengths and limitations of each standard and uses this process to establish a set of recommendations that should take place when implementing a legislative, culturally appropriate standard for minimum dwelling sizes in New Zealand. Developing a body of research in this way allows us to understand of how and why we should develop spatial standards for the whole of the country.

To allow for a common variable across the standards being researched, ‘dwelling’ is used as a universal terminology to cover all dwelling types, including both apartments and stand-alone housing. This allows for a common variable across all standards selected, regardless of the typology they cover and has been implemented in this way due to the scope of existing spatial standards in New Zealand. This paper
Developing Culturally Appropriate Spatial Standards for Dwellings in New Zealand examines the relationships between the standards and guidelines, identifying key components that must be considered when developing a universal spatial standard for New Zealand. It also establishes a method for developing a stronger relationship between the existing standards for dwelling sizes and the cultural guidelines.

Research was broad in scope, through a combination of digital and physical archival research, and identified key dwelling standards from New Zealand and around the world. While attempting to consider the diverse range of ethnicities in our country many of the considered standards were either not in a format that could be translated to English or the circumstances of their development were beyond the scope of this report and were thus not used in this body of research. From this process, the following standards and guidelines were identified:

- Minimum Standards for Residential Apartments – MSRA (New Zealand, 2005)

Similarly, common variables were identified across cultural guidelines, identifying “Ki te Hau Kainga” and the “Pacific Housing Design Guide” as key cultural guides. Both standards were found to contain narrative-focused information for interior spaces including: bedrooms, formal living, informal living, bedrooms and utility spaces. It is important to note that the terminology they used varied from guideline to guideline, but the overall purpose for each space remained the same.

3. Spatial Standard Research

Understanding existing spatial standards for dwellings in New Zealand allows for the identification of whether they are appropriate for regulating spatial requirements for New Zealand’s culturally diverse population. The five standards investigated form the foundation for the body of spatial standard research in this paper. This research acknowledges that these five standards are only a select few of what is available in New Zealand but have been selected for the sake of a set of common variables. We also referred to “Homes for Today and Tomorrow” by Parker Morris, published in 1961. Known as the Parker Morris report (1961), it was compiled by the Parker Morris Committee to focus on space standards in the United Kingdom’s booming post-war public housing. The report, influenced by empirical data including the measurement of kitchen benches, utensils and human anatomy requirements, concluded that the overall quality of social housing in the UK needs to be improved to align itself with the rising living standard of its people. The Parker Morris report also acts as the foundation for the London Housing Design Guide (2010).

Research into the existing spatial standards for dwellings in New Zealand, England and Ireland highlighted that a strong structure and background allowed for spatial standards to make justified recommendations towards what an ‘adequate’ area of living should be. It was also identified that the methodology published in the Parker Morris report, which provided insight into how calculations of recommendations were made, allowed for flexibility in the design of dwellings. With a consideration for these, the standards gave the designer the opportunity to design dwellings beyond the minimum requirements set out. However, it also found that all five standards investigated lacked consideration for the dynamic needs of varying cultures. Many of the recommendations made in these standards assume a ‘universal’ client – or inhabitant – rather than considering the needs of a culturally diverse population. If
New Zealand were to introduce a legislated minimum standard that addresses the unique needs of its diverse range of cultures, it will need to address the diverse array of living requirements to ensure an adequate area of living is provisioned for everyone.

4. Cultural Guideline Research

Existing cultural design guidelines in New Zealand were examined in order to understand whether their scopes were appropriate enough for developing a legislated, minimum standard for dwelling size in New Zealand. It is essential to note that both guidelines have been published by HNZ for their specific developments but the recommendations in each are universal to the cultures they discuss.

Written by Rau Hoskins, Rihi Te Nana and Peter Rhodes in 2002, the “Ki te Hau Kainga” Māori housing guideline was published by HNZ to compliment their annual dwelling spatial standard, highlighting the dynamic needs of the Māori culture. The “Pacific Housing Design Guide”, written by Faumuina and Associates, was published for the same use, but specifically for Pacific cultural needs. The guidelines are predominantly narrative-based, focusing on internal amenity layout and the need for increased spatial requirements to accommodate for fluctuating occupancy levels for Māori and increased occupancy levels for Pacific people. They illustrate the importance of Māori and Pacific social, cultural and economic aspirations in a contemporary context. The guidelines cover proposed dwelling patterns, general planning principles, specific design issues and illustrate their recommendations within a set of conceptual Māori and Pacific dwelling solutions. The recommendations put forth in the guidelines are performance based, setting out the minimum spatial requirements that need to be met for both cultures. Through doing so, the guideline gives designers and planners a much-needed, flexible but thorough approach to designing dwellings for the dynamic, cultural needs of these specific populations. However, further research would need to determine spatial requirements for other populations not included here.

5. Discussion

5.1. Spatial standards discussion

New Zealand does not currently have a residential spatial standard, containing square meter values for adequate floor areas, which considers the dynamic needs of its varying cultures, specifically for people of Māori, Pacific, Indian and Asian ethnicity. In fact, New Zealand does not have an enforced spatial standard for any residential properties outside of HNZ housing. As Marriage emphasised, there are no minimums in New Zealand, which is unusual amongst developing nations. The new Auckland plan has since stipulated a target for a minimum requirement, but other councils have not followed suit. There are, however, recommendations being made, if not enforced, and the ground work for a legislated, minimum standard of living is there, ready to be built upon.

5.2. Floor area recommendations

The HNZC, CCANZ and MSRA standards recommend a combined living, dining and kitchen floor area of 36m², 30m² and 37.2m² respectively for two-bedroom dwellings (Table 1: Floor area requirements for Two Bedroom Dwellings whereas the London and Ireland standards recommend a combined floor area of 27m² and 30m² respectively. The same relationship is present for three-bedroom dwellings (Table 2), where the recommendations are 46m², 34m² and 44.2m² for the New Zealand standards compared to 31m² and 34m² for the international publications.
On average, this data illustrates that the New Zealand standards recommend an 18.75% larger living, dining, and kitchen space for two-bedroom dwellings and a 24% larger space for three-bedroom dwellings compared to international practices. The same calculations can be made for analysing bedroom spaces, where the HNZC, CCANZ and Minimum Standards for Residential Apartments standards recommend an average bedroom floor area of 9.5m², 13m² and 9m² respectively for two-bedroom dwellings compared to 10m² and 12.2m² in the London and Ireland standards.

For three-bedroom dwellings, the New Zealand standards make recommendations (Table 2) for an average bedroom floor area of 9.3m², 13m² and 9m² and the international standards 9.3m² and 10.5m² respectively. These findings show existing standards in New Zealand currently favour a focus towards larger living, dining and kitchen spaces compared to international practice, whereas recommendations made for bedroom floor areas are relatively the same.

### Table 1: Floor area requirements for Two Bedroom Dwellings

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### Table 2: Floor area requirements for Three Bedroom Dwellings

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<td>Storage</td>
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5.3. Cultural guideline discussion

Existing cultural guidelines in New Zealand do not contain recommendations that can be translated to a legislated standard for dwelling size that is appropriate to our culturally diverse population. The existing documents for Māori and Pacific dwelling design, both published by HNZ, lack the numerical data to support how a dwelling for a Māori family, for example, differs in floor area size to a dwelling for a European family. Both documents focus on the internal layout of amenities, offering narrative input into how spatial requirements should be implemented—rather than numerical floor areas. The two documents are intended to be used alongside the 2015 HNZ Housing Design Guide, but do not offer explicit instructions as to how floor areas should be changed to meet tenant needs. It important to note that the international spatial standards examined provided no data towards the design of culturally sensitive spatial living conditions and instead emphasised that the recommendations they put forward are for their respective societies as an entirety.

5.4. Spatial and cultural relationship discussion

The research into both spatial standards and cultural guidelines in New Zealand highlighted a disconnect between existing floor area recommendations for dwelling design and spatial relationships in cultural design guidelines. Spatial standards make recommendations for minimum floor areas for adequate living spaces, but fail to acknowledge the living needs of our culturally diverse population. In contrast to this, the cultural design guidelines, which were produced with the intention of giving designers and planners a go-to guide for understanding how to design adequate dwellings for varying cultures, make no recommendations for what their adequate area of living should be. This leaves open the opportunity for developers to design dwellings that are meeting the minimum spatial recommendations of New Zealand’s standards, but not the socio-spatial needs of the country’s culturally diverse population. It also highlights that spatial standards, although published with the intent of providing adequate areas of living for everyone, are failing to acknowledge that each culture has its own unique way of living and this may possibly alter the sizing recommendations that they are making.

5.5. Recommendations

To determine how New Zealand could go about developing a standard that acknowledges its culturally diverse population, the following set of recommendations outline steps for how existing cultural guidelines could possibly be translated into numerical floor areas. The following steps act as a guide for policy-makers and planners who wish to develop such a document. They form the foundation for the future steps in this body of research.

1. Identify key demographic statistics at the time the standard is being considered. This is essential for understanding the various cultures that should be acknowledged in the document, specifically if separate versions are published for different regions of the country.
2. Examine typical occupancy levels for each culture: Māori, Pacific, European, etc.
3. Identify existing cultural design guidelines for each demographic. Develop an understanding for the circumstances of their development, their purpose and application. It is important to note, from the findings of this research, that these documents are likely to be heavily narrative-based. If a guideline for a specific culture does not currently exist at the time the standard is being considered, consultation with representatives of that ethnic group is essential to developing an understanding for their requirements of living.
4. Understand the **differences in spatial requirements** for each culture and identify where similarities occur. Be aware that these similarities can form spatial requirements that benefit more than one culture and allow for a simplified standard.

5. Identify **differences and similarities in occupancy levels** and use these to determine how much additional space each culture requires.

6. Develop a set of **spatial requirements for each culture**, providing a required floor area for each room of a dwelling (refer to the initial variables in this research). Identifying the additional space each culture requires and adding these to existing European requirements should help in determining these values.

6. **Conclusion**

Based on the findings of this research, this report recommends that the following points should be considered when implementing a **legislated, minimum standard for dwelling size** in New Zealand that acknowledges our culturally diverse population: methodology and diversity.

6.1. **Methodology**

Any universal, legislated standard for dwelling size in New Zealand should **provide a methodology for the minimum floor areas it proposes**. This methodology should give designers and planners the circumstances to which minimum floor areas have been produced, including how calculations were made.

6.2. **Diversity**

Any universal, legislated standard for dwelling size in New Zealand, with the purpose of creating a ‘better’ New Zealand in terms of adequate dwelling space, should ensure it **considers the diverse cultural needs of New Zealand’s growing population**.

6.3. **Summary**

These recommendations have been established to ensure a minimum standard for dwelling size in New Zealand is published in a manner that considers the needs of different cultures in the country. This will ensure designers and planners are given the flexibility to design beyond the minimum requirements, enabling specific client types to be accommodated for where they may have not been to begin with. These steps are essential to the acknowledgement of New Zealand’s culturally diverse population and their dynamic spatial requirements.

6.4. **Concluding points**

This paper set out to understand how New Zealand should go about producing a culturally sensitive spatial standard for minimum dwelling size – a spatial standard that acknowledges the needs of the country’s culturally diverse population. It identified that a selection of the country’s existing spatial standards do not adequately acknowledge the country’s various ethnic groups and their requirements for living everyday lives. Ethnic crowding has been a major issue in New Zealand over the past decade and we express the view that the issue lies with not only the sizes of dwellings our ethnic communities are residing in and thus the lack of adequate space for living that they provide, but also in the spatial layouts and relationships between particular rooms. To alleviate this situation, we recommend that if a legislated
spatial standard for minimum dwelling sizes is to be published, it needs to acknowledge the country’s culturally diverse population, provide a methodology for its calculations and require developers to look beyond minimum requirements. Through doing so, such a standard will give designers and planners flexible design options and the ability to adapt beyond any minimum requirements to meet the needs of their clients, regardless of cultural background. It is essential that designers, planners and developers begin the process of acknowledging the dynamic spatial needs of New Zealand’s population to avoid the ethnic crowding issues we are seeing today. Developing a universal, culturally sensitive spatial standard is the first major step in this process.

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The Impacts of Social and Physical Context on Neighbourhood Satisfaction in the Suburbs

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**Abstract:** Neighbourhood satisfaction is a key contributor to psychological wellbeing and sustainable community. This paper asks whether physical built environment characteristics or social factors have the greater impacts on satisfaction with residential suburban neighbourhoods. Quantitative analyses via a survey of 247 residents living in three Australian suburbs were conducted. First, Pearson correlations was used to investigate the relationship between perceived neighbourhood satisfaction and a number of independent social and physical neighbourhood design variables. The results showed that neighbourhood satisfaction is strongly associated with physical design characteristics, even allowing for the interaction of sociodemographic variables. Hierarchical multiple regression was then conducted to examine the extent to which five groups of physical characteristics impacted neighbourhood satisfaction: (1) street layout, (2) pedestrian environment, (3) neighbourhood connectivity, (4) public space provision, and (5) dwelling form when socioeconomic factors are controlled for. Physical built environment characteristics such as provision of open spaces, street type and trees coverage were more significant predictors of residents’ satisfaction than socio-demographic factors (income, length of residency and number of household members). This indicates that well designed neighbourhoods can be more attractive for residents. The findings also suggest that satisfaction associated with the social and physical needs of residents can be critical influences that planners and decision makers need to consider when designing for sustainable communities in contemporary suburban contexts.

**Keywords:** Satisfaction, Physical environment, Neighbourhood, Sustainability, Socio-demographic factors, Suburbs.

1. Introduction

This paper examines the impact of certain physical environment characteristics on neighbourhood satisfaction in suburban neighbourhoods in Australia. Neighbourhood satisfaction is defined as the degree between ideal neighbourhood aspirations of residents and actual residential environments (Kweon et al., 2010). It is also identified as one indicator of life satisfaction and is often used to evaluate quality of life in neighbourhood (Fried, 1984; Parkes et al., 2002). It has been argued that neighbourhood design contributes to quality of life via increased residents’ satisfaction; reflected by the facts that satisfaction is one of the most investigated issues in neighbourhood research. Studies often indicate that neighbourhood satisfaction is positively related to well-being (Zhang et al., 2017) and it is associated with
social interaction as well as sense of community, correlations all presumed to be impacted by physical features via creating a friendly pedestrian environment (Lund, 2002; Hur and Morrow-Jones, 2008; Brower, 2013).

Recent studies have acknowledged the association between neighbourhood satisfaction and the physical design of neighbourhoods. For instance, provision of greenery and pedestrian environment, access to facilities, traffic and safety (Hur and Morrow-Jones, 2008; Howley et al., 2009; Lee et al., 2017). While it is recognised that in high density suburbs neighbourhood satisfaction is influenced by physical design characteristics, there is little evidence of the impact on satisfaction of such characteristics in low-density suburban environments – particularly the types of low-density suburbs that ring Australian cities. Moreover, studies have evidenced contradictory impacts of some factors on neighbourhood satisfaction. Thus, this study examines in the context of Australian suburbs the relative impacts on neighbourhood satisfaction of socio-demographic variables and five groups of urban design characteristics: (1) street layout, (2) pedestrian environment, (3) neighbourhood connectivity, (4) public space provision, and (5) dwelling form. These characteristics have been selected because of the importance attached to them in the literature and because they can vary widely between suburbs in Australia depending on when those suburbs have been established. We explore if these neighbourhood physical characteristics have impact on neighbourhood satisfaction after controlling for sociodemographic variables that have been shown to impact satisfaction. Accordingly, this paper answers the questions; (1) what design characteristics of neighbourhoods predict neighbourhood satisfaction in low-density Australian suburbs? and (2) which of these characteristics are the strongest contributors to neighbourhood satisfaction. Neighbourhood satisfaction is measured in the study using the satisfaction with residential environment quality scale (Bonaiuto et al., 2003). The analysis shows that neighbourhood satisfaction is significantly predicted by six physical variables: (1) provision of open spaces, (2) trees coverage, (3) street type, (4), dwelling type, (5) connectivity by walking, and (6) number of community spaces, while income was the strongest predictor from the sociodemographic factors. Thus, physical design was seen to make greater contribution to satisfaction than sociodemographic factors in three suburban neighbourhoods.

2. Background

The physical characteristics of the built environment are important influences on residents’ satisfaction with their neighbourhoods, which in turn impacts community satisfaction and quality of life (Kweon et al., 2010). Yet the extent to which the physical environment impacts neighbourhood satisfaction compared to sociodemographic factors is still largely unaddressed in empirical research (Hur and Morrow-Jones, 2008; Lovejoy et al., 2010). Investigating how the physical and social contexts of suburbs are comparatively associated with neighbourhood satisfaction can improve understanding of how physical environments influence residents’ wellbeing and support sustainable living.

Neighbourhood satisfaction has been seen to be correlated with health outcomes (Grogan-Kaylor et al., 2006), such that less satisfaction is associated with poor health, decreased mobility and lower quality of life. Moreover, satisfaction determines resident decisions about staying or moving from neighbourhoods; suggesting higher satisfaction maintains social stability (Lee et al., 2017). Research has shown that a major reason for residents moving from urban to suburban neighbourhoods is perceived safety, which determines the extent of satisfaction with the local neighbourhood (Anderson, 2006). Neighbourhood satisfaction is seen to be impacted by three categories of influence: (1) sociodemographic features such as length of residence, age and income; (2) psychosocial factors such as feeling safe,
neighbouring (numbers of social connections and supports between neighbours), level of attachment and other socio-cultural issues; and (3) the physical characteristics of neighbourhoods e.g., pedestrian access to other spaces, presence of trees, traffic volume (Hur and Morrow-Jones, 2008; Lee et al., 2017). Thus, these subjective and objective factors are the main determinants of a residents’ satisfaction with their neighbourhood (Cao and Wang, 2016; Lee et al., 2017).

Socio-demographic factors have been well researched and also have been found to influence neighbourhood satisfaction and residential choice. For example, age of residents (Parkes et al., 2002; Lee et al., 2017), income level (Parkes et al., 2002; Lovejoy et al., 2010; Lee et al., 2017), household size, and education level (Lovejoy et al., 2010) have all been shown to have positive association with neighbourhood satisfaction. While some studies have found that long term residency influences satisfaction (Lipsetz, 2001; Mohan and Twigg, 2007; Comstock et al., 2010), other research has showed that length of residency, gender and number of children had no significant impact (Grogan-Kaylor et al., 2006; Hur and Morrow-Jones, 2008; Lovejoy et al., 2010).

Environmental qualities positively associated with neighbourhood satisfaction are: perceived quality and provision of greenery and open spaces, better pedestrian environment, traffic safety, upkeep and shared outdoor space, and presence, location, and access to facilities (Kearney, 2006; Hur and Morrow-Jones, 2008; Howley et al., 2009; Cao and Wang, 2016; Lee et al., 2017; Zhang et al., 2017). In high density living, some dwelling types (particularly terraced houses) (Mohan and Twigg, 2007; Bramley and Power, 2009), traffic issues, and lack of services and facilities are negatively associated with neighbourhood satisfaction and with neighbourhood social outcomes (Lipsetz, 2001; Howley et al., 2009).

3. Methodology

A quantitative methodology is used with the support of measured observations of physical neighbourhood characteristic variables using on-street photography and high-resolution satellite Photomaps by NearMap. A questionnaire was used to collect data on the scale items used to indicate residents’ satisfaction with their neighbourhood. Data were collected from residents in three suburbs in the southwest of Geelong, Australia. The three study have: socio-economic equivalence, varied urban design layout, and different periods of residential growth (3). Three suburbs were selected: Belmont, is the oldest residential area being first developed during the 1950s and 1960s; Grovedale was developed mostly through 1970s and 1980; and Waurn Ponds is the newest suburb seeing rapid growth in the 1990s.

3.1. Participants

Two methods were used to collect the data indicating neighbourhood satisfaction:

1. Survey questionnaires, with plain language statement and consent form, were delivered to the mailboxes of 600 residents selected randomly - 200 in each of the three suburbs (Belmont, Grovedale and Waurn Ponds). Survey was used as this is the most frequently adopted method for collecting quantitative indicators of a variable (i.e., Neighbourhood Satisfaction) that have an empirical structure. Participants returned responses using supplied stamped and addressed envelopes. Data were collected from 184 residents aged between 18 and 80 years old, with 68 questionnaires received from Belmont, 65 from Grovedale and 51 from Waurn Ponds. Sociodemographic indicators were gathered to confirm the socioeconomic profiles of the residents: gender, age, income, household tenure, length of residence, number of house members and children, and educational level.
2. Face-to-face survey was also carried out to increase the sample size, as it was (correctly) predicted that mailbox survey alone would result in low participation rates. Participants were recruited from public spaces adjacent to the neighbourhood libraries of each suburb. A plain language statement and consent form were provided to these participants, along with a brief description of the project. The questionnaires were matched to residential streets by asking the participants their addresses. Thus, the researcher recorded 29 face-to-face respondents from Belmont, 15 from Grovedale and 19 from Waurn Ponds. The total number of completed questionnaires from both methods of data collection was therefore 247.

3.2. Survey instrument

Neighbourhood satisfaction scale

The fourteen-item neighbourhood satisfaction scale, including positive and negative items (Bonaiuto et al., 2003), was used to measure satisfaction with: neighbourhood, quality and provision of parking, walkability, access organization, and neighbourhood connections with the city-centre and other places. Positive examples included in the scale were “it is easy to cycle around; there is a good availability of parking spaces; this neighbourhood is well-suited for handicapped people; and this neighbourhood is well-connected with important parts of the city.” While Negative examples were “parking places and parking lots are lacking; there is not enough space to walk; It is dangerous to cycle and this neighbourhood is too cut-off from the rest of the city”. The residents responded to each item according to a 5-point Likert scale (strongly disagree to strongly agree) with high scores referring to higher satisfaction with the physical environment. Cronbach’s alpha, used to assess the reliability of the satisfaction, was 0.813.

Measurement of urban design characteristics

Physical urban design characteristics were measured according to five categories and objective indicators:

- Street layout: three variables were selected are street type, traffic flow-through and on-street parking. because: (1) street type (traditional grid; conventional loop and cul-de-sac; conventional loop (curvilinear) can shape perception and influence interaction; (2) traffic volume (low traffic; moderate and heavy traffic) is associated with lack of safety, noise, negative impacts on the street environment and thus reduced pedestrian street activities—in particular, children playing and contact between neighbours and (3) street parking (number of cars per house) can have conflicting impacts, for while parking can allow residents contact with their street and connect socially during departure and return to home, negative effects include creating unsafe places for walking and driving.
- Pedestrian environment: three variables of pedestrian environment were identified that impact perceptions of the walking environment: footpath (no sidewalk; sidewalks on two sides and wide sidewalk on one side), nature strip provision (nature strip on 1 side; nature strip on 2 sides and gravel strip) and percentage of tree coverage (0-10%; 20-30%; 30-40%; and 40-50%) of tree-coverage. The footpath/nature-strip zone is where important street furniture is located, including seating, trees and light poles, and thus contributes to accessibility, safety, and opportunities for social contact.
- Neighbourhood connectivity: the extent of walkability to community facilities indicates how well residents can access these facilities, whether via walking or public transport (0-20%); (20-40%); (40-60%) (60-80%); and (80-100 %). The walkability scale has been generally used in new
developments to measure the connectivity of community facilities to residential streets. Previous studies have determined a distance of 400m or 5-minute walk for both comfortable walkability and for walking catchment from any public transport stop.

• Public space provision: public spaces are significant features in neighbourhoods for their functional, aesthetic, social and wellbeing contribution. Further, they facilitate informal connections and socialising, in particular if they have good location and visibility. Public space provision was identified according to two variables: (1) the number of open public spaces in each street (on a binary scale (one space and more than one space); (2) community spaces (no community spaces with walking 5 minutes; 2-3 community spaces with walking 5 minutes; more than 3 community spaces with walking 5 minutes) i.e., facilities and services, including schools, churches, childcare and sports clubs, which are places where neighbours meet and interactions take place.

• Dwelling form: four variables were measured indicating the relationship of the dwelling to the street that research suggests affect neighbourhood satisfaction — dwelling setback (narrow; varied; and wide setback); street boundary delineation measured via average fence height in each street; garage location (50% garage on façade and 95% garage on façade) and dwelling type (80% detached houses; 90% detached; 100% detached houses).

4. Results

This study hypothesised that urban design characteristics affect neighbourhood satisfaction when sociodemographic variables are controlled for. The results are reported in three sections: (1) comparison of the three neighbourhoods (2) correlation with social-demographic and physical design variables, and (3) hierarchical regression analyses.

4.1. Differences in neighbourhood satisfaction between Suburbs

One-way between-groups analysis of variance explored the impact of neighbourhood differences on neighbourhood satisfaction. This analysis aimed to determine if there were significant differences in scores for neighbourhood satisfaction between the three types of neighbourhood — (traditional (Belmont), conventional loop and cul-de-sac (Grovedale), and conventional loop (curvilinear) (Waurn Ponds). Analysis showed that there is a statistically significant difference (F (2, 240) =13.6 p = .000), in neighbourhood satisfaction. In Belmont, the mean of neighbourhood satisfaction was (3.78, SD = 0.47), while in Grovedale it was (3.59, SD = 0.49) and in Waurn Ponds (3.35, SD = 0.57). The effect size (calculated using eta squared as 0.10, which is considered a large effect (Cohen, 1988, p. 284). Thus, neighbourhood satisfaction is significantly impacted by neighbourhood design differences in the three suburbs.

4.2. Correlations of neighbourhood satisfaction with independent variables

Correlation examined how respondents' socio-demographic variables and physical design variables relate to neighbourhood satisfaction. Results indicated that three socio-demographic variables: income (r = -0.21, p < 0:01), number of household members (r = -0.17, p < 0:01) have negative significant correlation with neighbourhood satisfaction, length of residency (r = 0.15, p < 0:05) has positive correlation, while five variables have no significant correlation with neighbourhood satisfaction: age, home-ownership, education, gender and number of children. Only the socio-demographics variables that were found to be strongly correlated (p-value < 0.05) with satisfaction were explored via hierarchical regression analyses.
On the other hand, neighbourhood satisfaction has a number of strong correlations with the physical urban design variables; most strongly with street type (r = -0.31, p < 0.001), dwelling type (r = -0.32, p < 0.001), and nature strip (r = -0.16, p < 0.05) were negatively related to neighbourhood satisfaction, while tree coverage (r = 0.30, p < 0.001), connectivity by walking (r = 0.24, p < 0.001), and transport (r = 0.18, p < 0.01), provision of open spaces (r = 0.28, p < 0.001), dwelling setback (r = 0.21, p < 0.01), community spaces, garage on facade and average fence height (r = 0.16, p < 0.05) were positively related to neighbourhood satisfaction.

4.3. Regressions model for predicting neighbourhood satisfaction from urban design characterises and demographic factors

Five sets (hierarchical models) of independent (predictor) variables were used in five separate regressions to find if five categories of (predictor) variables – (1) street layout (2) pedestrian environment (3) neighbourhood connectivity (4) public space provision; and (5) dwelling form – predict neighbourhood satisfaction after controlling for the influence length of residency, income and number of household members. All five regression models were statistically significant (p < 0.001) but the strength of the models differed in prediction power. In every model, demographic variables entered at Step 1 explained 8.8% of the variance in perceived neighbourhood satisfaction.

Table 1: Summary of hierarchical regression analyses-dependent variable: neighbourhood satisfaction

<table>
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<th>Predictor Variable</th>
<th>B</th>
<th>SEB</th>
<th>β</th>
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<tr>
<td>Income</td>
<td>-.075</td>
<td>.021</td>
<td>-.202***</td>
</tr>
<tr>
<td>Street type</td>
<td>-.185</td>
<td>.040</td>
<td>-.282***</td>
</tr>
<tr>
<td>Tree coverage</td>
<td>.135</td>
<td>.036</td>
<td>.278***</td>
</tr>
<tr>
<td>Connectivity by walking</td>
<td>-.152</td>
<td>.076</td>
<td>.221*</td>
</tr>
<tr>
<td>Community spaces within</td>
<td>-.187</td>
<td>.077</td>
<td>-.201*</td>
</tr>
<tr>
<td>walking distance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open space</td>
<td>.525</td>
<td>.133</td>
<td>.441***</td>
</tr>
<tr>
<td>Dwelling type</td>
<td>-.150</td>
<td>.053</td>
<td>-.220**</td>
</tr>
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Note: *p < .05, **p < .01, ***p < .001; B= unstandardized regression coefficient; SEB= standard error of the coefficient; β =standardized coefficient, only significant predictors shown in the table

In the first regression, in the final model only two variables were statistically significant, with street type recording a higher beta value (beta = -.28, p < .001) than income (beta = .20, p < .01). In the second regression, in the final model, two variables were statistically significant, tree coverage, recording a higher beta value (beta = .27, p < .001), than income (beta = .20 p < .01). In the third regression, in the final model two variables were statistically significant, with income recording the highest beta value (beta = .22, p < .001), and connectivity by walking (beta = -.20 p < .05).

In the fourth regression, in the final model three variables were statistically significant, with provision of open space recording a higher beta value (beta = .44, p < .001) than income (beta = .20, p < .01) and then community spaces (beta = -.20, p < .05). In the final regression, in the final model only two variables were statistically significant, with income recording the higher beta value (beta = .22, p < .01).
5. Discussion

Results revealed significant differences in neighbourhood satisfaction between three suburbs, with residents in traditional neighbourhood layouts having higher levels of satisfaction than those in conventional, cul-de-sac and curvilinear streets. This finding is consistent with Lovejoy et al. (2010), who found neighbourhood satisfaction was higher in traditional neighbourhoods. The results evidence: association between length of residency, income, number of household members, physical design characteristics and neighbourhood satisfaction; that neighbourhood design significantly contributes to neighbourhood satisfaction when sociodemographic variables are controlled for.

The regression, show five groups of physical characteristics significantly predict neighbourhood satisfaction $p<0.01$: street layout, pedestrian environment, neighbourhood connectivity, public space provision, and dwelling form. But only six physical design variables predicted neighbourhood satisfaction when controlling for length of residency, income number of household member: street type; tree coverage; connectivity by walking; provision of open spaces community spaces within walking distance; and dwelling type. From the three socio-demographic variables, only income significantly predicts neighbourhood satisfaction. Furthermore, the results show that physical variables affecting neighbourhood satisfaction differ in their prediction power, such that open spaces, street type, and trees coverage were more significant influences on neighbourhood satisfaction respectively than income level. Dwelling type $p<0.01$, connectivity by walking and community spaces within walking distance were less significant impacts $p<0.05$ on satisfaction than income. The findings suggest that enhanced neighbourhood design can contribute to increased satisfaction; attract people to live and interact socially; increase attachment; and improve quality of life, this in turn can achieve broader objective of social sustainability.

The finding that income level is associated with neighbourhood satisfaction is consistent with research showing that residents having a higher income are more satisfied with their neighbourhood (Adams, 1992; Parkes et al., 2002; Lovejoy et al., 2010; Lee et al., 2017; Zhang et al., 2017). Interestingly, other socio-demographic variables were not associated with neighbourhood satisfaction, which is inconsistent with studies claiming that socio-demographic features such as length of residency (Parkes et al., 2002; Mohan and Twigg, 2007) and age (Parkes et al., 2002; Lee et al., 2017) can be the most important factors influencing the perception of neighbourhood satisfaction.

This overall finding is in line with previous studies showing that the physical characteristics of neighbourhoods are strongly correlated with neighbourhood satisfaction (Kweon et al., 2010; Bonaiuto et al., 2015; Lee et al., 2017). For instance, provision of open space was the best contributor of neighbourhood satisfaction, which is consistent with research indicating that open spaces ameliorate satisfaction (Kim and Kaplan, 2004; Kearney, 2006; Hur and Morrow-Jones, 2008; Comstock et al., 2010; Cao and Wang, 2016; Zhang et al., 2017). Such findings also support evidence that open spaces that are easily accessible within walking distance are positively viewed by local communities (Wang et al., 2015).

The results described above suggest that street type, tree coverage, connectivity by walking and community spaces with access are important determinants of neighbourhood satisfaction. More precisely the regression models suggest that residents in traditional streets with higher degrees of trees canopy and provision of adequate community spaces within walking distance are more satisfied with their neighbourhood. This finding is in line with studies showing that neighbourhood satisfaction is higher among the residents of traditional neighbourhoods (Kim and Kaplan, 2004; Lovejoy et al., 2010), with more trees (Kearney, 2006; Hur and Morrow-Jones, 2008; Kweon et al., 2010; Zhang et al., 2017), and with presence and quality of community service (Bonaiuto et al., 2015) and facilities within walking
distance (Hur and Morrow-Jones, 2008; Cao and Wang, 2016). Connectivity that improves the pedestrian environment is also associated with residents’ satisfaction (Bonaiuto et al., 1999; Zhang et al., 2017). Although our findings indicated that traffic and street parking were not significant predictors, previous research has found that traffic and car parking problems negatively impact neighbourhood satisfaction (Hur and Morrow-Jones, 2008; Howley et al., 2009; Lee et al., 2017).

While all dwelling form variables (dwelling setback, garage on façade, average fence height and dwelling type) significantly correlated with satisfaction, only dwelling type (less detached dwellings) was significantly associated with neighbourhood satisfaction. This finding is in contrast with Parkes et al. (2002) who found that residents in detached house were more satisfied with neighbourhood. However, Mohan and Twigg (2007) found that dwelling type, whether detached or semi-detached, has no association with neighbourhood satisfaction. Our finding suggests that in Australian low-density suburbs, it may be that the greater separation of detached houses, leading to lack of connection between residents, leads to reduced levels of neighbourhood satisfaction.

In high density contexts provision of open spaces, street type, tree coverage, connectivity and dwelling type have been found to be associated with neighbourhood satisfaction (Parkes et al., 2002; Hur and Morrow-Jones, 2008; Howley et al., 2009). Moreover, in Australian urban higher-density neighbourhoods, it has been found that dwelling position, noise, community involvement, traffic rates, crowding and availability of parking significantly predicted neighbourhood satisfaction (Buys and Miller, 2012). Some of these variables differ from those that we have found to influence satisfaction in Australian low-density contexts. Clearly, further research is needed to compare the impact of physical design features on neighbourhood satisfaction between lower- density and higher-density suburbs. The results suggest: (1) neighbourhood satisfaction associated with physical characteristics can increase social stability, determine resident location preferences; and improve quality of life; (2) social interaction could be facilitated through suburban planning; and (3) vital environments can meet the goal of community sustainability. Moreover, identifying the essential factors that support sustainable of community in suburbs can provide understanding for future urban design and planning, and in turn offer insight of how contemporary neighbourhoods are functioning in low density suburban housing.

6. Study limitations

There are limitations to this research that need acknowledging. Most notable are the influences on residential satisfaction not considered due to the empirical confines of the study, such as physical activity, diversity, housing quality and crime rate (Grogan-Kaylor et al., 2006; Potter and Cantarero, 2006; Comstock et al., 2010; Hur and Nasar, 2014; Lee et al., 2017), other psychosocial factors, particularly perceived aesthetic appearance, safety feeling (Parkes et al., 2002; Kearney, 2006; Hur and Morrow-Jones, 2008; Lovejoy et al., 2010; Lee et al., 2017), social problems (Hur and Morrow-Jones, 2008), sense of community (Kim and Kaplan, 2004), and neighbouring interactions (Parkes et al., 2002; Mohan and Twigg, 2007). Finally, as Lovejoy et al. (2010) have observed that residents in suburban areas are less satisfied with neighbouring and social ties, it would also be worth exploring how these social connectivity factors impact neighbourhood satisfaction in relation to the physical built environment.

7. Conclusion

This study sought to determine if physical built environment characteristics or socio-demographic factors have the greatest impacts on residents’ satisfaction with low-density suburban neighbourhoods in
Australia. The research provides clear evidence that even with controlling of socio-demographic factors, perceived neighbourhood satisfaction is associated with: provision of accessible open and community spaces, street type, trees coverage, connectivity by walking and dwelling type. This strengthens the case for the importance of physical design features in influencing neighbourhood satisfaction. This paper also shows that provision of open space within walking distance was the best predictor of neighbourhood satisfaction. Thus, when comparing three types of Australian suburb, this study has shown that traditional suburban street types with more trees and better provision of public and open spaces are more positively related to higher levels of satisfaction. This in turn reflects that limited pedestrian access, lack of planting and car dependence in newer Australian suburbs need to be addressed by planners and developers. Our findings show that the relationship between the physical built environment of new suburbs and neighbourhood satisfaction requires crucial attention in Australia where low-density suburbs are home to approximately 70% of the population (Davison, 2006); a figure that continues to rise steeply as the cost of inner-city housing spirals (Roberts, 2007). Thus, to strengthen neighbourhood satisfaction and thus develop more sustainable communities in suburban contexts, it is clear that architects and urban designers need to better consider the social and physical needs of residents in their design processes.

References


Looking Ahead

Investigating Performance Art with Schoolchildren as a Catalyst for Urban Redesign

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Abstract: This paper describes the background to a recent and ongoing research project into the possible effect of performance art on environmental learning among a group of 8-10-year-old inner-city schoolchildren who participated in an environmentally-focused process theatre performance during a recent Fringe Festival in Auckland, New Zealand. As part of this investigation, a student researcher is carrying out a limited co-design process with the schoolchildren, towards making the Auckland cityscape more child-friendly through urban redesign. Focus groups with the schoolchildren have been conducted and interviews with some key stakeholders (e.g. parents, teacher), as well as analysing school work completed by the children. Early findings indicate that the children revelled in taking part in the whole performance experience, especially due to meeting and talking with adults during the performances. They are also well-informed about their city, which indicates their interest and concern for it. This included them raising issues such as traffic, dirty and building-dominated appearance, homeless people and the need for increased and cheaper housing and transport. Their ideas were organised into themes to develop a brief for design and draft ideas have been developed to take back to students for their feedback. Further design development and analysis is planned before an insightful conclusion can be drawn.

Keywords: schoolchildren; performance art; urban design; environmental education; co-design

1. Introduction

In keeping with the theme for this conference, this paper advocates for a ‘back to the future’ approach as we face accelerating environmental deterioration. It details a theatrical performance-based process for encouraging young people’s involvement in sustainable urban design and intergenerational knowledge sharing about environmental and urban issues. Research into the performance method and consequent findings, which will be explained in this paper, is on-going, so this is a positioning paper to present a theoretical rationale, describe the project and research method plus indicate some early findings.

An inner-city Auckland primary school worked with a performance artist to present a three-day show called ‘Lookout’ during an Auckland Fringe Arts Festival in February 2017. This involved sixteen 8-10-year-
old students sharing their differently constructed vision of future Auckland with a new adult participant for each of nine hour-long performances. The pair engaged with each other using both scripted and ad hoc dialogue about their experiences of the city, real and imagined, and their role within it. When the shows were over, the students were keen to continue their urban environment exploration, made especially topical given recent media attention about Auckland’s densification due to the recent partial implementation of the Auckland Unitary Plan (Auckland Council, 2016), coupled with a housing and rental crisis of spiraling prices and plummeting availability (e.g. Dastgheib, 2017). Therefore, led by their teacher they continued to explore the design of buildings and their ideas for improving Auckland.

A research project on this Auckland case study has been set up to investigate the performance-based process with the aim of considering if and how such an experience may motivate people to live differently. For data richness and triangulation purposes it is intended to collect and analyse multiple data sets from stakeholders, looking for evidence of both behaviour change and triggers for it. This follows a general shift in focus within environmental education research from valuing what is learnt to how and why? In addition, the research has included a side project to analyze the participant children’s schoolwork (writing and drawings) to help generate ideas for an urban design by a Landscape Architecture student. This aspect of the research project will be focused on in this paper as an example of involving schoolchildren in a design process and reciprocating ideas and learning across generations.

2. Theoretical Framework

2.1. Drama and Environmental Education

Although not often used, performance art has many tenets that recommend it as a legitimate format for exploring environmental issues as part of an environmental education programme. Defending drama as a teaching tool, Caldwell (2011) explains that it engages participants physically, emotionally, intellectually and socially - providing a means to explore complex issues in a non-threatening way, while developing confidence in themselves and expressing this. Paulo Freire, the Brazilian philosopher, revolutionary and emancipationist labelled traditional Western education as a banking system of perpetuated values that disfavoured marginalised groups such as women, poor and homosexuals (Freire, 1993). He developed the theory of critical pedagogy, which encourages taking ownership and action, towards transformational learning and lifestyles. These are verbs prominent both in performance art pedagogy (e.g. Reedy, 2008; Billard, 2009) and environmental education literature, such as Jensen and Schnack’s (2006) ‘Action Competence’, and Chawla’s (2008) ‘Pro-environmental Behaviour’, as indicative of lifestyle changes. It also resonates with the Enviroschools Programme, managed by Toimata Foundation, currently the most popular environmental education programme used by New Zealand schools. One-third of all levels of schooling follow this highly student-led (participatory) programme that advocates ‘shared decision-making’ and an action-oriented learning cycle (The Enviroschools Foundation, 2008; Toimata Foundation, 2015), which encourages ownership and reflection on projects and learning.

Curtis et al. (2014) describe two modes of performance art in education. ‘Theatre-in-education’ or ‘demonstration theatre’ occurs when performers develop and present theatre with, for example, an environmental theme. The second type is ‘process theatre’ or ‘pedagogical theatre’ (sometimes also called ‘play-building’ or ‘group-devised theatre’). Here, trained performers work with non-trained participants (e.g. school students) to completely or partially develop a piece that they perform. In the group of five case studies presented by Curtis et al., only one uses ‘process theatre’, which is the method employed in the theatre performance under investigation here. These authors found that the student
performers within their case study were adept at managing a question and answer session held after the performance, showing they had gained confidence with the content and they conclude that ‘process theatre’ combines several learning styles in a way that traditional classroom learning does not. This agrees with findings from a previous project this author was involved in (Wake, 2010), where young school students were part of a highly participative project to co-design and co-construct an eco-classroom with industry professionals. The students were emphatic that the learning they experienced was much more ‘real’ and enjoyable than reading or mathematics as usually taught. This suggests a potential connection between accessible and exciting learning and behaviour change.

Such transformational learning needs to include ‘learning about, learning for and learning with’ the environment (learning of the head, hands and heart respectively) (Sipos et al., 2008), since as Curtis et al. (2014) point out, people need information and awareness before they can develop attitudes about the issue in question. A government department with a strong stake in environmental education, the New Zealand Department of Conservation, has a guide book (Wilson, 2011) on engaging children with environmental education, which recommends that affective (emotional or values-based) learning is more likely to influence attitudes than a knowledge-based approach alone. This, they suggest, could happen through the vehicle of drama, especially where participants must put themselves in others’ shoes, so developing more active citizenship. They remind us it also has similarities to ‘play’, which is well accepted as a learning platform for children. A number of benefits have been cited from using drama as a tool within environmental education - especially focused on its encouragement of imagination, presentation of material in a non-confrontational way, holism of skills demanded, developing confidence in effective communication, and reviving the cultural art of storytelling (Adcock and Ballantyne, 2007). However, it can be difficult to ensure that learning translates into intentional change once the event is over, and nearly as difficult to measure this. The greater the degree of involvement and autonomy within the drama project (i.e. process theatre as opposed to theatre-in-education), the better the chance it would seem, as indicated by the following quote:

If a memorable experience in which the learners had direct involvement in manipulating the drama were to occur, then it is likely that effects would involve deeper understanding of environmental issues and an appreciation of the natural world which has the potential to foster pro-environmental behaviour (Gale, 2008, , p. 170).

2.2. Children and Urban Design

It has been established as a right through the UN Convention on the Rights of the Child (UNHCHR, 1989) that children should have a say in matters that affect them, for example the design of their environments. Further, it has been established as a reality through the new social studies of childhood that children are competent decision-makers who can play an active role in shaping their environment, rather than being seen as passive order-takers (Holloway and Valentine, 2000). Under the banner of UNICEF, the ‘Child Friendly Cities Initiative’ (CFC) has, over the last decade or so, taken on the role of setting out steps for cities to take to ensure their young people feel welcome and involved rather than marginalised and frustrated (see www.childfriendlycities.org). Part of the rationale for this is the realisation that many countries, including major world cities, are facing a future dearth of children (e.g. see https://eppc.org/publications/a-dearth-of-children/). New Zealand is no different and therefore needs to do all it can to retain its precious children (Jackson, 2011). In addition, it is now widely acknowledged that spaces and environments that work well for children, work well for other demographics, e.g. aged citizens. Linking to the urgency of creating child-friendly cities is research into independent mobility in children
(IM), since a recent study of Auckland schoolchildren found that children’s (and parents) perceptions of safety, dangers and movability within their neighbourhoods has a significant impact on their IM, i.e. their ability to move independently within their local environment (Witten et al., 2013).

In New Zealand, Whangarei, a small Northland city, is currently working towards CFC status. The largest city, Auckland, published its intention to ‘put children and youth first’ when it released its 30 year Auckland Plan (Auckland Council, 2012), which was followed by the ambitious Children and Young People’s Strategic Action Plan - ‘I am Auckland’ (Auckland Council, 2013). Against this backdrop, in 2015 the Auckland Design office conducted a Child-Friendly Audit of a popular pocket park called Freyburg Square in Auckland CBD. With the help of researchers from Massey University’s health-related SHORE research team the project involved children in a design project where they visited the square and made suggestions of ways to make it more appealing for them, then developed up the chosen ideas to brief the design team and, finally, were presented with the final designs and invited to give feedback on the process (Auckland Design Office, 2015). This important precedent has recently been opened to the public and according to Lisa Spasić from the Development Programme Office of Auckland Council:

“... the kids’ ideas and inputs definitely shaped the final design. After their feedback, we altered the concept designs to include a lot of areas of play. A large climbing tree was included in the final project, stepping stones in the water feature, a discovery track behind the Lord Freyberg statue, more drinking fountains etc. It was a very successful consultation with children and young people...” (email, 28 September 2017)

As is pointed out in the quote, this process leaned more towards being consultation than actual co-design, employing a method known as Gulliver’s Mapping (see Driskell, 2002). Children’s environments researchers in the UK have defined consultation as seeking opinions on design with intention to take these into consideration, while co-design involves children actively participating in the design process - being hands-on with research, modelling and decision-making, within their abilities (Parnell, 2014). The limitations on time (dictated by the Bachelor of Landscape Architecture student’s project time frame) has meant that the urban design project being presented here is more a consultation rather than a co-design example, although children’s art was included in the design process.

3. Method

3.1. Performance

An English performance artist, Andy Field, and his partner Beckie Darlington have developed the ‘Lookout’ theatre that was originally trialled in Manchester and then brought to Auckland. It has since travelled to Cairo and several UK cities. From the website, the show is described as:

Created in collaboration with local primary school children, Lookout is a one-to-one encounter between one adult audience member and one child performer taking place somewhere high up overlooking the city.

Together performer and audience member look out at the city and imagine its future. The conversation they share is a quiet journey through the past, present and future guided by the streets and landmarks laid out before them.

Through dreams of utopian architecture and possible catastrophes, hopes and fears, future fashions, proposed demolitions and progress real and imagined, they explore two very
different versions of the city they both inhabit. An exchange between two people who might not normally meet, about a future world they may or may not share.

Lookout is an attempt to consider big questions in a small way. Developed through a series of workshops with local children, each new version of the piece is unique to the city it is created in and the people who call that place home. (www.andyfield.co.uk)

From this reading it is evident that its focus is on the urban environment and the changes that may take place there. Underlying this is a strong sustainability message that the children were encouraged to explore, alongside their own views of the city and its functioning.

For the Auckland performance, staged through Q-Theatre, an inner-city school was contacted several weeks ahead of the performances in early March. Two senior classes of students were selected (years 5 and 6, ages 8-10). These approximately 50 children took part in a one day workshop where the artists took them through an exercise of a day in the life of a fictitious person living in that city both now and in the future - acting out all the objects such as toaster, alarm clock etc. The children significantly remembered this during the focus groups we ran some three months later - providing evidence of the retentive power of performance when it is truly engaging.

From this group, a cohort of 16 were chosen based on speaking ability and confidence, which is important to note as a possible limitation to the extrapolation of these results to other groups of students. These students went on to workshop the Lookout performance brief for two weeks. This can be regarded as an intensive exploration of Auckland’s issues from the perspective of children. They considered the city today and highlighted the current rampant apartment development, the rising cost of housing, the presence of homeless people and the transport and rubbish issues. Then they projected forward to their utopian vision for Auckland of the future, plus Auckland post-disaster. They formed their own stories and recorded them to make up part of the performance. These can be listened to at https://soundcloud.com/andy-field-1. During the performance period, 8-10 March 2017, each child spoke with an adult stranger for 45 minutes, three times per day for three days. According to their teacher and parents interviewed they were consistently exhilarated and buoyant after a day’s performances.

Encouraged by this and feeling that the topic was of great importance, the teacher carried it on for further weeks by getting the whole class to consider what they would like to improve about Auckland through writing and drawing.

3.2. Research

The research project based on ‘Lookout’ is a mixed data qualitative study that involved focus groups with the 16 children who participated in the performance (two groups of eight, held consecutively), interviews with four parents plus the lead teacher and Andy Field, the performance artist. Except for interviewing Andy Field (not completed yet) all sessions were held in May and early June 2017, following ethics application and approval in mid-May. The children’s schoolwork that was done with their teacher after the conclusion of the performances was also photographed for analysis and a warm-up question sheet that was completed by the children at the time of the focus groups was analysed. At this stage, the focus group and interview data has been transcribed and is awaiting thematic analysis for the environmental education focus of the research, while the written data from the children has been interpreted, mainly for the urban design portion of the research.
4. Early Findings

4.1. Environmental Education

So far, only the warm-up sheets that were completed as part of the two children’s focus groups have been analysed. This provides evidence that 14 of the 16 participants enjoyed the performance the most (chosen between the preparation workshops, the performances, and the later classroom activities). The most frequent reason was because it provided interaction with the audience (12 of 16 participants). Amongst these responses, it was clear that the children were interested and engaged in urban design issues for Auckland with one child saying, “because I like finding out what people think about the city”.

In terms of concern about the environment, an equal and majority number of students (9/16) felt that both the pre-performance workshops and the performance itself stimulated their thinking about the environment. The main reasons given were because of talking/thinking/learning (7 students), sharing (3), creating (2). This obvious enthusiasm indicates that the children saw the project as stimulating their environmental learning in a positive and democratic way. Interestingly, one child said, “I learnt how important NZ was”, which may mean that she appreciated New Zealand more due to the focus on analysing it during the process, or because of what she learnt through interacting with adults during the performances. One girl disagreed that she had made any changes in attitudes or behaviour - saying, “no, I allwase (sic.) think the same”. One boy said, “I care more about building/house prices and think about homeless people”, possibly indicating that children are influenced by adult and media-discussed situations such as the Auckland housing crisis, but they also notice things themselves as they move about the city, such as homeless people, and this worries them. It will be interesting and valuable to interrogate the transcribed data, for greater depth of material.

4.2. Urban Design

The data from the children’s schoolwork plus the starter questions from the focus groups was organised into six main design themes that emerged. In order of popularity (followed by the number of students out of 16 who mentioned each) these were; More environmentally-friendly (16), More nature/green space (15), More play/fun (13), Less traffic (11), Safer - e.g. cleaner, no smoking (10), Buildings - e.g. less boring, less expensive (10). These six themes became the design brief and it was decided to focus on the urban streets surrounding the school, especially those that form part of the school ‘Walking Bus’ route that many children use to get to and from school, accompanied by a roster of parents. A table of example ideas from the children under each theme is presented in Figure 1, below, and these are reflected in the design ideas that have resulted.

The design that has developed reaches out into the streets surrounding the school to connect the school more strongly with its community. Under the theme of ‘Play’, large footpath stickers of children’s art will connect a local Art Station that has a small community education garden with the school, and heading in the other direction the stickers will connect to a new cycling-themed playground, across the motorway and adjacent to a planned cycleway extension. Joining both sides of the school catchment (currently bisected by the North-western motorway), a new walking/cycling overbridge crossing the motorway by the school has been designed, to separate the two modes for safety reasons and with a roof for rain and to hold solar panels to provide striking LED coloured lights at night and make the bridge more distinctive and, hopefully, more iconic within its community. Panels along the interior of the bridge will hold art - as a ‘walking art gallery’ for the school and community, to engender ownership. Some could be recessed, cupboard-like spaces to house 3D art and a book exchange to encourage community interaction.
Cut outs of native birds and plants on the walls of the bridge will be infilled with coloured Perspex to reflect shadow shapes onto the ground - making a less boring building and enlivening the children’s trip to school (Figure 2 and 3). Fun rubbish bins (Figure 4) have been designed to be more environmentally-friendly and encourage use - to be positioned in strategic places along the walking bus route and in front of the school. To environmentally activate the street fronting the school, bird feeders will be added and kowhai trees (Sophora tetraptera) planted to encourage native tui birds. Moving tentatively towards having a traffic-free or parking-free street, a demonstration ‘parking garden’ will be designed (by children at the school) and installed in one existing parking space.

The next stage is to return to the school to present these ideas to the students and ask them to critique them so that the landscape architecture student can fold this into the design process.

<table>
<thead>
<tr>
<th>Themes</th>
<th>Nature</th>
<th>Play</th>
<th>Buildings/houses</th>
<th>Traffic</th>
<th>Safety</th>
<th>Environmentally-friendly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideas</td>
<td>More parks</td>
<td>Different activities</td>
<td>Less Expensive</td>
<td>Less Cars</td>
<td>More lights</td>
<td>More Rubbish bins (Colorful)</td>
</tr>
<tr>
<td>More trees</td>
<td>Lights in trees</td>
<td>More colorful buildings</td>
<td>More bikes</td>
<td>No smoking</td>
<td>Different rubbish technology</td>
<td></td>
</tr>
<tr>
<td>More plants</td>
<td>More public shows</td>
<td>Less high buildings</td>
<td>More walking paths</td>
<td>Less drunk drivers</td>
<td>More animals</td>
<td></td>
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<tr>
<td>Water parks</td>
<td>Interesting areas</td>
<td>Cool Shapes e.g. triangle Roofs</td>
<td>Flying trams</td>
<td>Less Broken Materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rooftop gardens</td>
<td>Help for homeless people</td>
<td>Easier to move around</td>
<td>Cleaner places</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Buildings with nice views</td>
<td>Underground powerlines</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Take down some apartment blocks</td>
<td>Less pollution</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Houses in the sky</td>
<td>Easier to move around</td>
<td></td>
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</tbody>
</table>

Figure 1: Summary of children’s ideas under the theme headings. (Source: B. Luo, with permission)
Figure 2: Perspective of exterior of new walking/cycle bridge (motorway beyond to right). (Image: B. Luo, with permission)

Figure 3: Perspective of interior of new walking/cycle bridge showing ‘walking art gallery’ of school & community art. Perspex shapes will reflect on the ground. (Image: B. Luo, with permission)

Figure 4: Perspective of environmentally-friendly rubbish bins focusing on recycling. (Image: B. Luo, with permission)
5. Conclusion

This paper has outlined the early stages of a research project to investigate whether performance art is a fertile medium for addressing issues of urban design and environmental awareness with schoolchildren. The research proposition is that performance may be a catalyst that, if employed in an integrated way with follow-up activities, could help create more child-friendly cities, robust communities and lead to possible environmental behaviour changes in participants due to development of pro-environmental attitudes. The process the students experienced was clearly greatly enjoyed and led to sharing of ideas between children and the adults they engaged with. This research project takes this further, notably in this paper, through a design process. Further research will introduce an iterative feedback loop for the design project and interrogate the transcribed data to determine whether the process has influenced participants’ behaviour towards the environment.

The part of the research project that has been presented here is not quite complete, yet it is already showing how one form of creative practice can springboard to another, while continuing to build capital in environmental and urban design knowledge. The ideas that came from the children’s work showed they had a well-developed understanding of their city and expressed valid concerns about aspects of it that they felt were unfair or unsafe. This agrees with findings from the IM study discussed earlier (Witten et al., 2013). While students’ ideas during the ‘Lookout’ workshops and subsequent performances included some rather ‘blue sky’ ideas, e.g. flying trams and rubbish bins, a helter skelter off the Sky Tower (not so improbable considering the Anish Kapoor design for London’s Olympic Park), they also included fundamental ways to improve Auckland for all Aucklanders. It is hoped that further analysis of the data may reveal some interesting insights on how performance might be used in environmental education and in contributing to urban redesign in a more child-centred way that is ‘back to the future’, as was evidenced in the ‘Lookout’ project.

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Agricultural By-products for the Production of Building Insulation in New Zealand

A first Look

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Abstract: New Zealand’s increasing population and economic growth is boosting the need for more buildings, and consequently more building materials. Increasing manufacture of building materials leads to the production of greenhouse gases as well as the depletion of finite natural resources. Approaches that reduce the environmental impact of construction can help achieve long term sustainability. One approach is the use of natural or recycled materials. Some agricultural by-products have characteristics similar to materials already used to manufacture insulation and could be an alternative bio-based solution. Rigorous analysis of the viability of this alternative is needed before such materials can be considered. This paper presents a literature-based study of technical research and opportunities evident in the New Zealand market.

Keywords: Insulation; bio-based material; feasibility; agricultural by-products.

1. Introduction

The construction industry has begun to integrate natural and local resources, addressing energy conservation and efficient use of material resources, into the design process in order to make this change successful, there is a need for increased research and innovation on supplementing and substituting, adapting use of existing materials and increasing recycling within the construction industry.

Increasing the use of recycled agricultural waste materials in bio-based insulation products could provide a more efficient use of limited resources and help create more positive perceptions of this waste. Increased fibrous content in insulation products can reduce thermal conductivity and increase sound absorption. Agricultural by-products are often described by their fibrous characteristics. Testing has shown that these qualities are comparable with contemporary insulation requirements, although these can vary with structure and environment (Korjenic et al., 2011). However, long term performance can be reduced as these materials may be degraded by moisture, bacteria, mildew and fungi. Issues of vapour permeability, fire resistance and moisture sensitivity also need to be considered (Korjenic et al., 2011). It has also been shown that natural building materials can have positive benefits for the wellbeing of the
inhabitants (Asdrubali, 2011). Research suggests that natural fibres, retained from agricultural production, are cheaper, lighter and have less impact on the environment compared to currently conventional sources for building insulation products (Joshi et al., 2004).

The agricultural industry in New Zealand is second in operating profit and income only to the real estate industry (Statistics New Zealand, 2015), with over 14 million hectares of land used in the production of agricultural products (Statistics New Zealand, 2012a). New Zealand has an abundance of maize (corn), flax, wheat and nut wastes which have the potential to improve building insulation production (Statistics New Zealand, 2012b; 2012c).

The three key motivations behind a recycling strategy for a construction project are: reducing environmental impacts; increasing benefits of the project; and improving the reputation of the construction and design team (Addis, 2012). Addis also notes that the consequences of not implementing these are: an increased waste; depletion of non-renewable resources; increased air and water pollution; and the loss of natural landscape and habitats.

Embodied energy within the construction industry also becomes more important as operational energy decreases. According to Thormark, embodied energy contributes to between 40 to 60% of the building’s total lifetime energy use, so material substitution becomes a viable strategy to decrease the overall impact of the embodied energy (Thormark, 2006). The most beneficial materials to use are those that have not processed and are left over from the first stage (i.e. production) (Addis, 2012). The decision making processes for the use of recycled materials sometimes requires compromise because some materials which have a higher energy consumption during manufacture are more durable and recyclable, whereas others may require lower maintenance (Conder, 2008).

2. Context

Stakeholders have the ability to facilitate the drive towards environmental improvements within the construction industry, however they have varied and sometimes unclear roles and responsibilities when it comes to choosing materials (Sandhu et al., 2010). The cooperation of multiple stakeholders in the development of new products has not been widely studied, and specifically how to implement this within green products in New Zealand is relatively unknown (Tari, 2011; Driessen and Hillebrand, 2013). The definition of a stakeholder is “any group or individual who can affect or is affected by the achievement of the organizations objective” (Freeman, 2010) which includes consumers, manufacturers, suppliers, regulators, Non-Government Organizations (NGOs), architects and designers.

Each stakeholder plays an important role within the waste management sphere. Government intervention enables direct and efficient waste reduction policies, so that the consequences of different waste products can be seen while decisions are being made encouraging waste minimization strategies for both manufacturing and consumer products (Denne and Bond-Smith, 2012). Implementation of such policies is occurring at various levels within New Zealand using funds from the Government’s Waste Disposal Levy under the Waste Minimization Act (WMA) (Denne and Bond-Smith, 2012). NGO’s are driven by community action, and have an important impact on changing public attitudes and persuading consumers towards using more environmentally sustainable materials, promoting recycling, reuse, composting, waste reduction, waste education and fostering partnerships (NZAIA, 2016; Community Recycling Network, 2017). To date, very little emphasis has been put on these issues within the construction industry (BBE, 2017).
Architects, as one of the key stakeholders in the construction industry, are prime candidates for such change at the beginning of the design phase through improved understanding of the importance of recycling (Bahamón, 2010). In a situation where there is still no defined or proposed legal requirement, personal interest and the ideas that are driven by the design team and clients can be the main impetus for change (Addis, 2012). The flow of decisions being made by the construction industry stakeholders dictate (or define) the values of the market. Ultimately they will develop a preference for a sustainable product. It is advantageous to the construction industry to recognise the future limits of natural resources, and increase the percentage of recycled content in today’s products (Slaughter, 2005; Albino et al., 2009; Rodriguez-Melo and Mansouri, 2011).

3. International Topical Background

The aim of building thermal insulation is to reduce the transmission of heat. Thermal ‘conductivity’, or its reciprocal ‘resistivity’, are key indicators. Some agricultural waste materials have been studied for their thermal behaviour, notably corn, coconut, flax, hemp, and rice.

Air and structure born sound transmission require different strategies for managing noise within the building industry. Air borne sound is measured by the sound absorption coefficient. These can be measured in a reverberation room, and/or impedance tube according to the size of the samples and accessible equipment. Flax, hemp, reed, rice, and coconut are among the frequently studied agricultural products with the potential to be a good acoustical absorbent.

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal conductivity (W/mK)</th>
<th>References</th>
<th>Sound absorption coefficient</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>0.101 to 0.139</td>
<td>(Lertsutthiwong et al., 2008; Paiva et al., 2012; Pinto et al., 2012)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Flax</td>
<td>0.09 and 0.33</td>
<td>(Kymäläinen and Sjöberg, 2008; Hajj et al., 2011; Korjenic et al., 2011)</td>
<td>0.5-0.9</td>
<td>(Hajj et al., 2011; Chabriac et al., 2016)</td>
</tr>
<tr>
<td>Hemp</td>
<td>0.0393 and 0.123</td>
<td>(Kymäläinen and Sjöberg, 2008; Korjenic et al., 2011; Stevulova et al., 2013)</td>
<td>0.67 – 0.9</td>
<td>(Oldham et al., 2011; Brenci et al., 2013; Chabriac et al., 2016)</td>
</tr>
<tr>
<td>Coconut</td>
<td>0.04 and 0.1854</td>
<td>(Sampathrajan et al., 1992; Khedari et al., 2003; Schiavoni et al., 2016)</td>
<td>0.5-0.9</td>
<td>(Sampathrajan et al., 1991; Fouladi et al., 2011; Berardi and Iannace, 2015)</td>
</tr>
<tr>
<td>Rice</td>
<td>0.049 and 0.061</td>
<td>(Sampathrajan et al., 1992; Yarbrough et al., 2005; Liu et al., 2012)</td>
<td>0.54</td>
<td>(Sampathrajan et al., 1991; Jayamani et al., 2015)</td>
</tr>
<tr>
<td>Reed</td>
<td>-</td>
<td>-</td>
<td>0.38-0.64</td>
<td>(Oldham et al., 2011; Doost-hoseini et al., 2014; Berardi and Iannace, 2015)</td>
</tr>
</tbody>
</table>
Environmental impacts are usually evaluated through Life Cycle Assessment (LCA) which encompasses different life stages of the material. Defining the system boundary is the initial step, then impacts should be normalized to the functional unit. For instance, the functional unit for building thermal insulation is the mass of the material which provides a thermal resistance of 1m²K/W. The environmental impacts can be expressed with energy or greenhouse gasses (GHGs) indicators. Generally, results of LCA of flax, reed, palm and hemp as natural fibres showed that they have less environmental impacts depending on their composition than other conventional competitors. If they also have better technical performance, the result is improved energy efficiency and fewer emissions (Joshi et al., 2004; Van der Werf, 2004; Benfratello et al., 2013; Zampori et al., 2013; Schiavoni et al., 2016). However, adding flame-retardants or other additives to insulation materials to improve their performance may make them hazardous (Schmidt et al., 2004; Schiavoni et al., 2016). Analyzing environmental impacts of palm and flax can also help in the determination of their LCA (van der Werf and Turunen, 2008; González-García et al., 2010; Ip and Miller, 2012; Chiew and Shimada, 2013).

Other characteristics of boards made with natural fibres, such as structural performance, fire resistance, and vapour permeability are studied in scattered pieces of research. Advantages and disadvantages of agricultural by-products used as insulation are classified in Table 2. There is limited data on properties such as: flexural properties; dimensional stability; fire resistance; water absorption; vapour permeability; strength; and tensile strength. These will be the subject of a future paper.

The non-homogeneous structure of natural fibres can make it difficult to predict their behaviour. Measurements can often indicate better results than the theoretical calculations and simulations (Berardi and Iannace, 2015). Once the material has been tested, a early step in commercialisation can be a comparison between built case studies rather than the use of theoretical models (Asdrubali, 2011). Other critical factors include the manufacturing process as it affects the characteristics of insulation, the measurement of environmental impacts and the economic feasibility (Joshi et al., 2004).

Table 2: General advantages and disadvantages of agricultural by-products as insulation, based on a wide range of reviewed literature.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Low thermal conductivity</th>
<th>Abundant</th>
<th>High damping</th>
<th>Lower environmental impacts</th>
<th>Renewable resources</th>
<th>Self-link</th>
<th>Natural</th>
<th>Bio degradable</th>
<th>Energy efficient</th>
<th>No skin irritation</th>
<th>Fast renovation</th>
<th>High specific heat</th>
<th>Cost effective</th>
<th>Less emissions</th>
<th>Non-toxic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disadvantages</td>
<td>Non-load bearing</td>
<td>Thicker</td>
<td>Variation</td>
<td>Hazardous additives</td>
<td>Lower durability</td>
<td>Treatment</td>
<td>Unsuccessful theoretical models</td>
<td>Contaminants</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. New Zealand Agricultural Situation

Each region has specific agricultural production according to the climate and geographical situation. Hence, feasibility studies need to be carried out locally. Using local materials has the advantage of reducing transportation energy and production phase costs.
In New Zealand, wheat, barley, oats and maize are the main grain and seed crops (Statistics New Zealand, 2012c). According to reports on grain and seed production (2002) the area of highest arable land for the production of Wheat, Barley and Oat was in the Canterbury area, followed by Southland, Otago and the Manawatu-Wanganui area. For maize production the North Island is the primary location with hotspots in the Waikato, Gisborne, Manawatu-Wanganui, Bay of Plenty and Hawkes Bay.

Following harvesting and extraction of these grains and seeds, they enter the processing industry being used for flour, malt and animal feed (Zydenbos, 2008). Straw, a by-product, can have different uses including: returning to the soil for nutrients; burning and returning the ash to the soil; or selling as straw for purposes such as mushroom production, bedding for animals or garden mulch (Zydenbos, 2008), and potentially in the future for insulation. The supply of the potential agricultural waste products can vary year to year, due the weather, economics and competition. In 2013, New Zealand, arable crops produced 11.7 tons of waste per year (Tonkin & Taylor Ltd, 2014).

Flax is abundant throughout the nation. Maori have many uses for flax, including weaving. Discarded pieces were to put under the plant to ultimatley convert into compost (Brown, 2011). Growth of manufacturing, with the support of government, saved the flax industry in 1930, by promoting the use of flax for woolpacks for farmers, and other uses such as underfelt, floor coverings, upholstery materials and binder twine. However, just 50 years later in 1985 the last manufacturer was closed because of synthetic fibres and a lack of government support (Matheson, 2000). In the 2000s, growing interest in renewable resources has made the flax industry strong again. Researchers are currently exploring new uses for flax and its manufacturing residues, looking for opportunities in new industries such as building materials, furniture and packaging (Swarbrick, 2007).

Industrial hemp has been grown in New Zealand since 2003, but not yet intensively. Hemp grows to a height of between one and five meters in three months, at a density of 150 plants per square meter (Berger, 1969). The industrial hemp industry has a wide range of uses that can contribute to the health and therapeutic markets as well as many other areas. The high-quality fibre is taken from its stalk and used in manufacturing cordage, textile, paper and fibreboard. The value of these natural bast fibres are defined in terms of length and content of lignin (Aghedo, 2007). The deep roots of the plant prevent erosion; enable cleansing the ground, can control insects in orchards, providing a disease break and aerating the soil. It needs less labour and energy during growth because it does not need husbandry until harvesting, but extracts nutrients from the ground much faster than other crops. The high yields of hemp provide a good alternative to traditional building materials such as wood in many applications (NZHIA, 2015). Plant fibre extraction requires highly mechanised processes with expensive machinery making the cost to developing composite materials quite high (Hobson et al., 2001). Simplifying the processes and lowering the cost to the production of these materials is of concern (Saheb and Jog, 1999; George et al., 2001). The inner woody core (70-80% of the stalk) was previously considered waste, but has the potential to be used as tissue, newsprint pulp, rayon, biomass fuel, cellophane, food additives, and industrial fabrication materials. It can also be mixed with lime and used in construction industry as molded interior and exterior walls (Merfield, 1999). Generally, the utilization of this fibre crop has increased in food, textiles, oil and construction market since 2002 (NZHIA, 2015).

5. Evaluation of Solutions

The summary of the results for these bio-materials suggest that there are several potential options for further development of unconventional and sustainable sources of building materials. Flax and hemp are two materials that already have existing infrastructure for the use of their waste products which could be
adapted to the construction industry. Other products, such as wheat, barley, oats and maize, have high levels of yield which make them good New Zealand options but lack existing uses to provide infrastructure for potential use in construction materials.

Table 3 summarises the results of an international literature review of bio-materials, available in New Zealand, which are used elsewhere for building insulation products. The evaluation criteria for possible materials are defined as follows:

1. **Availability**: locally grown, yield high enough to produce;
2. **Technical viability**: acceptable performance in use, e.g. thermal, acoustical and physical;
3. **Environment friendly**: acceptable LCI (environmental Lifetime Cycle Impact);
4. **Infrastructure needs and availability**: technically possible to grow with existing technologies and processing facilities;
5. **Potential benefits**: creating new jobs, possible to grow profitably as future economics.

Considerable international research has been undertaken on flax and hemp in various products to evaluated their thermal and acoustical properties. Limited research has been undertaken on the environmental, social aspects and economic issues. Wheat, barley, oats and maize are abundant in New Zealand but there is still not enough research to show that they are viable options in terms of thermal and acoustic performance, or other characteristics. However, they have fibrous characteristics of similar bio-based materials which are used for insulation. Nut shells such as from chestnuts, hazelnuts, macadamia or walnuts have the potential to be used as components or additives to building insulation boards but there are very few technical studies so more research is required to prove feasibility.

<table>
<thead>
<tr>
<th>Material</th>
<th>Availability</th>
<th>Technical viability</th>
<th>Environment friendly</th>
<th>Infrastructure</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flax</td>
<td>+</td>
<td>+</td>
<td>+*</td>
<td>+</td>
<td>+/-*</td>
</tr>
<tr>
<td>Hemp</td>
<td>+</td>
<td>+</td>
<td>+*</td>
<td>+</td>
<td>+/-*</td>
</tr>
<tr>
<td>Wheat</td>
<td>+</td>
<td>+*</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Barely</td>
<td>+</td>
<td>+*</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Oat</td>
<td>+</td>
<td>+*</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Maize</td>
<td>+</td>
<td>+</td>
<td>+*</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Nut shells</td>
<td>+*</td>
<td>+*</td>
<td>+*</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*indicate that in this criteria few researc studies have been undertaken.

Positive factors in this criteria according to the literature are being locally abundant, having comparable thermal, acoustical and physical performance with other contemporary building insulations, having an environmentally friendly production process, requiring less or inexpensive infrastructure and meanwhile having social and economical benefits for the local society. Apparently negative factors indicate lack of these characteristics. The most reasonable and technically feasible alternatives in terms of technical and environmental characteristics, production rate and existing infrastructures are flax and hemp. Flax and hemp are two materials that can be used in the form of mat or loose-fill insulations, or can be blended with other fibrous materials, composites and/or natural binders to make stronger and durable insulation boards depending on the purpose of use, also they have both good thermal and acoustical behavior.
Table 3 provides an partial guide to current knowledge of the use of the selected unconventional bio-
materials for making building insulation. However, because the essential research, as well as
manufacturing, distribution and business development, is not complete, it is not currently feasible to
select the best option(s).

6. Conclusion

This paper provides a brief overview of the potential for agricultural wastes (bio-materials) to be used in
the production of insulation materials in New Zealand. It is offered as a starting point for a future,
complete analysis. The discussion and findings use an analytical framework developed through literature
review. Through identification of influential factors in the develop a new building material, the study has
shown that flax and hemp offer opportunities for further investigation.

This study has considered the potential for agricultural by-products to be used in terms of their
environmental and technical performances and their availability perspectives. New Zealand has a top
position in OECD rating of economic growth, and the most important growth industry is construction, but
actions in this sector can result in benefits to all stakeholders. While a range of potential benefits have
been discussed, it is likely that there are more which could be considered when evaluating agricultural by-
products for recycling. These include health benefits, natural degradation, transportation requirements,
growth rates and aesthetic. These matters will be the subject of future research.

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Reverberations

Architectural Practice through the Lens of Multiscale Dynamical Fractal Systems Theory

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Abstract: The postmodernist emphasis on context encourages us to pursue understandings of the communities within which buildings exist as a central component of the discourse of architectural practice. However, significant challenges to this approach exist, since the contexts in question subextend a wide range of spatial and temporal scales, and are driven by self-referential dynamical systems that are centred on the psychologies of agents who perform complementary and overlapping roles as building-dwellers and community-dwellers. This work addresses this epistemic gap by exploring the causal relations between object and context through the introduction of the concept of building-as-community. Specifically, this entails a radical rejection of the dichotomy between buildings and communities, arguing that together they form a complex system that can be explored from the ontological perspectives of dynamical systems theory and fractal geometry; the spatiotemporal patterns thus elucidated can helpfully inform aspects of architectural science. For example, the interactions within (and without) a building can be understood as a microcosm of the interactions between the building and its embedding community, suggesting a shift in emphasis towards a unified, congruous framework for understanding both buildings and communities as interrelated phenomena operating on non-coextensive but nonetheless overlapping and intertwined spatiotemporal scales.

Keywords: Dynamics; community; multiscale.

1. Introduction
To engage in a conceptualisation of architectural practice divorced of its spatial and historical context is to commit the pre-Structuralist error, first popularised by Claude Lévi-Strauss, of mistaking phenomenological content for meaning (Blackburn, 2008). The appeal of this epistemological elision is that it allows the observer to sidestep the uncertainties and complexities inherent in understanding (much less quantifying) the complex relationships between the dynamical structures that govern the relevant contexts; furthermore, it allows the observer to substitute his or her own normative discourses for those that are in fact instantiated in situ, thereby rendering the object of study more understandable.
(or, perhaps, acceptable) within his or her sociocultural context and biases, even if, thus rendered, the object becomes caricatured to those who possess deeper appreciation of the context from which it was duly appropriated. An example is where a poor person’s version of community dwelling, forced by circumstances and scarcity of resources (e.g. a ‘chawl’ in Mumbai) has metamorphosed into the design typology for a rich person’s playground (e.g. a ‘café’ or ‘bar’ in Gurgaon) (Chaturvedi, 2017).

Confronted with these existential challenges to our endeavour, how can we best go about understanding ‘buildings’ in the full richness that their spatiotemporal environment demands? This is a deeply studied problem, and a plethora of approaches exist (Wells, 2007). However, a common limitation of these approaches is that they typically focus on particular aspects of the context, and thus belong to normative dialectics of their own. While ‘objective truth’ has never fully recovered from its problematisation at the hands of postmodernists, this does not mean that all viewpoints are equally valid (or, more radically, that there is not a single most valid view). Thus, although ‘absolute’ objectivism remains chimeral, it nonetheless remains possible in some circumstances to identify certain discourses as having comparatively more or less referential bias, or comparatively narrower or broader scope. While mathematics is not without its vocal critics (Burton, 1995), sufficiently broadly interpreted, it is arguably one of humanity’s most far-reaching and successful projects; its ontology is perhaps unique in being accessible across millennia, cultures, linguistic paradigms, socioeconomic strata, and gender barriers. Certainly, most if not all cultures that have codified architectural practices have adopted the ontology of mathematics with remarkable consistency. Thus, the formalism of mathematics, if used appropriately, offers a potential theoretical underpinning that is uniquely poised to be (to the extent possible) nomothetic and, contra Heidegger, orthogonal to historicity.

While ipso facto appearing to show promise, a ‘mathematical’ approach to architectural practice also includes profound challenges, both theoretical and practical. To begin with, it is not immediately obvious what this approach would even entail. Broadly speaking, traditionally there are two common approaches in which mathematical principles can be applied to (seemingly) non-mathematical subjects: as analogy and as abstraction. A famous example of the former is Jacques Lacan’s treatise relating the signifier of the phallus to the imaginary number, i.e. the square root of –1 or i. In the context of Lacanian mathematics, i is analogous to the image of the phallus:

Thus the erectile organ comes to symbolize the place of jouissance, not in itself, or even in the form of an image, but as part lacking in desired image: that is why it is equivalent to the square root of –1 of the signification produced above, of the jouissance that it restores by the coefficient of its statement to the function of the lack of signifier –1. (Lacan, 1960)

Thus, despite Lacan’s daring use of the term ‘equivalent’, within the context of the argument, Lacan is using the formalism of i to conceptualise the ‘irreducible inconceivability’ of the image of the phallus, in analogy with the irreducible inconceivability of i (Plotnitsky, 2009). Such approaches have come under intense criticism from the scientific community, partly due to the observation that by such analogies any object or concept in the world may be similar to any other, no matter how distant (Sokal and Bricmont, 1998). Similarly, the mathematical concept of ‘topology’ has been used for over 50 years as a point of departure to theorise within the architectural context about the ‘geometry of place’ (Hartoonian and Utomo, 2012): notably, the use (and usefulness) of the topological conceptualisation of architecture lies almost entirely in its ability to inspire and provoke, rather than, for example, generate equations that can literally be parameterised and solved; this ipso facto solidifies its classification as an example of mathematics-as-analogy.
While mathematics-as-analogy is principally practiced by non-mathematicians (Sokal and Bricmont, 1998), mathematics-as-abstraction typically falls within the normative discourse of mathematics itself. Mathematics-as-abstraction involves the quantification of *a priori* unquantifiable subjects, thereby typically (although not always) sacrificing semantic content for computational tractability. A classic example is the computational linguistics embodied in Google’s Ngram Viewer, which provides historical analyses of word usage statistics. Only the bitterest student of literature would argue that the resultant histograms represent the most interesting or meaningful aspect of literature; yet, even these simplistic analyses have yielded some surprisingly meaningful results: in terms of global impact, perhaps the most notable of these is the discovery that Google search term frequencies are the best available predictor of flu outbreaks (Ginsberg et al., 2009).

Thus, we have two nearly orthogonal approaches, yet both of which possess a modicum of legitimacy in their claim to be a ‘mathematical’ discourse. If we may facetiously pillory mathematics-as-analogy as ‘interesting but wrong’ and mathematics-as-abstraction as ‘true but uninteresting’, a midway approach has the potential to be – one would hope – ‘interesting and true’. The crucial epistemic gap between these two constructs is as follows. Macroscopic observable facts of the ‘natural world’ can, in principle, be represented mathematically; however, the usefulness of this representation declines as the conceptual distance grows between mathematical primitives and the phenomena in question. For example, the ontological distance between the mathematical (as opposed to socio-historical) concept of ‘the square root of −1’ and Lacan’s psychosocial and ethnographic ‘image of the phallus’ is such that no presently conceivable mathematical statement could close this gap. Likewise, the phenomenological distance between statistically quantifiable word frequencies and the change in the ‘meaning’ of texts over time is also so vast as to appear unbridgeable; while the breathtaking development of convolutional neural networks and deep-belief nets has rapidly brought ever-greater semantic content within algorithmic reach – such as, most famously, unsupervised identification of the faces of cats from YouTube videos (Le et al., 2013) – such algorithms still fall well short of capturing a meaningful portion of the lived experience.

To address the unique challenges posed by the interdisciplinary nature of architectural practice, we require a middle ground between the extremes of mathematics-as-analogy and mathematics-as-abstraction. Is there a way to proceed towards the potential elucidations offered by mathematics, while avoiding the trap of pseudoscientific hyper-quantification, or, worse, becoming mired in abstruse integrals? Here we describe an approach that aims to draw on the insights offered by mathematical approaches by *formulating* questions and theories in mathematical terms, while remaining cognisant of the limitations imposed by the scarce data available. This approach, which could perhaps be termed ‘mathematics-as-possibility’, in some aspects combines the ‘mathematics-as-analogy’ and ‘mathematics-as-abstraction’ approaches, while in other aspects it is unlike either; a (necessarily non-rigorous) schematic of these three approaches is given in Figure 1.

Proceeding under the assumption that mathematics-as-possibility has potential utility, the next step is to choose which aspects of mathematics to adapt for this purpose. Here we will proceed to provide an outline of one particular example of this approach – namely, exploring the implications of conceptualising buildings and communities as multiscale fractal dynamical systems – as follows. First, we provide a brief treatment of dynamical systems theory, laying the groundwork for understanding the relationships between buildings and communities as they evolve over time. Second, we introduce fractal theory, to facilitate the deconstruction of recurrent patterns that span multiple spatiotemporal scales. Finally, we propose the concept of building-as-community, which links these concepts together to unify
the conceptualisation of buildings and communities within this shared framework. The framework outlined herein is necessarily tentative and speculative, and far more questions are posed than answers; our aim is, instead, to establish a multilogue between the thinkers and theorists whose work spans from mathematics and data science through to urban and community planning, since such syntheses and integrations between disciplines are likely to be critical to the advancement of the field of architectural science over the next 50 years.

Figure 1. Conceptual correspondences between mathematical and non-mathematical discourses.

A mathematician versed in the normative traditions of mathematics-as-abstraction will likely note the dearth of proofs, equations, and lemmata in this paper. We do not posit precise forms for the dynamical or fractal equations presented here, much less purport to solve them. Partly, this is due to a fundamental, albeit conceivably addressable, limitation: the data that would be required to constrain the parameters of such equations are not available. While architecture databases do exist, few such databases reliably record easily quantifiable data that could be used to interrogate phenomena of genuine interest to architectural theorists; for architectural science to mature as a field of inquiry, major efforts to develop such repositories will need to be undertaken over the coming decades.

Where the argument developed in this paper departs from both mathematics-as-analogy and mathematics-as-abstraction is that these approaches typically treat mathematics with considerable deference, and, more problematically, rigidity. While this is essential for mathematics-as-abstraction to succeed on its own terms, it seems equally true of mathematics-as-analogy. Even if Lacan’s use of the square root of \(-1\) could have been equally well served by analogy with \(\aleph_0\) (i.e., the cardinality of a countably infinite set, which also possesses ‘irreducible inconceivability’), or if Banham’s ‘topology’ could have been replaced with simpler notions from topography or geometry, such equivocations are rarely welcomed. In contrast, this paper presents concepts from two areas of mathematics, dynamical systems theory and fractal geometry, whose applicability to architectural science is predicated by the fact that they have both been successfully applied to phenomenologically proximal fields, such as urban design. Of course, this paper constitutes a preliminary and necessarily brief exploration of this topic, and we do not presuppose that these are the only, or even the most pertinent, areas of mathematics for
interrogating the spatiotemporal patterns instantiated in architectural practice; rather, we state merely that they were the most self-evident due to their pre-existing discursive corpora.

2. Buildings as evolution: dynamical systems theory

One may legitimately ask what relevance dynamical systems theory has for the ‘hard and lifeless matter’ of buildings (Scribner, 1990). Yet, even buildings which remain physically static over time – and of course many do not – nonetheless evolve in context of their surroundings, as well as the people who inhabit them. Thus, one must consider the dynamicism of not just the building itself, but the reference points by which it is to be understood, and how they evolve in concert.

Certainly, one cannot expect to formulate a literal, closed-form solution of the fundamental equation of dynamical systems, i.e. \( y = \int f(t,\theta)dt \), for any nontrivial quantity of interest \( y \), where \( t \) signifies time, \( \theta \) are the parameters of the system, and \( f \) represents an arbitrary functional relationship. Furthermore, even if it were possible to formulate such an equation, it is extremely unlikely that it would be possible to obtain sufficient data to inform the parameters to solve the resultant equation, even numerically. Yet, despite the literal infinitude of possible formulae and parameterisations, particular mathematical patterns arise repeatedly in vastly disparate systems, which often allows the adoption of a general form of a problem to make the solution tractable, known as an ansatz. These ansätze can help facilitate thinking about the possible solution-space for a problem even if considerable uncertainties remain.

For example, the long-term behaviour of non-chaotic dynamical systems is typically either a stable fixed point or an oscillatory limit cycle. These dynamical primitives can be observed to reflect, respectively, irreversible changes in architectural practice and cyclic aesthetic fashions (Carbon, 2010). As an example of the latter, ornate decorative styles that were enormously popular in the 18th and 19th centuries fell out of fashion in favour of the clean utilitarian lines of modernism. However, in recent years there has been considerable backlash against these movements: the Brutalist aesthetic that was ascendant half a century ago is now considered ‘an eyesore’ (Rodrigo, 2015). The point is not, of course, that it is possible to actually formulate a quantitative differential equation to calculate the historical evolution of aesthetic preferences in architecture. Rather, it is to recognise that such a formulation would, in principle, be possible, and thus the general mathematical principles of periodic and ergodic systems apply, even if their particulars are unknown. For example, only systems with certain structures and parameters show limit cycle behaviour; however complex they may be, if aesthetic fashions can be shown to follow such cyclic behaviour, it follows that they can be expressible in this formalism. Since a system only shows periodicity when it has both a specific functional form and a specific set of parameters, such periodicity could cease with a sufficient shift in parameter values, even if the functional form remains unchanged.

As an example of this shift, consider the choice faced by architects of choosing heating via coal-burning stoves versus electric heating. Shortly after the introduction of the latter, each technology had practical advantages and disadvantages, leading to the ultimate choice in a given building being subject to the principles of aesthetic limit cycles. However, as the parameters underlying the relative costs and benefits shifted decisively in favour of electric heating, it now represents a fixed point in the vast majority of cases (subject, of course, to modification in the face of unforeseen future technological developments). In general, it is not possible or indeed necessary to quantify the functional form in order to identify what the parameters in the equation were: in this case, they were likely financial, logistical, environmental, and legislative, among others. Hence, while precise predictions are unlikely to arise from
such a framework, it nonetheless informs the possible parameter space within which architectonic decisions are made. This type of approach also invites the architectural theorist to consider not merely what was and is, but, critically, what could have been: for example, a wood-burning stove in a design is a far more interesting phenomenon after the introduction of coal and (especially) electric heating than before; a choice, rather than a necessity. In mathematical terms, one would say that the system has additional free parameters. While doing so is beyond the scope of this paper, it may even be possible to define a ‘free energy principle’ for architectural practice, in much the same way that it has been defined for other complex systems such as the human brain (Friston, 2010).

3. Buildings as patterns: fractality as an organising principle

While it is commonly believed that the fractal geometry of cities arises from their stochastic element – that is, their intrinsic rebellion against ‘the architect’s physical determinism’ (Batty and Longley, 1994) – this view is more focused on the distributed, non-centralised and stochastic spatio-temporal processes that result in the ‘fractal city’. Even at the scale of the building, though, centralised, deterministic, or non-stochastic factors can also result in fractal morphology by the designer’s explicit intention. As shown in Figure 2, buildings themselves, though (presumably) free of stochastic components, can show remarkably fractal geometry: in this case, a demonstration of the pragmatic utility of the fractal structure – namely, one that incentivises the ratio of surface area to volume. Remarkably, the pseudo-fractal designs shown in Figure 2 both predate the formal discovery of fractals by more than a decade. Mathematically, the generation of non-stochastic fractals – such as the arresting beautiful Julia sets (Douady and Hubbard, 1984) – is typically accomplished via deceptively simple recurrence relations, such as the logistic map or the closely related complex quadratic polynomial $z_{n+1} = z^2_n + \alpha + \beta i$, where $z$ is a complex-valued variable, $\alpha$ and $\beta$ are real-valued constants, and $i$ signifies (in the non-Lacanian sense) the square root of $-1$. Thus, principles of generative, parametric design in architecture may be said to characterise the ‘fractal’ idea, where a certain simple motif or rule is repeatedly applied to produce geometries and topologies of increasingly complex natures, possibly at several scales. Another example of such design, though not fractal, would be Stiny’s work on shape grammars (Stiny, 1980).

![Figure 2. Left: Sierpinski gasket, a type of fractal. Middle: The Municipal Orphanage in Amsterdam by Aldo van Eyck (1960). Right: Robert Moses’ Stuyvesant Town, New York (1943-1947). (Sources: Wikimedia Commons (M); Jeffrey Milsteain/Rex Shutterstock (R))](image-url)
Stochastic and rule-based approaches for generating fractals should not be thought of as being wholly distinct: there is a tight connection between the fractal nature of a city’s network of roads and suburbs, a building’s network of corridors and rooms, and a person’s network of blood vessels and organs, as all of them are in a sense optimised (even if by unconscious and undirected causes) to facilitate the transport of entities among the nodes of the network: people and blood cells, respectively. Mathematically, this invariance is captured by a power law: $P(x) \propto x^{-\gamma}$, where $P$ is probability, $x$ is a quantity, and $\gamma$ is the exponent. Remarkably exact scaling laws have been found for both cities and people: the exponent $\gamma$ has been calculated as 2.3 and 3.0 for road and vascular networks, respectively (Kalapala et al., 2006; Huo and Kassab, 2012), with the difference in the value of the exponent due to the fact that cities are approximately two-dimensional structures while humans are approximately three-dimensional (unlike Euclidean objects, fractal objects have non-integral dimensionality).

In contrast to vascular systems and transport networks, buildings often do not span the sufficiently wide range of spatial scales required in order to make quantitative statements about the dimension of their fractal geometry. However, this does not imply that the principles of fractal geometry do not apply. Qualitatively, the principles that apply on systems of scales from micrometres to metres (the human body) and on scales from hundreds of metres to hundreds of kilometres (cities and urban agglomerations) should reasonably apply to systems that exist at a mesoscale: indeed, as shown above, evidence exists that they do. Once fractality is identified as an organising principle, questions abound: in what contexts do buildings adhere to these principles, and when do they violate them? Can the fractal dimension of buildings be quantified with respect to their optimality? Is the fractality of buildings meaningfully related to the fractality of the cities in which they exist? An example of this is the case of mid-twentieth century Soviet and Chinese central planning, which resulted in fractal buildings as well as cities, but many examples in the West exist as well, such as New York City’s Stuyvesant Town – which, perhaps not coincidentally, also represents a blurring between building and community.

4. Buildings as community: Reverberations of multiscale fractal dynamics

Having laid the theoretical groundwork of both dynamical systems theory and fractal geometry, we now have the tools required to ask the central question of this paper: by integrating across both space and time, to what extent can buildings be conceptualised within the same multiscale dynamical system as the communities within which they exist? More formally, in information-theoretic terms, can we quantify the bidirectional transfer entropy between building and community?

Aside from dialectics interrogating Frank Lloyd Wright’s *Broadacre City* and Le Corbusier’s *La Ville radieuse* (Batty and Longley, 1994), surprisingly little attention has been paid to the import that urban historiography (and the hermeneutics thereof) has on architectural science. This is even more remarkable given the overlapping scales between large buildings and small communities: Geneva’s Le Lignon consists of 2780 units and houses some 6800 inhabitants, which would, remarkably, place it near the 50th percentile of ‘city’ size (Eeckhout, 2004). As a consequence of the comparative invariants of human behaviour – the tyrannical mundanities of commuting, waste production and removal, etc. – it follows that there exist significant overlaps in the challenges that are dealt with by the architects of large buildings and the planners of (or theorists of) communities, whether said communities are self-contained or constitute part of a larger urban agglomeration.

What consequences arise if buildings and communities are conceptualised not as distinct epistemic entities *qua* phenomenology, but rather as points along a continuum? This is not to deny that each has its own unique and valuable discourse. However, by considering communities and buildings as
multidimensional Bayesian distributions with considerable degrees of practical and theoretical overlap, we propose that the hermeneutics of architecture and urban studies have a more substantive nexus than is commonly recognised. This statement goes beyond the truism that urban design and architecture are both buffeted by the same cultural currents. By conceptualising buildings and communities as overlapping dynamical distributions, it acknowledges the realisation that buildings and communities coextend over space, time, and most critically, inhabitants, prompting a radical rejection of their epistemic orthogonality. This point echoes the observation by Jane Jacobs, who, more than 50 years ago, asked a similar question regarding cities themselves:

Why have cities not, long since, been identified, understood and treated as problems of organized complexity? If the people concerned with the life sciences were able to identify their difficult problems as problems of organized complexity, why have people professionally concerned with cities not identified the kind of problems they had? (Jacobs, 1961)

Buildings, too, can be understood as complex systems, regardless of whether their designers interpret them that way: yet, the field of architecture has, if anything, been even more resistant than urban studies to adopting the principles of complexity theory. One possible explanation of this conservatism is that the epistemology of a dynamical fractalist approach de-legitimises the exclusionary patriarchalism of the unquestioned dominance of Euclidean geometry:

The maintenance of patriarchal ideology sends ripples in the production of spaces, particularly in architecture and urban planning. Architecture is consummated by organizing and articulating meaningless Euclidean space to accommodate human habitation and insertion of existential meanings. Hence, architecture transcends the neutrality of geometrically determined and physically defined structure and enclosure to become a site of lived life, where cultural processes, gender transactions, and modus of sexual desire are continually enacted. (Lico, 2001)

Aside from searching more meaningfully for a theoretical epistemic connection between community and building, this framework encourages us to ask: what are the bidirectional influences and synergies between the two spheres of building and community, thereby forging them into a single ur-phenomenon, building-as-community? Even brief reflection shows that the connection is a strong one. To cite the simple example of building height – due to its straightforward quantifiability rather than its criticality to the enterprise of architecture – there exists a deep connection to city size. The Burj Khalifa would not exist in a village (notwithstanding Dubai’s remarkable transformation from being just that), and nor is a modern megalopolis devoid of skyscrapers conceivable either. The height of a building is an implicit characterisation of density, and increases in density are intrinsically linked to the growth of a city, outwards and upwards. Figure 3 plots the height of the tallest buildings over time in each of the three cities that has at one point been the largest in the world since 1880: London, New York, and Tokyo. Of these, initially London was the largest and had the tallest building; now, Tokyo holds both honours. Most of the height increases in New York City happened within 10 years of the point at which it claimed the mantle of the world’s largest city (around 1920); similarly, during the period 1960–1980, when Tokyo rapidly outgrew New York City for the first time, the height of its tallest building increased by a factor of three. Unlike the case of mid-century Soviet cities and buildings, where one could claim morphological correlation due to an external cause (the system of centralised planning) rather than direct causation (i.e., the bijective mapping between buildings and community), in this case the evidence suggests that larger cities strongly necessitate, or at minimum facilitate, taller buildings.
Surprisingly, despite the fact that cities operate on spatiotemporal scales orders of magnitude greater than buildings, the latter can often have a quantifiable impact on the former. The corollary of the example discussed above is the infamous ‘skyscraper index’, which associates the construction of excessively large buildings with economic downturns. While recent evidence has challenged this correlation (Barr et al., 2015), there is nonetheless support for the view that in certain cases, if the floor space provided by large buildings is significantly larger than demand, it can negatively affect the city’s economy, as happened in Kuala Lumpur in the late 1990s following the completion of the Petronas Twin Towers (Keong, 2006). As a more positive example, Frank Gehry’s Guggenheim Museum in Bilbao provided a major economic boost, which, together with a series of additional investments, led to a major revitalisation of the entire city in the 1990s (Rodriguez and Martinez, 2003).

5. Conclusions: Theoretical advances and empirical challenges

The relentless trajectory towards the mathematisation and ‘quantificationism’ of epistemic inquiry has had a chequered past, at least when such trends have extended beyond the narrow purview of the hard sciences; examples where excessive quantification has done more harm than good are not hard to find (Brown et al., 2013). Thus, one should not approach the enterprise of mathematisation lightly. While it is often considered a myth of scientism that mathematics is intrinsically more difficult than other disciplines, it is nonetheless true that mathematics typically has a high barrier to entry, especially for those unexposed to its rigidly normative discourse. Yet, mathematical approaches have often elucidated aspects of inquiry that had been resistant to traditional methodologies.

Conceptualising buildings and communities within a single unified framework – namely, as a multiscale dynamical fractal system – immediately suggests a holistic approach that has surprising similarities with Structuralist thought, despite the profoundly disparate origins of each paradigm.
Namely, by dissolving the artificial boundaries and conflicts we construct (and perform) between the ‘architectural’ and the ‘urban’ (since, as alluded to above, the inhabitants of a city are supervenient on the inhabitants of its constituent components), we open ourselves to new possibilities in understanding architectural practice as a ‘rhythmically erotic’ choreography (Frampton, 2006), moving through both space and time, seamlessly flowing between buildings and the communities whose semiotics they profoundly, if fleetingly, reflect.

References

Identifying a Model Urban Precinct

Impact of built Mass for thermally Comfortable Living in Tropics

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Abstract: The Research investigates the behaviour of tropical micro-climates in urban precincts, affected by building masses; focusing in to a commercial zone in Colombo Central Business District. The tendency of growth in developing countries contributes by blocking wind path ways and cycling the solar rays of reflection resulting Urban Heat Islands. Three case study areas with similar urban microclimates and activity patterns were selected for the investigation. The building mass, aspect ratio, height / width ratio, air temperature, sky view factor (SVF), velocity of the wind and relative humidity are considered as basic attributes. Measured data were analysed by the software RayMan-Pro to provide Physiological Equivalent Temperature (PET) with a conceptual and suggestive attribute in a model urban precinct, for better thermal satisfaction levels. The qualitative changes of each precinct have been identified by onsite climate surveys; while thermal indices behave according to Interrelationships in micro climates. The results demonstrate the urban precincts with dense building mass are having a higher air temperature levels in addition to PET behaviour, wind and shadings by SVF cannot participate positively when considered separately, but altogether make healthier micro climatic conditions with the best level of building mass composition in urban precincts in tropics.

Keywords: Urban microclimate; sky view factor; urban precincts; albedo.

1. Introduction

A comfortable healthy indoor/ outdoor environment is always being made by manipulating the built up mass to obtain a comfortable thermal situation. The construction field nowadays rapidly focus on balancing the fundamental relationship between urban massing and Thermal comfort in the built
environment. Building Technologies incorporated with Architecture plays a major role in making a bioclimatic design which improves indoor as well as the outdoor environment more comfortably. In urban precincts, building is known as the primary fundamental unit of the city which contributes to a larger impact on whole urban climate thus human behaviours of the city. Further, the atmospheric context for the building within the city includes both the natural climate and the urban effect (Mills, G., Cleugh, H., Emmanuel, R., Endlicher, W., & Erell, E. 2010). Thus the research intends to investigate the opportunities which are available for better thermally comfortable “Urban Outdoors” in warm humid climates. Within the tropics, the study zoomed in to Colombo, the capital of Sri Lanka, where a higher trend exists in changing the urban microclimate due to varying density of the rapidly developing urban-scape; land coverage, height of buildings, orientation and width of streets, subdivision of the building lots etc. These urban formation trends amalgamate lack of cross ventilation in outdoor micro contexts, inappropriate building forms (Chen, N. H. 2009), Reduction of convection heat removal due to the reduction of wind speed (Moonen, P., Defraeye, T., Dorer, V., Blocken, B., & Carmeliet, J. 2012) can be identified as failed interventions throughout the study area/region. Therefore it would be useful in identifying the model attributes of a thermally comfortable urban precinct in Colombo development area.

In this regards, the key factors which have been considered are building composition, aspect ratio, temperature, relative humidity, SVF| Sky View Factor and wind movement which always contribute in creating comfortable outdoor microclimate to increase user perceptions in highly urbanized areas during most effective hours of the day among a higher occupancy level.

2. Research Background

Colombo CBD | Central Business District’s population of employment during day time is 986,763 (www.statistics.gov.lk: October 2014) which have distinct relationship against climate at scales from the local to the global. This urban effect is due to the physical form of the city as a three-dimensional geometry and material composition, and its day-to-day activity patterns that generate emissions of waste heat and materials into the overlying air effects on creating the global warming crisis. Urban climate science is grappling with how climate change is likely to impact specifically on cities and their populations.

In terms of human consequences, it is the urban canopy layer that is of greatest interest and, in this regard we can differentiate between the indoor and the outdoor environments. With respect to this, the urban building physics and their thermal impact become significant with a higher balancing factor to overcome the climate issues in urban cities. The Architects’ responsibility in the building designs with respect to each impacts alluded to above can be linked to a scale of climate–built environment interaction, at which intervention will effect mostly. Sri Lanka as a tropical country has a wide range of a temperature difference. Colombo being the most affected from this phenomenon is being lead to a hot-humid city, affected by Urban Heat Island (Emmanuel 2004). As the empirical evidence suggest hard cover in Colombo increased by three and half time during last 44 years and the temperature has increased by 1°C.

The combination between human anatomy and the outside environment, directs into thermal sensation and thermal dissatisfaction of people exposed to moderate thermal environments. Creating favorable urban environments has become a huge radical challenge that needs to be faced by urban developers, climatologists and architects. In this flow, designing outdoor spaces, applying of generic
attributes to the building facades preventing any detrimental doings towards global warming becomes vital.

As a hierarchical study the whole urban context can be divided into smaller units also known as “Urban Precincts”. These urban precincts can be varied according to their building composition, Building category, system of road network and immediate vegetation. The idea of research is to understand the essential design components of an urban environment and investigate the extent of the impact of individual building designs. Objective of the study is to focus on the individual buildings to measure and investigate the thermal behavior in the ambient urban precinct. It will intensify the contribution of a single building for the urban climate. Identifying the issues in the building leads to sharpen the opportunities of the building design and avoid the restrictions.

Effects of the surrounding environments are studied by the physics of heat and mass exchanges between body and the environment. Impact of buildings can be a procurement of micro climate changes inside the precinct. The climatic parameters can be verified as air temperature, wind velocity and the relative humidity. These parameters affect in different ranges in both indoor and outdoor environments, thus they can be improved considering different spaces and volumes. Spacing in between buildings effects on the SVF of the location, reflectivity and emissivity effects with surface Albedo, vegetation coverage of the surrounding, orientation towards adjoining roads affects thermal indices of particular urban precincts. The role of a building can be either modifying healthy thermal comfort of the precinct or exceeding thermal thresholds of the human body. In climate point of view the distances in between buildings affects solar rays and wind exposure of individual buildings as well as the precincts in between. A typical height of an urban building with 12m (39’) should have 4m (13’) of distance with the immediate building maintaining 3:1 ratio. When considering the ventilation, even a narrow width of a street with 4m is possible to maintain the wind flowing through buildings. The distribution of SVF too plays a vital role in such urban micro climatic situations (Oke 1988, Sakakibara 1996).

Sri Lanka is less focused on providing wider spaces in between buildings, but the concerns have been paid in overcoming the heat increments, having ventilation through shaded areas during both day and the night. In tropical climates the constant and uniform provision of sunshine appears to be the main reason for the building designs to have an interaction between micro climate and urban climate. Urban morphology is far beyond this idea which leads the understanding of spatial structure and character of metropolitan, city by examining the patterns of its component parts and the process of its development. In this case, the optical characteristics of materials used in urban environments and specially albedo to solar radiation and emissivity to long wave radiation have an important impact on the urban energy balance.

2.1. Study Framework

The research context covers dynamic climatic change due to building mass, layout, landscape, space in between buildings and group of buildings, building function. The research aims to examine the temperature difference, air flow and humidity changes along the street and also to know the situation, location and area of urban heat island in this zone under the easily prevailing wind situation. The above individual measures of a certain urban precinct derive from group of buildings which share same façade characteristics and attributes. More over the study is carried within the Colombo city and the sample section for the study is a long street with three key points with the same orientation to check the atmosphere and the climate changes along with building mass (with respect to heights, building layouts,
material selection). The case studies are located in the heart of the Colombo, a fine setting with a water body in front.

The impact of the heat island phenomenon increases the air temperature in a range of 1-2°C during the day and a range of 4-5°C at night time (Met Dept. SL). Measurements were taken during typical, representative days in month of January at a height of 1.5m from the ground, from 6 a.m. to 6 p.m. (Solar time). The data obtained during the empirical study measurement session takes into the variation of temperature generated by the different ambient conditions in open urban spaces.

3. Research Methodology

Selected case studies are facing West 1 ½ km’s away from the marine belt. The main water feature of the surrounding, “Beire Lake” and urban landscape along the lake w distinctively enveloped by huge proportion of green areas. The selected First case study has a dense built environment with narrow streets running through the buildings. The second precinct study point which is a bear land with a wide perimeter covered by two main roads locating the High rise complex in near future became the base case. The third Case Study is shadier with more greenery and tall buildings comparing to the case study one.

Figure 1: Locations of the selected three urban precincts (source - author)
The results of the study was lead with the temperature measurements, relative humidity and wind velocity with the usage of measuring equipment and the nature of the shading patterns in the selected case studies.

The collection of above data is entered to an excel graph showing the changes of the above physical parameters. When the empirical study is done, the simulation work was started according to the findings and user data with the software RayMan Pro. The presentation of work was asserted as in the graphs in order to evaluate the outcomes,

- Conducted field experiment in three different urban precincts
- Establish the prediction model for the thermal environment based on the long-term meteorological data
- Evaluate the long-term thermal comfort frequencies based on the local thermal comfort criteria a
- Examine the effects of urban street shading on long term outdoor thermal comfort...

### 3.1. Data Collection

The data collection was done during the solar time using HOBO Data logger and KESTREL 3000 Anemometer. The Anemometer & two data loggers were placed at two relative key points in one urban precinct. Data logger readings took in every 10 minute of the hour while at the same time Anemometer readings took in every 10 minute. Hourly average temperature of two HOBO data loggers at each urban precinct were analyzed in graphical format as follows.
Figure 4: Comparison of Average air temperature at three precincts

Figure 5: Comparison of wind velocity at three precincts

Figure 6: Comparison of Average Relative humidity at three precincts
The Sky View Factor in the given precincts varied according to their building composition, formation, building heights and the Tree canopies. The SVF in between 0 – 1 is simulated during the process of adding the relevant information to the RayMan model with fish eye images at each precinct. Sky View Factor at the precinct 1 is at 0.480 where the lesser number of trees and the whole mid-rise buildings covering the Sky view from below. The SVF at the precinct 2 is indicated as 1 at the moment. The Building composition at the precinct 3 indicated a SVF value of 0.166. SVF decreased with height of the buildings accordingly.
3.2. Data Analysis

Analysis of the study focused on the observed and simulated Data. Three urban precincts are assessing thermal comfort levels of the microclimate, variations in building massing and the building layouts. Collected data at the field survey were analysed via graphs, charts and polar diagrams when Research analysis is based on Temperature values, PET Values, Wind Velocity, Aspect ratio and SVF| Sky View Factor.

4. Research Analysis

Collected data from the empirical study was entered into the RayMan Pro simulation program. PET| Physiological Equivalent Temperature became the research analysis key by inserting the relevant values for the simulation program. A complete assessment of the bioclimatic precinct layouts became possible based on the output RayMan Pro PET values. The raw data of geographical location and the user general, average personal attributes, clothing and activity were added as regional standard data to generate the PET values.

Former data analysis suggested that the wind and SVF as factors which directly affect thermal comfort of three precincts in varied formations. It is evident that the Outdoor thermal comfort in the tropical climates is a positive attribute as it ensures better tolerance to outdoor conditions. Shaded and the Un-shaded precincts result the contrast in simulated PET values. As per the results, partially shaded first precinct shows a slight variation comparing to other two precincts.

Table 1: Standard Thermal perceptions of the RayMan Pet analysed data.

<table>
<thead>
<tr>
<th>PET</th>
<th>Thermal perception</th>
<th>Grade of physiological stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>4°C</td>
<td>Very cold</td>
<td>Extreme cold stress</td>
</tr>
<tr>
<td>8°C</td>
<td>Cold</td>
<td>Strong cold stress</td>
</tr>
<tr>
<td>13°C</td>
<td>Cool</td>
<td>Moderate cold stress</td>
</tr>
<tr>
<td>18°C</td>
<td>Slightly cool</td>
<td>Slight cold stress</td>
</tr>
<tr>
<td>23°C</td>
<td>Comfortable</td>
<td>No thermal stress</td>
</tr>
<tr>
<td>29°C</td>
<td>Slightly warm</td>
<td>Slight heat stress</td>
</tr>
<tr>
<td>35°C</td>
<td>Warm</td>
<td>Moderate heat stress</td>
</tr>
<tr>
<td>41°C</td>
<td>Hot</td>
<td>Strong heat stress</td>
</tr>
<tr>
<td></td>
<td>Very hot</td>
<td>Extreme heat stress</td>
</tr>
</tbody>
</table>
Average PET value varies between 26.54 °C and 35.07 °C. The whole value ranges belong to warm and slightly warm categories during the solar time. Grade of physiological stresses of the precincts are Moderate heat stress and the Slight heat stress. It is evident that the precinct can sustain as a more thermal healthier microclimate with other modifications of the building mass, retain the wind flow paths and provide more shading.

Open Bare land precinct PET values vary between 20.35 °C and 29.8 °C. The PET Thermal perception index indicates that these values maintain the Warm, Slightly warm and the Comfortable levels. Since Wind is a controlling factor of thermal perception levels of the human body, these results can be analysed as having a higher wind velocity gives a comfortable level in the precinct microclimate. This concludes that the Grade of physiological stresses will be No thermal stress, Slight heat stress and the Moderate heat stress.

The Simulations of the actual given data result, the precinct’s PET values vary in between 28.7 °C and 39.5 °C. These values obtain PET Thermal perception index as Hot, Warm and slightly warm. During the
measured time User’s Grades of Physiological stresses were recorded as Slight heat stress, Moderate heat stress and the Strong heat stress.

After the practical study the measured and observed data were analysed to provide Physiological Equivalent Temperature, which is more suitable to evaluate the human well satisfied thermal component of different climates. It has been derived from energy balance of the human body and it is therefore thermo physiologically significant and reproducible. PET values demonstrated the values which are output results of the actual situations and given a certain idea of regional climate which can be modified by providing more vegetation grounds and consider about the aspect ratio as well.

4.1. Evaluated Research Outcomes

Same aspect ratio with slight differences is not affecting the micro climatic behaviour. SVF is a crucial factor in urban climate which are highly affecting the air temperature and shading levels in each precinct. It was evident that the wind movement and wind velocity affects the thermal comfort which were evaluated using PET values. PET (Physiological Equivalent Temperature) is a collective analytical data of the suitable micro climate condition in each precinct assessed after combining the results of geographical data, relative humidity /vapour pressure, impact of building composition/ SVF and the wind velocity. After observing the three urban precincts within same macro context the qualitative changes have become the output of onsite climate survey.

Building composition as a measuring factor can change the micro climate in urban precincts. Colombo CBD requires more concern on the impact of new high rise buildings. Concerning the issues, two stages were considered assessing the thermal comfort in urban precincts, field experiment as the first part and PET modelling stage for checking the validation. Furthermore hourly PET values were used in the broader analysis and predicted thermal perception levels for the precincts. Analytical results had indicated that wind and shading (SVF) cannot play individually but altogether make a healthier micro climatic condition in dense urban areas.

References

What Makes A City ‘Biophilic’?
Observations and Experiences from the Wellington Nature Map Project

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Abstract: Despite clear benefits of maintaining human relationships with nature, people increasingly live in urban settings and spend high proportions of time indoors. Both of these trends are increasing globally. This means it is vital to ensure that future cities are designed, created and managed to enable meaningful human / nature connections. Cities that are examples of urban environments where human / nature relationships are innately encouraged and are part of residents’ daily experiences have been termed ‘biophilic cities’. Wellington, New Zealand is one of a select few cities internationally that has been identified as a biophilic city. In order to test the validity of that claim, this research set out to use GIS mapping to determine specific areas, sites and buildings that could be identified as being biophilic within Wellington. In order to do this, a unique biophilic cities framework was devised where 30 unique characteristics of biophilic cities were identified and used to map Wellington. Results from this mapping research are examined. Key findings include that when several identified aspects of biophilic design are nearby in urban settings, experiencing these through time while moving through a city enhances the positive effects of these elements.

Keywords: Biophilic design; urban design; urban nature; mapping.

1. Introduction

An increasing body of international research details the benefits that arise when people have a direct or indirect relationship with the natural world. Evidence is clear that positive physical benefits occur such as reduced blood pressure, reduced stress, and increased immunity (Gullone, 2000). Evidence of psychological benefits includes positively modified behaviour (particularly in terms of social interaction and reduced violence), decreased rates of depression, and increased ability to concentrate (Browning et al., 2014). A review of more than 500 recent academic papers detailing quantifiable evidence of benefits of various aspects of biophilic design found that inclusion of such elements into spatial design could ‘enhance productivity and performance and have a positive impact on attention restoration and stress reduction; increase positive emotions and reduce negative emotions; [lead to] relaxation of the brain, ocular muscles and lenses; [and lower] diastolic blood pressure and stress hormone (i.e., cortisol) levels in the blood stream.’(Ryan et al., 2014). Economically, introducing certain elements of nature into commercial buildings results in increased productivity and employee satisfaction (Browning et al., 2012).
When applied to health care environments time to recover from surgery or illness reduces (Ulrich, 1984). Despite the clear benefits of emphasising and maintaining human relationships with nature, people increasingly live in urban settings and spend high proportions of time indoors. This means it is vital to ensure that future interior environments and indeed whole cities are designed, created and managed to enable meaningful human / nature connections (Turner et al., 2004).

2. Urban Biophilic Design

Design that seeks to purposefully create human / nature relationships or leverage these to create increase human wellbeing is termed ‘biophilic design’ (Kellert et al., 2008). Cities that are examples of urban environments where human / nature relationships clearly exist and are purposefully designed have therefore been termed ‘biophilic cities’ (Beatley, 2011). These are cities where ecological restoration, architecture, landscape architecture, and urban planning are deliberately used to heighten the physical, psychological, and economic benefits that contact with nature can bring to city inhabitants.

3. The Wellington Nature Map Project: Methodology

Wellington, New Zealand is a relatively small and compact city of approximately 200 000 residents. It is a coastal settlement located in the southern-most part of the North Island of New Zealand, and is a city of steep and often deep green, bush clad hills surrounding a large harbour. Mostly because of its setting and access to ‘wild’ nature, Wellington has been identified as a biophilic city, through the international Biophilic Cities Network (Beatley, 2016). In order to test the validity of the claim that Wellington actually is biophilic, this research set out to use GIS mapping to determine specific areas, sites and buildings that could be identified as either: sites of nature in the city; nature activities on offer; or places where the urban fabric reflects some sort of special relationship to the land and sea. The resulting interactive publicly accessible map, termed ‘The Wellington Nature Map’ (Pedersen Zari et al., 2017) was published online in early 2017, and is a joint project between the Wellington City Council, Victoria University of Wellington’s School of Architecture, and the Wellington Living Architecture group, with assistance from Victoria University’s School of Geography, Environment and Earth Sciences. Aside from providing a quantifiable evidential basis to the claim that Wellington is in fact ‘biophilic’, the aim of the Wellington Nature in the City project was to produce replicable methodologies and categorisations for mapping of other cities in terms of urban nature relationships. This is in order to produce measurable comparisons of the types, locations, and ranges of spatial design elements related to biophilic design, so that strategic decision making regarding urban planning for increased wellbeing could be enhanced in the future.

3.1. Elements of Biophilic Cities Framework

Various researchers have sought to define sets of biophilic design elements in architectural and interior architecture contexts (Kellert, 2005; Kellert et al., 2008; Ryan et al., 2014) and in urban settings (Beatley, 2011). In order to devise a suitable framework to enable physical mapping of actual biophilic sites or elements of a city, a unique biophilic cities framework had to be formulated. The resulting Elements of Biophilic Cities Framework identifies and categorises 30 unique characteristics of biophilic cities (tables 1-3). These categories are primarily combinations of aspects of cities deemed important in terms of creating relationships between people and nature as defined by Beatley (2011, 2016), that are supplemented by understandings of more abstracted notions of nature-related design that are applied at the building or interior architecture scale. These categories are discussed further in the following sections.
3.1.1 Nature in the city - biophilic conditions and infrastructure

The Nature in the City category addresses the physical and ephemeral presence of nature in urban environments. This includes plant life, water, and animals, as well as sounds, scents, light, wind, and other natural elements. Incorporating nature, both designed and wild into cities has numerous benefits including climate change mitigation and adaptation (Gill et al., 2007), increased urban biodiversity (Rastandeh et al., 2017), more effective storm water systems (Donovan, 2017), cleaner and cooler air, and cleaner water (Samson et al., 2017). There are also measurable and proven benefits to human wellbeing. People who have access to nature tend to be less stressed, healthier, more creative, less violent, more productive and even more sociable (Gullone, 2000; Browning et al., 2014). Table 1 elaborates on the different elements included in the Nature in the City category.

3.1.2 Nature activities – learning about and interacting with nature in the city

A biophilic city has activities for residents and tourists alike that enable connection with and enjoyment of nature, that encourage learning about the specific nature of that place, that keep ecosystems healthy or regenerate them, and enable participation in activity outdoors (Beatley, 2011). This shows how important or celebrated nature is to a city and its residents. By enabling residents to have equal opportunities to access nature, wild places, and other biophilic places in an urban setting, increased physical and psychological wellbeing can occur along with a greater understanding of ecological values and the value of nature based on local conditions (Mitchell et al., 2016). Table 2 details elements in the Nature Activities category.

3.1.3 Nature of spaces and places - designed biophilic buildings and spaces

The Nature of Space and Places category relates to how certain kinds of spaces or spatial relationships in buildings, between buildings, or in urban spaces relate to configurations in nature that can cause people to have positive reactions (Kellert et al., 2008). This includes our innate need and desire to be able to see beyond our immediate surroundings, or to be able to get an overview of a space from up high; our interest in the thrilling or slightly dangerous; and our curiosity to explore spaces that may be partially hidden (Ryan et al., 2014). This category also includes buildings that enable us to connect to the surrounding climate, geography, and ecology through techniques such as: passive ventilation; access to natural daylight, views, and fresh air; and bioclimatic design (where buildings are designed to work with the site and climate they are located in). Table 3 depicts elements in the Nature of Spaces and Places category.

<table>
<thead>
<tr>
<th>Icon</th>
<th>Element name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Parks</td>
<td>Parks and urban green spaces are perhaps the most recognisable and accessible way to enable public access to nature in urban settings.</td>
</tr>
<tr>
<td>2 Green belts / connected ecosystems / wild and semi wild native nature spaces</td>
<td>Preserving and regenerating native bush areas within a city enables residents to be familiar with and to value indigenous ecosystems. Access to wild nature allows a different kind of experience to visiting only designed and managed park areas.</td>
</tr>
</tbody>
</table>
3 Habitat provision
Having the opportunity to interact with animals including insects, birds, and fish is essential for a biophilic city. Interacting with animals has proven benefits for children, the elderly, and those with mental health issues (Barker, 1999). By including certain plants, water sources, or feeding stations in urban areas to attract living creatures to them, the biodiversity of a city may be increased. This may make a city more resilient to certain climate change impacts (Brink et al., 2016).

4 Rivers / streams / wetlands / marine reserves
Being able to see, hear, and feel water can be of great benefit to people psychologically (Gullone, 2000). By understanding how water ways and oceans interact with weather, climate, pollutants and each other, people may understand better the importance and value of water.

5 Water features
Water allows people to access different emotional metaphors, from ‘still waters running deep’, to ‘water under the bridge’, to the swift flows of change. Water enlivens a space and allows people to connect with an essential element of life (Browning et al., 2014).

6 Street trees and canopies
Introducing trees into urban streetscapes has benefits such as providing shade, filtering air, providing habitat to birds and insects, locking up carbon, reducing storm water flows, and possibly providing food (Donovan, 2017). It also allows for interaction with living nature as people walk below trees or near plantings, or experience these as views from surrounding windows.

7 Green roofs / walls / rooftop gardens
Living green walls (vertical gardens on the sides of buildings and other structures) have benefits that include: bringing more nature and biodiversity into built-up areas, filtering air and soaking up rain water, and deterring graffiti (Francis and Lorimer, 2011). Green roofs can lower temperatures inside buildings meaning less energy is used in cooling and can protect roofing materials for longer.

8 Community gardens / edible landscaping
Engaging in food growing, foraging, or harvesting in urban settings has significant benefits in terms of sustainability and human health, and may enable deeper relationships to form between people and nature (Viljoen and Howe, 2012).

9 Nonvisual nature
Sounds, smells, tastes, and things people can feel or touch engage the senses beyond just sight. This different sensory information, particularly that from ‘nature’, is processed in a different way by the human brain. This can in turn increase cognitive performance, aid in relaxation and lowering of blood pressure, and have other positive effects (Browning et al., 2014).

10 Sensory stimuli
When people experience surprising movements, or sounds that are not predictable timing wise, this can be positive physically as well as psychologically. Examples include leaves falling off trees, objects moved in a breeze, birds flying past etc. These random movements can temporarily delight and distract, usually on a subconscious level, and can increase the ability to concentrate for longer periods. Such movement can also facilitate relaxation of the eye (Browning et al., 2014).

Table 2: Elements of nature activities – learning about and interacting with nature in the city.

<table>
<thead>
<tr>
<th>Icon</th>
<th>Element name</th>
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</table>


1 Nature clubs and groups
Support for groups that focus socialisation, learning, or exercise around outdoor activities enable people to get outside and enjoy and learn about the natural aspects of the city. Such groups may range from tramping and jogging clubs, to gardening and outdoor meditation groups.

2 Outdoor activity centres / sports fields / places to swim
Facilities for outdoor activities, including sports, swimming and ‘messy play’, enable people to get outside and enjoy the climate and ecology of the city.

3 Camping grounds
Opportunities to sleep outside and experience camping enable people to connect to nature in a different way than typical dwelling situations.

4 Pedestrian zones / bike paths / tramping walkways
A city with dedicated spaces for people to walk or bike rather than use cars, both in high density parts of the city and in more ‘wild’ areas, not only enables this kind of activity to happen, but it sends a signal to people to engage more with the outdoors.

5 Gathering spaces in nature / playgrounds
Places in the city where people can gather outdoors for private or public events, and where there are dedicated facilities such as toilets, bbq’s, or playgrounds, normalise being outside and experiencing different climatic conditions while learning more about the ecology of the region.

6 Cafes / restaurants with outdoor spaces
Cafes and restaurants that offer outdoor spaces allow people to be outside on fine days and to enjoy the climate while experiencing the urban environment in a different way.

7 Natural history museums / botanical gardens / environmental education initiatives
Museum and education facilities dedicated to preserving and learning about a city’s natural heritage, ecological history and present condition, and indigenous flora and fauna are part of ensuring citizens understand and value their ecological setting.

8 Natural history markers / celebrations
By calling attention to, marking, and explaining sites of important natural history events or locations, people have a richer appreciation and understanding of the dynamic nature of ecosystems and past events that have shaped the present.

9 Ecosystem restoration / conservation projects
One of the markers of a biophilic city is how many of its citizens are actively engaged in ecological restoration or conservation projects (Beatley, 2011). These may be paid activities or voluntary.

10 Local / international sustainability organisations
Regional and national organisations that focus on various sustainability issues having a noticeable presence in a city helps to reinforce the value of conserving, regenerating and valuing the natural heritage and climate of the city, and wider environment.

Table 3: Elements of nature of spaces and places - designed biophilic buildings and spaces.

<table>
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<tr>
<th>Icon</th>
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<td></td>
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</tbody>
</table>
1 Bioclimatic buildings

Bioclimatic buildings are ones that work with climate. They have a designed connection with nature (sun, wind, rain, ecology, and seasons) to create comfortable interior conditions while being energy and materials effective (Yeang et al., 1994). Bioclimatic design can help people to understand and connect to the seasons and climate around them in a positive way.

2 Biomorphic buildings / spaces

Biomorphic buildings are ones that have organic or natural looking forms, patterns or textures or that make use of spatial hierarchies similar to those encountered in nature such as fractal patterns (Joye, 2007). Biomorphic forms allow users to make connections to nature through abstracted representations of shapes or textures that are associated with nature. Biomorphic forms and patterns can in some cases create a more visually preferred environment that enhances cognitive performance while reducing stress (Taylor, 2006). Biomorphic design can be a decorative component such as a façade treatment, or can be part of the actual structure of a space.

3 Dynamic natural light

The human eye is attuned to and works better in light that changes in intensity over time. Although people in developed countries typically spend upwards of 80% of our time indoors, human eyes evolved in conditions where they had to adjust constantly to clouds moving over the sun, or to moving in and out of shaded areas. Slight changes in lighting levels actually enable people to better concentrate and stay more alert (Browning et al., 2014). Human eyes are also better adjusted to the colour spectrum of natural light rather than artificial light, and natural light regulates important hormonal functions. It helps to regulate circadian cycles which relate to sleep, mood, depression, heart rate and body temperature regulation. This is why allowing natural light, through windows or skylights is important particularly in working and learning environments. It also allows people to be in contact with the time of day or year and to experience the drama of changing weather patterns in comfort.

4 Thermal and airflow variability

An environment devoid of sensory stimulation and variability can lead to boredom and passivity. Variations in air flow and slight temperature and humidity changes indoors have been linked to increases in worker or learner comfort, short term memory, concentration, well-being and productivity, and even the desire to dwell for longer in a space over time (Browning et al., 2014). This is why being able to open and close buildings to the exterior is important.

5 Material and colour connections with nature

Spaces or buildings that demonstrate a material connection with nature are ones made from materials or elements that reflect the local ecology or geology. This helps to create a distinct and authentic sense of place. Although research is limited, spaces with high ratios of natural materials (like timber or stone) can calm people, lower blood pressure, and increase pulse (Browning et al., 2014). Use of the colour green, or use of a series of gradients of similar colours as opposed to use of contrasting block colours may have similar results (Gushiken, 2012).

6 Celebration of nature / climate / bioregion

Spaces can generate awareness of seasonal and temporal changes as characteristics of healthy ecosystems. By highlighting ecological features along with their history, people can appreciate and therefore value their surroundings more. Ways that nature / climate / bioregion can be celebrated include through art works, murals, street furniture, eco-revelatory design (where ecological processes are made visible to people), biomimicry (where the processes or functions of nature or living creatures are mimicked in design) (Pedersen Zari, 2010), and marking of spaces that are sacred to various groups of people due to cultural beliefs about nature.
7 Prospect / view
These kinds of spaces enable a view over a distance for surveillance and if designed well feel open and without restriction, while portraying a sense of safety and control. Potential benefits of such spaces include reductions in stress, irritation, and perceived vulnerability, as well as improved comfort (Browning et al., 2014). Even having a distant or middle-distance view from a working or learning environment can serve to rest eyes, reduce fatigue and improve concentration.

8 Refuge / sanctuary
Refuge and sanctuary spaces are ones where people can withdraw from weather conditions, busy streetscapes, or other people. Such spaces can provide a sense of retreat and withdrawal enabling protection, contemplation, and rest. Refuges are important for stress reduction, and can result in lowered blood pressure and heart rate, and reduced irritation, fatigue and feelings of vulnerability. Potential benefits include improved concentration and attention. A well-designed refuge space enables people to feel protected behind and overhead while still being able to see out beyond the refuge (Browning et al., 2014).

9 Mystery, surprise, and curiosity
It is possible to set up a sense of mystery and surprise in spaces. This can be done by offering the promise of more information through partially obscured views or other spatial techniques that intrigue people and draw them deeper into the spaces. Using mystery in biophilic design is based on the idea that people have two basic needs in environments: to understand and to explore. A sense of mystery, surprise or anticipation can create a strong pleasure response within the brain because people like to guess and anticipate what might be coming (Browning et al., 2014).

10 Risk and peril
This relates to when people can perceive an identifiable threat which is coupled with a safeguard to minimise actual danger. People might like the thrill of a scary movie or a roller coaster ride for example because they know that ultimately it is safe. Being able to control risk can lead to positive experiences that result in strong pleasure responses. Such experiences are important in developing risk assessment during childhood. For adults when short doses of dopamine occur this can stimulate motivation, memory, and problem solving (Browning et al., 2014).

3.2. Geographic information system (GIS) mapping and Story Maps
After the biophilic categories were determined, the team worked with a specially designed GIS mapping application to locate with global positioning system (GPS) coordinates the approximately 170 locations to be shown in the map. Locations were documented through photography and video, and a brief written explanation for each location was prepared in terms of description, history, and relevance to human / nature relationships. The intention was not to map every possible biophilic element of the city, but to focus on elements that were primarily in the inner-city area, were easily accessible, were well known or iconic to Wellington, and that demonstrated a good range of examples of each category.

Once the data had been collected, it was entered into an Esri ArcGIS ‘Story Map’ software system (http://storymaps.arcgis.com). Story Maps combine maps and other GIS information with narrative text, images, and multimedia content in order to explain, enhance, and navigate maps. This platform was the one of choice by the Wellington City Council, who ultimately host the Wellington Nature Map. Combining narrative techniques with geo-spatial mapping is increasingly part of people’s navigation experience of modern life, and reflects several global converging trends, such as increased citizen geo-awareness, and fast evolving geotechnologies and sharing systems. These trends are likely to continue to rapidly change how people understand and experience the world around them, particularly as portable digital technologies also evolve (Kerski, 2015).
The Wellington Nature Map Story Map is organised into three sections following the Elements of Biophilic Cities Framework (tables 1-3) with a combined section that overlays all of the mapped elements onto a single map. This demonstrates where biophilic areas of intensity exist in Wellington, and enables planning of routes to experience Wellington as a biophilic city (Figure 1). Each mapped icon relates to a site reflecting a specific category of biophilic urban experience. When an icon is selected a pop-up text and image box appears that provides further details for each site.

![Wellington Nature Map](image)

**Figure 2 Screen shot of the Wellington Nature Map**

### 4. Results and Discussion

Mapping specific biophilic features of Wellington has enabled a tangible and quantifiable way to demonstrate that Wellington is likely to be a city that has enhanced human wellbeing attributes because of opportunities afforded for human / nature relationships and connections to occur. This is in part because of the geography and surrounding ecosystems of the city itself. Because Wellington is a complex folded landscape that surrounds a harbour and is in turn surrounded by bush or green spaces to a large extent, many residents have views of nature from homes and workplaces. These unplanned biophilic aspects of Wellington relate largely to the Nature in the City category of biophilic elements (green icons - table 1), and in particular: green belts / connected ecosystems / wild and semi wild native nature spaces; habitat provision; rivers / streams / wetland / marine reserves; and nonvisual nature. These green icons on the Wellington Nature Map, were the most abundant of the three categories and illustrate that tangible literal inclusion of nature into the city is an important part of Wellington being deemed ‘biophilic’.

It should be noted however that many aspects of the Nature in the City elements, and all of the other two categories of biophilic city elements (tables 2 and 3) are aspects of Wellington that are deliberately planned, encouraged, and patronised by the residents and managers of the city. Aspects of the city like the abundance of outdoor activities available to residents, the large number of volunteer driven regeneration projects, and the active celebration of natural history sites (and many of the other yellow icons element in the Nature Activities category) demonstrate that Wellington being biophilic is not just an accident of geography but is also in part due to the actions of the residents and the support for such activities, groups, sites etc.st. A key finding of the research remains however that an abundance of nearby wild nature is vital to the creation of a biophilic city because of its relationship to the evolution of outdoor or nature based activities residents can participate in.
The least abundant category of mapped elements related to the Nature of the Spaces and Places category (the blue icons). These relate to deliberate acts of designing spaces and buildings that reflect or create nature / human relationships. Typically, these are buildings or designed urban outdoor places. It is of note that many (but certainly not all) of the sites and places that were mapped as belonging to the Nature of Spaces and places category are among some of Wellington’s newer buildings and spaces. Perhaps this reflects a changing attitude toward nature in the city, to architectural and urban design, or to a Wellington identity or sense of place that relates to human / nature connection in the city.

Spatially there are clear areas of biophilic intensity in the city. These relate to some of the large wildlife reserves and botanical gardens to the west of the city (Zealandia, Otari-Wilton’s Bush, and the Botanic Gardens), but more densely urban biophilic zones also exist. Interestingly, these tend to centre on already often visited culturally significant parts of the city. One central city biophilic zone centres on the Civic Square area of the city, which is often thought of as the heart of Wellington City. This zone is a combination of dense street plantings, urban parks, art works, and markers of natural history. Another biophilic zone centres on lower Lambton Quay and the parliament buildings, through various art works, buildings and urban parks. A third zone which connects the first two zones stretches along most of the waterfront area from the local ferry terminals to Oriental Parade and is a collection of urban outdoor features such as bridges, sites of outdoor activities, and several of the city’s natural history museums. A final key finding therefore was that the spatial design and materiality of buildings as well as public works of art in cities impact on biophilic experiences, and that when several identified elements of biophilic design are nearby in an urban setting, experiencing these through time while moving through a city enhances the positive effects of biophilia.

6. Conclusions

In conclusion, the Wellington Nature Map is a first step in investigating the presence and effects of biophilic design in Wellington. Future research will include observation and survey of how people use the Wellington Nature Map and examination of how its use has (or has not) altered perceptions of the city or of human / nature relationships. The methodology and framework for investigation presented are transferable to other cities. Mapping other cities in a similar way that are part of the Biophilic Cities Network, and using control cities with are not, will enable geospatial comparisons to be made between cities of different sizes, in different climates, and with different demographics, ecological features, and cultural systems. This will contribute to quantifiable evidenced based research investigating biophilic cities and their benefits or impacts on human well-being and relationship to the ecological wellbeing of urban areas. It will enable differences between the preferences or needs of different groups to be deduced and can then contribute to rethinking urban and architectural planning priorities and strategies. This is important for safeguarding both the physical and psychological wellbeing of individuals and communities in the coming decades as humanity increasingly becomes urbanised and removed from outdoor environments, and as digital technologies become ubiquitous.

Acknowledgements

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References

Coastal Retreat

Future Implications for Architecture in New Zealand’s Coastal Hazard Zones

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Abstract: Climate adaptation strategies evident in New Zealand local authority planning schemes suggest an awareness of coastal hazard issues caused by global warming and subsequent sea level rise. Coastal land identified as hazardous has limits on new residential development. Alterations to existing buildings are required to be within specific floor level heights and constructed of materials that lend themselves for removal. The emphasis is, however, on managing the impending hazard, rather than reducing or removing the risk. Limits on local authority powers and the fee simple entitlement of ownership mean the ability to order removal of buildings is limited to dangerous health and safety issues of immediate concern. Planned building retreat or removal in the face of future uncertainty is not possible without the cooperation of the landowner, a challenging scenario given the high cost and desirability of coastal land. This paper will overview key literature surrounding climate change adaptation policy as it relates to coastal hazards and sea-level rise. It will evaluate and compare the coastal hazard adaptation policies of two district schemes within New Zealand and suggest future strategies around the concept of “managed retreat” that may serve to minimise the potential damage to buildings (and their owners) living within hazardous coastal zones.

Keywords: Environmental policy; adaptation; local government.

1. Introduction

Comparative policy analysis is the systematic study and comparison of public policies and policy-making in different jurisdictions “…to better understand the factors and processes that underpin similarities and differences in policy choices.” (Gupta, 2012) Effective comparisons between, as in this paper, the natural hazard adaptation policies of two distinctly different Local Authorities, can elicit clarity about the determining factors that make for the variations in policy and hence “serve as a foundation for theory-building.” (Smit et al, 2003) They enable policy makers to draw inferences from the experience of other jurisdictions, and thus help improve the overall quality of adaptation policies across the local government spectrum. Adaptation policies, by their very nature, are dealing with the unknown in an incremental way such that a region’s vulnerability, or susceptibility to “negative climate-related impacts” is reduced (McEvoy, 2013). All local governments have some scope for formulating localised policy choices, in spite
of common restraints such as a lack of capacity, scarce resources and central government placed limitations to their authority. The choices they make provide fertile grounds for comparison (Vogel, 2015). This paper then, compares the degree to which the coastal hazard policies within two district schemes, the AUP and the Western Bays of Plenty district scheme, align with the adaptation policies outlined in the New Zealand Coastal Policy Statement (NZCPS). Both district plans border areas of low-lying coastal land. A comparison of their coastal hazards policies is a useful opportunity to test the level of compliance against the NZCPS, the overriding document, and to assess the architectural implications of these policies.

Research studies into the effects of global warming and its anticipated effect on sea level rise (SLR) have undergone a significant increase in the last 15 years (McSweeney, 2015). These studies have a particular relevance to the New Zealand context. Hall et al, for example, suggests present day sea levels in the United Kingdom could rise by up to 0.69 metres by the year 2080 (Hall et al, 2006) with damage depending on size and frequency of surge event (Hulme, 1998, 2002). Studies emanating from Latin America suggest population rise and building development in coastal areas is set to continue alongside rising sea levels and changes to extreme sea levels associated with storms, thereby adding to the risk level (Reguero et al, 2015) and, of course, the cost (Jongman et al, 2012). Peer-reviewed publications such as Rahmstorf (2007), using techniques that relate sea level to historical average temperatures, suggest a rise of 0.55 metres to 1.25 metres, depending upon emission scenarios. Other researchers (Vermeer & Rahmstorf, 2009; Horton et al, 2008; Grinsted et al, 2015, Pfeffer et al, 2008) range in their estimates of a sea rise level from a low 0.18 metres to a high of 1.6 metres by the year 2100, depending upon the methods used and the various emission scenarios. Research studies in New Zealand by the Commissioner for the Environment suggest similar increasing frequencies of 100-year exceedences over time, with Auckland’s rise lagging that of other New Zealand cities due to tidal differences (Parliamentary Commissioner for the Environment, 2015). Gollende et al (2015), Naish et al. (2015) suggest, the upper limit of SLR projections could be too conservative, with ice sheet melt from Antarctica alone estimated in their modelling to contribute a base sea rise of as much as 0.40 metres by the year 2100 if a maximum global temperature rise of 2 degrees is not maintained. This would result in a significant increase in the Intergovernmental Panel on Climate Change (IPCC) report estimates, which in 2013 estimated a SLR range from a low 0.26 metres to as high as 0.98 metres, depending on the Representative Concentration Pathway chosen (Church et al, 2016). Golledge et al’s (2015) scenario, (a projection that has a present IPCC low confidence rating due to levels of uncertainly in the modelling of these process-based projections), would, if borne out, result in Antarctic sea-ice melt, ice shelf erosion (and subsequent melt) and a resultant SLR of several metres. Such research reinforces the need for greater understanding of the coastal hazard processes and a long-term commitment to mitigating the effects that cause it.

2. Methodology

The policies relating to coastal hazards are outlined in Section 3. Section 4 discusses and compares the various policy attributes under the appropriate criteria derived from the NZCPS. Table 1, within this section, summarizes the results and tabulates the architectural implications for residential construction.
3. Policy Context

3.1. Auckland’s Unitary Plan Section E36: Natural Hazards and Flooding

Five objectives and policies (excluding flooding) are specifically devoted to natural hazards and define the type of land subject to risk, specify conditions under which subdivision and development is allowed and outline, in detail, the risk assessment considerations for such development proposals that would be considered in any specialist (resource consent) application. These include the type of activity, its effect on public safety, consequences for other activities including effect on landscape values, public access, retention of land forms, nature of the site layout, planting to mitigate the severity of the hazard and the design and construction profile of the building and its ability to be relocated in the future should this be required. Other pertinent policies that relate specifically to coastal inundation and SLR include formulas that establish the finished floor levels of buildings located within the natural hazard zones. (Auckland Unitary Plan, 2017)

3.2. The Western Bay of Plenty District Council (WBOPDC) District Scheme (Waihi Beach Coastal Protection Area)

Research into coastal processes was first commissioned by the Bay of Plenty Regional Council in 1993. The special “Coastal Protection Areas” for Waihi Beach grew out of this research. They were incorporated into the first District Plan for the district in 1994, becoming operative in 2002 (WBOPDC: Coastal Protection Zone, 2015). The initial research was revisited as recently as 2015 with the modified protection zones for Waihi Beach incorporated into the present Operative District Plan soon after (WBOPDC: District Scheme, 2015). This northern semi-rural district forms an arc around (but does not include) the fast-growing Bay of Plenty city of Tauranga, now the fifth largest city in New Zealand. It contains the iconic ocean beaches of Waihi and Pukehina, the former being the particular focus of this study. Waihi Beach is a long-established holiday retreat for many New Zealanders, with many small holiday houses (baches) dotting the coastline. As with many others coastal areas, development pressure and desire for coastal land over the last 30 years has seen the small holiday bach give way to the large house and the urban apartment. Much of the early development was ad hoc and gave scant regard to the long-term effects of coastal processes. As the town of Waihi Beach has grown, however, issues such as flooding, flood plains and coastal hazards including erosion and inundation have come to the fore.

3.3. New Zealand Coastal Policy Statement 2010

Both the Auckland Unitary Plan (AUP), Auckland City’s new Planning document, and the Western Bay of Plenty District Council’s (WBOPDC) scheme are in fact a series of plans that detail how the regional area will deal with managing the “use, development and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety” (Auckland Regional Policy Statement, 2016). These statutory planning schemes are the vehicle through which local government manage development and growth and make and implement land-use decisions. The development decisions should reflect the regional planning priorities, advance the purpose of the RMA in achieving ecological sustainability and take account of the

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1In Previous AUP versions: Ch5.12.
short and long-term environmental effects development on climate change. In the specific areas of Coastal management, the RMA requires local and regional government to give effect to the objectives and policies stated in the New Zealand Coastal Policy Statement 2010 (NZCPS). Within this document are the specific objectives and policies that pertain to coastal hazards local government is required to give effect to (Department of Conservation, 2010). They will in this paper become the base criteria against which the respective natural hazard policies of the two jurisdictions are compared.

4. Results and Discussion:

4.1. Significant issues outlined and hazard identification clearly stated in the adaptation policies.

Both scheme plans acknowledge the risks associated with their locality, including coastal erosion, coastal inundation, tsunami, land instability, flooding, earthquake and volcanic eruption.

4.1.1. Definitions. The AUP, unlike the WBOPDC scheme, gives a detailed definition of land that may be subject to natural hazards. More specifically, this is land defined as:

a) within a horizontal distance of 20m from the top of any cliff with a slope angle steeper than 1:3 (18 degrees);

b) on any slope with an angle greater than or equal to 1 in 2 (26 degrees);

c) at an elevation less than 3m above Mean High Water Spring MHWS if the activity is within 20m of MHWS; and

d) any natural hazard area identified with the Council’s natural hazard register, database, GISviewer or commissioned natural hazard study (AUP, 2017).

4.1.2. Hazard Mapping. Both schemes augment written information with maps or databases that identify the location and scale of the hazard. In the AUP, the Auckland Council has taken the map technology one step further, with the National Institute of Water and Atmospheric Research (NIWA) assigned to instigate a series of digital overlay maps based on cadastral level information which, when overlaid over any base zone map, provide information about the projected extent of coastal inundation within a zoned area (Figure 1).

4.1.3. Hazards Database. The WBOPDC scheme identifies other natural hazards, such as land instability and notates them on the plans, unlike the AUP which, for reasons associated with the new city’s size and complexity, has elected to schedule hazards other than those associated with coastal hazards on separate databases. The onus in this latter case would be on the user to search out and identify these hazards prior to initiating a project for consideration.

4.2. New development and coastal hazards.

Both plans have addressed the issue. The Waihi Beach Coastal Protection Plan differs from the AUP, which has incorporated only one Coastal Hazard Zone, that being the 100 year projection. As with the AUP, the WBOPDC allows limited residential development to proceed outside the coastal erosion zones (where it is prohibited), provided hazard protection work is not required. The mapped presence of primary (50 year) zone and the secondary (100 year) coastal erosion zones in the local Waihi Beach area is another positive feature (Figure 2). Sub-divisional development located within these erosion zones is prohibited. Elsewhere in inundation zones, it is restricted to heights related to a common datum and to an assessment regime
that takes into account the degree of portability of the structure, the avoidance in the use of concrete walls and floors, minimum distances to dune toe and the degree to which the sub-division impacts on the coastal environment.

Figure 1. Digital overlay (left) to part Kawakawa Bay map (right) showing extent of coastal inundation predicted for a 1% AEP + 1 metre SLR event. (Source AUP)

The AUP’s policy allows subdivision in certain limited circumstances but in all cases, requires a full risk assessment of each sub-divisional proposal. Eleven specific criteria are outlined against which the subdivision proposal is measured. These include type, frequency and scale of the natural hazard, type of activity, design and scale, effects on public safety, exacerbation of an existing natural hazard, ease of movement for the building should it be required by severe shoreline retreat and the use and retention of natural landform buffers over hard engineering solutions. All such land requires an engineering assessment to confirm whether the land is, or will be, subject to erosion, inundation or instability over the next 100 years.

4.3. Existing developments and Coastal Hazards

The WBOPDC District Scheme plan allows for development of land already developed in urban areas now known to be at risk from natural hazards “only when any likely adverse effects can be avoided or appropriately mitigated.” (WBOPDC District Scheme, 2015) Clause 8.5.2 of the plan elaborates on risk assessment criteria, with dwellings, alterations or extension located in inundation areas required to be above the 2 percent AEP storm tide event plus a 0.50m freeboard height.

Development of existing land and building in the AUP is subject to the same restrictions as subdivision and new development i.e., engineering assessment to assess its hazard free status. Failing that, a resource consent is required (special planning permission) in which the risk criteria summarised in Section 4.2 are examined. Should planning consent be given, finished floor levels for dwellings, alterations or extensions to the dwelling(s) located in coastal inundation areas are required to be above the mapped 1 percent AEP storm tide event plus 1.0m projected SLR.
4.4. Policy attitudes to natural and hard engineering coastal hazard defences

The WBOPDC policy requires “the encouragement and enhancement of natural features such as sand dunes and wetlands which have the capacity to protect existing developed land.” (WBOPDC District Scheme: Cl.8.2.2) Hard engineering works are seen as last resort. Where hazard protection works are necessary “form, location and design are such as to avoid or mitigate potential adverse environmental effects,” a difficult proposition to achieve, as Figure 3 illustrates.

The AUP requirements have the same intent, but are more specific in what is not acceptable as a hard engineering solution. For example, such solutions must not “undermine the foundations at the base of the structure, cause erosion in front of, behind or around the ends of the structure, cause settlement or loss of foundation material, movement or dislodgement of individual structural elements, long term loss of sediment from the immediate vicinity or long term adverse visual effects on coastal landscape and amenity values.” (AUP: E36.3.12. (a-i))
4.5. Policy attitudes to managed or voluntary retreat within coastal hazard areas

The issue of “planned retreat” for existing communities is not addressed to any degree of resolution in either scheme, even though consideration is a part of the NZCPS objective and a logical outcome of the RMA focus to “avoid, remedy and mitigate adverse effects” from planning decisions. The prospect of later building removal as a result of future coastal erosion and inundation is implicit in Policy 8 of the WBOPDC scheme in that it requires re-locatable buildings and prohibits “the use of concrete and blockwork foundations, floors and walls in the coastal erosion zones.” (WBOPDC District Scheme: Cl.8.2.2(8)) The AUP similarly hints that the ability of a building proposal to be relocated in the future would be one of the factors influencing permission to develop or subdivide land (AUP: E36.3.(5)). However, there is no specific requirement in the present planning scheme for existing buildings in coastal hazard areas to be re-locatable or relocated over time. Even new additions or alterations within these existing buildings are required only to ensure the risk from their presence to people, environment and infrastructure is not increased, and where practical, reduced. This policy is tested by resource consent application. Absent as a specific policy is the concept of managed retreat, where communities and local government discuss and agree on long-term action strategies to remove building stock from inundation and erosion prone areas. Studies, such as the Climate Change Research Institute (CCRI, 2011) report, have expressed concern that coastal management at a local authority level in New Zealand, particularly in relation to SLR and its effects, is even now not taken seriously enough, in spite of recent internationally published estimates from researchers such as Rahmstorf (2007) and Pfefeer, et al (2008). CCRI’s report expresses the view that existing settlements in low lying coastal areas, such as Waihi Beach, may have already accepted the inevitability of a coastal adaptation approach that depends on hard engineering stabilization. This approach, whilst it may be appealing in the short-term, “will decrease community resilience and increase vulnerability in the long-term” (CCRI, 2011).

3. Conclusions

This research is a first stage attempt to compare coastal hazard adaptation policies for scheme plans of two very differently scaled settlements. One is a large metropolitan city, the other a semi-rural district with pockets of urban coastal settlements. The comparison analysis exercise is tabulated in Table 3. The exercise suggests value in additional research where a wider cross section of coastal hazard adaptation policies can be compared and rated in accordance with the degree of specificity of a policy to a particular hazard or locality. That is, the more generic or global the objective or policy, the less its assessed value. The more focused the policy on geographically specific risk, the higher the rating. This approach is supported by academic research that suggests good adaptation processes include working with coastal communities to achieve change, understanding existing local risks and vulnerabilities to coastal hazards and identifying and mitigating the most adverse in a flexible process that is open to change through ongoing monitoring.

Whilst there are wide differences between the two district schemes in terms of scale and urban density, there is a window of commonality in that both jurisdictions contain tracts of low-lying, erosion prone coastal land. The comparison found that in both schemes coastal land identified as hazardous within the two district schemes had limits on new residential development. Alterations to existing buildings are required to be within specific floor level heights and constructed of materials that lent themselves for removal. The emphasis is, however, on managing the impending hazard, rather than
Table 4: Comparison of Development Conditions in Coastal Hazard Zones: Implications for Construction

<table>
<thead>
<tr>
<th>Item</th>
<th>WBOPDP – Waihi Protection Plan</th>
<th>Auckland Unitary Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>New buildings within a new subdivision</td>
<td>Not permitted</td>
<td>Permitted with conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Full engineering risk assessment required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Multiple conditions: type, frequency, scale of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>development, public safety, exacerbation of existing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>hazards; type of activity, design &amp; scale, ease of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>movement off site if required (shoreline retreat)</td>
</tr>
<tr>
<td>Existing and new buildings within existing subdivisions (including</td>
<td>Permitted with conditions:</td>
<td>Permitted with conditions:</td>
</tr>
<tr>
<td>alteration, additions)</td>
<td></td>
<td>• Subject to engineering assessment to determine hazard</td>
</tr>
<tr>
<td></td>
<td></td>
<td>status</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Floor datum height limitations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 per cent AEP storm tide + 0.50m freeboard height</td>
</tr>
<tr>
<td>Mitigation of coastal defences through hard engineering works</td>
<td>Permitted only as “last resort”. Natural defences</td>
<td>Permitted under specific conditions:</td>
</tr>
<tr>
<td></td>
<td>encouraged.</td>
<td>• Subject to engineering assessment to determine hazard</td>
</tr>
<tr>
<td></td>
<td></td>
<td>status</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Floor datum height limitations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 per cent AEP storm tide + 1.0m projected SLR.</td>
</tr>
<tr>
<td>Consideration given to future managed or voluntary retreat:</td>
<td></td>
<td>• H/E works must NOT undermine the foundations, cause</td>
</tr>
<tr>
<td></td>
<td></td>
<td>erosion to structure, cause settlement, loss of foundation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>material, movement or dislodgement of structural elements,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>loss of sediment from the immediate vicinity, long term</td>
</tr>
<tr>
<td></td>
<td></td>
<td>adverse visual effects on coastal landscape and amenity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>values.”</td>
</tr>
<tr>
<td>Existence of managed or voluntary retreat policy:</td>
<td></td>
<td>• The degree of building relocatability is a consider-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ation in permitting construction of a dwelling in the</td>
</tr>
<tr>
<td></td>
<td>• No</td>
<td>coastal erosion zone.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No</td>
</tr>
</tbody>
</table>
reducing or removing the risk with a long-term community strategy of managed retreat. Limits on local authority powers and the fee simple entitlement of ownership mean the ability to order removal of buildings is limited at present to dangerous health and safety issues of immediate concern. Specific policies on managed or voluntary retreat in the face of future uncertainty is a significantly more complex policy field, and one that will, without governmental support, unfairly test the limited resources of many coastal local authorities. The development of a national government strategy on the equitable sharing of risk associated with SLR between community, local and national government would help significantly in informing coastal property owners of the issues associated with ongoing coastal ownership in an era of rapid climate change. This strategy would need to include such issues as compensation, if any, for the curtailling of property rights, issues associated with coastal property insurance, criteria defining the limits in the use of hard engineering solutions to mitigate coastal erosion, and consistency in the approach to building construction within hazardous areas.

References


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Speculations on the Representation of Architecture in Virtual Reality

How can we (continue to) Simulate the Unseen?

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Abstract: This paper discusses the present and future possibilities of representation models of architecture in new media such as virtual reality, seen in the broader context of tradition, perception, and neurology. Through comparative studies of real and virtual scenarios using eye tracking, the paper discusses if the constantly evolving toolset for architectural representation has in itself changed the core values of architecture, or if it is rather the level of skilful application of technology that can inflict on architecture and its quality. It is easy to contemplate virtual reality as an extension to the visual field of perception. However, this should not necessarily imply an acceptance of the dominance of vision over the other senses, and the much-criticized retinal architecture with its inherent loss of plasticity. Recent neurology studies indicate that 3D representation models in virtual reality are less demanding on the brain’s working memory than 3D models seen on flat two-dimensional screens. This paper suggests that virtual reality representational architectural models can, if used correctly, significantly improve the imaginative role of architectural representation.

Keywords: virtual reality; representation; perception; neurology.

1. Architectural Representation

Architecture and forms of representation have always been inseparable. It is not possible to build without having some sort of representation, of at least the idea, of the building. This representation can exist on many levels of abstraction and can be created in many ways, with the 3D scale model being one of the most obvious and widely used. It can be a simple model made of wood, or a wildly advanced digital model created with the latest print, milling, or simulation technologies. An important and interesting feature about the nature of the representation is that it is not in itself the final product, but only an essential means of achieving the realization of the full-scale architectural idea. One can add yet another layer to this representational hierarchy by insisting that even the building is not the final product, but only a framing or articulation of the interaction taking place within it.
‘A building is not an end in itself; it frames, articulates, structures, gives significance, relates, separates and unites, facilitates and prohibits. Consequently, basic architectural experiences have a verb form rather than being nouns.’ (Pallasmaa, 2005)

Thus, architectural representations serve at least two different purposes as a medium to convey both the rational concise organization of matter, but also as a framework for the imagination of the activities that make the building an architectural experience and a meaningful space for humans to occupy. This purpose, has not fundamentally changed, even though the digital tools and technologies are rapidly evolving and changing the possibilities of creating digital architectural representations on new levels of immersion. Focusing on architectural representation, the imaginative model, virtual reality (VR) becomes an interesting means of communicating and interacting through exactly those layers of experience Pallasmaa addresses.

2. A Comparative Study

To investigate the perception of space and potential use of VR models in architecture, an experiment was set up to compare a real physical space to its virtual counterpart.

2.1. Experiment Setup

The experiment was set up using a medium size auditorium as the real life scenario and a BIM model of the same auditorium as the virtual scenario. In the real life scenario, we define the “normal condition” as a situation where a test person is experiencing a specified existing physical architectural space.

In the virtual scenario, the same architectural space, is presented to the test person through the HMD VR technology (a modified Oculus Rift SDK 2 fitted with eye tracking equipment), using a 3D digital architectural building information model. We used 60 students for the test: 30 for each scenario, respectively the real life scenario and the virtual scenario.

We used both eye tracking and a quantitative/qualitative interview matrix to assess to what extent the perception of space through VR technology holds similarities to the experience under normal, or close to normal, circumstances. In both scenarios we used the same two specific locations: the first being just inside the entrance to the space, and the second approximately in the middle of the room. We applied each test person’s correct eye-height in the viewer. In addition to a silent ten-seconds-long eye tracking logging at the beginning of each location, a series of questions were posed to the test subjects, and the answers, along with the eye tracking data, were logged. The questions addressed four different areas of architectural perception: the space itself, lighting, sensation and estimation, and materials. The matrix questionnaire draws inspiration from C. Melhuish’s thoughts on corporethics (Rattenbury 2002) and S. Zeki’s perception model involving microconsciousnesses (Mallgrave, 2010).

2.2. Reflective and Immediate Perception

While the abovementioned interview matrix data addresses a conscious reflection about perception of space, interesting on its own account, this paper introduces results from the first rough comparison analysis of the eye tracking data accompanying the questions. The collected eye tracking data related to each question, address a layer of behavioral perception less consciously controllable by the test subjects. Answering a question about the room involves both a conscious reflection on answering and a less
conscious eye movement behavior. Thus, we could log the immediate perception results from eye tracking along the verbal reflective perception from the answers to the questions. By tracking where the test subjects are actually looking, in respectively a real and a virtual scenario, we can compare the results and estimate how similar the eye movement behavior are in the two scenarios, when answering the same question from the same location.

While the eye tracking, once the equipment is set, is collecting data quite automatically, the subsequent analysis can be a very time-consuming process that requires the development of a consistent way of picking the right ranges for analysis. We picked eight instances of each participant’s response (Table 1) representing both a free perception (no questions asked) and a more guided perception (by posing questions).

Table 1: Instances and questions selected for eye tracking

<table>
<thead>
<tr>
<th>#</th>
<th>Description of instance or question</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Instance (no specific question): First 10 seconds after entering the room</td>
</tr>
<tr>
<td>2</td>
<td>Question - The room: The want to go deeper into the room</td>
</tr>
<tr>
<td>3</td>
<td>Question - The lighting: Is the room sufficiently lit</td>
</tr>
<tr>
<td>4</td>
<td>Instance (no specific question): First 10 seconds at second location in the room</td>
</tr>
<tr>
<td>5</td>
<td>Question - Sensation and estimation: Estimation of the height of the room</td>
</tr>
<tr>
<td>6</td>
<td>Question - Sensation and estimation: Estimation of the width of the room</td>
</tr>
<tr>
<td>7</td>
<td>Question - Sensation and estimation: What row to sit at for a lecture</td>
</tr>
<tr>
<td>8</td>
<td>Question - Materials: Sensation of the quality of materials</td>
</tr>
</tbody>
</table>

For the analysis, we extracted 10 seconds of eye tracking data at the beginning of each of the two locations and subsequently the 10 seconds immediately after a question had been posed.

Figure 1: (A) The heatmap on a gradient scale from red to green showing eye tracking data related to a set of answers to a specific question. (B) An opacity map of the same data without the colours but with a gradient intensity. (C) The Histogram used to calculate the average intensity value in the image (Mean).

The resulting maps from the eye tracking contain a lot of different information, such as Time To First Fixation (TTFF), Time Spent in the different areas of interest, and the number of fixations. A fixation is a cluster of gaze points in the same spot. Below is an example (Figure 2) of the visualization of eye tracking data in respectively an aggregated heat map (A) and an opacity map (B). The Opacity map has been converted to grayscale, and using the histogram produced by Adobe Photoshop (C) it is possible to
measure the average intensity value in the image to measure the balance between the numbers of black and white pixels in the grayscale image.

Combining the opacity map feature with the Adobe Photoshop histogram and difference filter provided a precise and relatively fast way of comparing the overall areas of interest (AOIs) in the various images. This comparison is designed to give a general indication of the trends between the real and virtual environment. In this way, we managed to cross-reference the AOIs of all the images as described in the following method of comparing.

2.3. Method of Comparing

Comparing the images from the eye tracking using the opacity maps has an obvious advantage in relation to the amount of time needed to perform the analysis. Using the visual output and layering it in Photoshop using the difference filter gives a possibility to see and measure the difference of fixations.

In the example (Figure ) the comparison between eye movements related to the location in respectively the real life scenario (A) and the virtual reality scenario (B) is created by finding all the non-corresponding areas, the difference, of the two images (C). This resulting image of the differences between the two previous (A & B) can then be measured by using the histogram mean value.

Figure 2: Instance 1 real life (A) compared to instance 1 in virtual reality (B) combined into the resulting difference map (C). (Source: the author, 2017)

The example (Figure ) show the same procedure with a comparison between two scenarios, this time with the same question in the real life, RL, scenario (A) as in the virtual reality, VR, scenario (B) with the resulting difference (C).

Figure 3: Question 2 in RL (A) & VR (B) and differences (C). (Source: the author, 2017)

In the third example (Figure ), the comparison of eye tracking in the same location, but with two different questions, results in more white pixels in the difference image (C) signifying a higher amount of difference than in the previous two examples. By measuring all the images against each other, we should
be able to spot where the highest amount of difference exists in relation to fixations in the various scenarios.

Figure 4: Question 5 RL (A) compared with question 7 VR (B) and the resulting differences (C). (source: the author, 2017)

2.4. Differentiation

The average intensity value in the grayscale pictures are represented by the ‘Mean’ value, measured using the Adobe Photoshop software. The results from applying this method on all the combinations of the images are collected in the following tables.

The first measurements (Table ) show the difference between the same instances and same questions in respectively real life and virtual reality, RL and VR. The number after RL or VR corresponds to the number of instance or question (Table ). The horizontal separation line in the middle of the table is between the two different locations. RL & VR 1-3 are the first location in the scenario and the RL & VR 4-8 are the second location, a bit deeper in the room.

In the next table (Table ), the measurements are cross-referenced comparing the eye movements between different questions, while still naturally comparing only within the same location, since a change between locations would make the incongruent images useless for the purpose of this investigation. Obviously, there are more combinations of non-matching instances and questions than of matching, which is why the percentage of the full results, both matching and non-matching instances and questions, is calculated in the last column.

Table 2: The difference between same instances and questions

<table>
<thead>
<tr>
<th>Same instances and questions</th>
<th>Difference Filter (Mean)</th>
<th>%</th>
<th>Average Mean</th>
<th>Average %</th>
<th>Total average %</th>
<th>Of full results %</th>
</tr>
</thead>
<tbody>
<tr>
<td>RL 1</td>
<td>VR 1</td>
<td>4,24</td>
<td>1,66</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 2</td>
<td>VR 2</td>
<td>2,18</td>
<td>0,85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 3</td>
<td>VR 3</td>
<td>2,68</td>
<td>1,05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 4</td>
<td>VR 4</td>
<td>9,60</td>
<td>3,76</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 5</td>
<td>VR 5</td>
<td>6,64</td>
<td>2,60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 6</td>
<td>VR 6</td>
<td>2,88</td>
<td>1,13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 7</td>
<td>VR 7</td>
<td>3,70</td>
<td>1,45</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 8</td>
<td>VR 8</td>
<td>9,61</td>
<td>3,77</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2,04 37,09
Table 3: The difference between mixed instances and questions

<table>
<thead>
<tr>
<th>Mixed and questions</th>
<th>Difference Filter (Mean)</th>
<th>Average Mean</th>
<th>Average %</th>
<th>Total average % Of full results %</th>
</tr>
</thead>
<tbody>
<tr>
<td>RL 1 VR 2</td>
<td>4.64</td>
<td>1.82</td>
<td>1.62</td>
<td>3.45 62.91</td>
</tr>
<tr>
<td>RL 1 VR 3</td>
<td>3.68</td>
<td>1.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 1 RL 2</td>
<td>5.02</td>
<td>1.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 1 RL 3</td>
<td>3.50</td>
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<td></td>
</tr>
<tr>
<td>RL 2 VR 1</td>
<td>6.32</td>
<td>2.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 2 VR 3</td>
<td>4.09</td>
<td>1.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 2 RL 3</td>
<td>2.31</td>
<td>0.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 3 VR 1</td>
<td>5.42</td>
<td>2.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 3 VR 2</td>
<td>2.14</td>
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<td></td>
</tr>
<tr>
<td>RL 4 VR 5</td>
<td>9.30</td>
<td>3.65</td>
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</tr>
<tr>
<td>RL 4 VR 6</td>
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</tr>
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<td>RL 4 VR 7</td>
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<tr>
<td>RL 4 VR 8</td>
<td>12.65</td>
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<tr>
<td>RL 4 RL 5</td>
<td>9.03</td>
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<tr>
<td>RL 4 RL 8</td>
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</tr>
<tr>
<td>RL 5 VR 4</td>
<td>15.91</td>
<td>6.24</td>
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<td>13.35</td>
<td>5.24</td>
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<tr>
<td>RL 5 VR 7</td>
<td>14.74</td>
<td>5.78</td>
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</tr>
<tr>
<td>RL 5 VR 8</td>
<td>16.44</td>
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<td></td>
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</tr>
<tr>
<td>RL 5 RL 6</td>
<td>13.03</td>
<td>5.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 5 RL 7</td>
<td>13.96</td>
<td>5.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 5 RL 8</td>
<td>11.58</td>
<td>4.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 6 VR 4</td>
<td>13.03</td>
<td>5.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 6 VR 5</td>
<td>11.21</td>
<td>4.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 6 VR 7</td>
<td>3.70</td>
<td>1.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 6 VR 8</td>
<td>9.94</td>
<td>3.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 6 RL 7</td>
<td>4.25</td>
<td>1.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 6 RL 8</td>
<td>4.19</td>
<td>1.64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 7 VR 4</td>
<td>15.13</td>
<td>5.93</td>
<td></td>
<td></td>
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<tr>
<td>RL 7 VR 5</td>
<td>11.19</td>
<td>4.39</td>
<td></td>
<td></td>
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<tr>
<td>RL 7 VR 6</td>
<td>4.39</td>
<td>1.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 7 VR 8</td>
<td>12.56</td>
<td>4.93</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 7 RL 8</td>
<td>6.41</td>
<td>2.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 8 VR 4</td>
<td>12.95</td>
<td>5.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 8 VR 5</td>
<td>10.27</td>
<td>4.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 8 VR 6</td>
<td>5.66</td>
<td>2.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 8 VR 7</td>
<td>6.38</td>
<td>2.50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.5. Findings

Comparing the result from the investigation, we can see that the correlation between same questions in the two different scenarios is higher than the correlation between different questions (Table).

The difference between that matching instances and questions in RL and VR amounts to 37.09% of the full result while the difference between non-matching questions amounts to 62.91% of the full result. The divergence between the two results are thus 25.83%.

<table>
<thead>
<tr>
<th>Table 4: Divergence in percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same instances and questions</td>
</tr>
<tr>
<td>37,09</td>
</tr>
</tbody>
</table>

This shows that there is actually a better correspondence in eye movements between a scenario in real life and its counterpart in virtual reality, in the specific situations, than between eye movements in general when observing the space. In other words, the 25.83% divergence shows clearly more consistency between the RL and VR scenarios than what can be attributed to coincidence.

It could be argued, that a screening out of some of the instances and questions could be useful for the clarity of the investigation. Especially instances 1 and 4, which are not accompanied by questions can be difficult to compare in this way, since a free look around can vary a lot with no direct link to perception of a specific sensation or quality of the space. In addition, question 8, dealing with the quality of materials, could be screened out as well due to both a slight fuzziness in the articulating of the question, but also due to an obvious (though intended) lack of material quality in the VR model, which was not constructive in this specific case. If these premises are accepted, the resulting measurements (Table, Table) shows the same trend with even more clarity.

<table>
<thead>
<tr>
<th>Table 5: Results of mixed instances and questions (1, 4 &amp; 8 screened out)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed instances &amp; question</td>
</tr>
<tr>
<td>RL 2</td>
</tr>
<tr>
<td>RL 2</td>
</tr>
<tr>
<td>RL 3</td>
</tr>
<tr>
<td>RL 5</td>
</tr>
<tr>
<td>RL 5</td>
</tr>
<tr>
<td>RL 5</td>
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<td>RL 5</td>
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<td>RL 6</td>
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<tr>
<td>RL 6</td>
</tr>
<tr>
<td>RL 6</td>
</tr>
<tr>
<td>RL 7</td>
</tr>
<tr>
<td>RL 7</td>
</tr>
</tbody>
</table>
Table 6: Results of same instances and questions (1, 4 & 8 screened out)

<table>
<thead>
<tr>
<th>Same instances and questions</th>
<th>Difference Filter (Mean)</th>
<th>Average Mean</th>
<th>Average % of full results %</th>
</tr>
</thead>
<tbody>
<tr>
<td>RL 2 VR 2</td>
<td>2.18</td>
<td>3.62</td>
<td>30.61</td>
</tr>
<tr>
<td>RL 3 VR 3</td>
<td>2.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 5 VR 5</td>
<td>6.64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 6 VR 6</td>
<td>2.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL 7 VR 7</td>
<td>3.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The calculation (Table ) now shows a resulting divergence of 38.78 % between the matching and the non-matching instances and questions.

Table 7: Divergence in percent (1, 4 & 8 screened out)

<table>
<thead>
<tr>
<th>Same instances and questions</th>
<th>Mixed instances and questions</th>
<th>Resulting Divergence</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.61</td>
<td>69.39</td>
<td>38.78</td>
</tr>
</tbody>
</table>

3. Perceiving Space

Perception of space has always been a crucial area of interest to architects. The relation of body, consciousness, and perception has been the focus of much consideration in attempts to define a phenomenological structure of perception (Merleau-Ponty, 1962) that has continued to intrigue us.

Recently the field of perceiving aesthetics is being addressed, by neurology, with studies of the visual cortex and the biological foundation of vision. For instance, it can be discerned that colour is perceived before form, which is again perceived before motion (Zeki, 1999). Architecture as environmental neuroaesthetics as summerized by N. Rostrup (Lauring, 2014) activates many different areas of the brain, that is the perception of a building façade may be mentally processed both as a background and as a configuration of objects, involving different areas of the brain.

Even though the limited space of this paper does not allow much elaboration, such studies of the brain must be addressed to assist the understanding of perception, and should be embraced by architects as a new source of information to the intricate connections between perception of space, aesthetics and behaviour.

3.1 Perception in VR

The phenomenon of perception in VR has been described by Jonathan Steuer (1992) as a combination of the variables ‘vividness’ and ‘interactivity’ together forming the level of sensation of telepresence.

Vividness means the representational richness of a mediated environment as defined by its formal features, that is, the way in which an environment presents information to the senses. [...] Interactivity is defined as the extent to which users can participate in modifying the form and content of a mediated environment in real time.
It is noteworthy that interactivity seems to be the most important factor of the two, overruling the level of realism in the VR scene (Slater, 2009). Research that is more recent shows that e.g. distance perception is not decreasing significantly even with a severe degradation of visual realism in a scene (Vaziri, 2017). An argument is that the sense of being present or immersed in a virtual environment highly depends on the ability to act and receive direct feedback from one’s actions in the virtual environment (Sanchez-Vives, 2005). This is sustained by the suggestion that the reflections on experiences of architectural space in VR can be simulated corresponding to the same scenario in real life, in many aspects (Hermund, 2016). Comparisons between answers in respectively a real environment and a virtual reality model, indicates a high similarity in the answers given about the perception of space.

3.2 VR perception and Neurology

Neurology studies indicate that the brain uses less working memory when perceiving representation models in VR compared to flat two-dimensional representation models due to reduced task complexity and an eliminated need for cross-dimensionality in the translation of geometry from 2D to 3D (Neubauer, 2010). A recent test (DR2, 2017), involving assessment of a small 3D game in VR and on a traditional screen while measuring the electroencephalogram (EEG), showed that the VR version did actually induce less cognitive load on the brain than the same task performed on a flat screen. This is in accordance with results from testing 2D & 3D non-immersive and 3D immersive scenarios (Kozhevnikov, 2012) concluding that the desktop graphics are ineffective or even counterproductive in relation to 3D immersive environments when aiming for tasks in simulated real world scenarios from an egocentric frame of reference. VR, in this case, creates a more natural environment for the brain, than 2D screens.

4. Discussion and Conclusion – Simulating the Unseen

It has become apparent that a virtual environment through the visual dimension of perception, in combination with interactivity feedback, can be helpful in generating immersiveness, the sensation of being present, even while one is maintaining a conscious knowledge that it is only an illusion – a model.

The model, and digital models, are still a central means of creating architecture. Until recently, the digital regime, although fundamentally a 3D regime, all happened on flat screens. However, VR can perhaps be a step towards a more natural way of representing and dealing with digital architecture. The investigation presented in this paper suggests that VR can indeed simulate a physical scenario to a degree where human behaviour shows correspondences. Furthermore, a virtual scenario contains the possibility to incorporate elements of interaction that cannot be provided to the same extent, using traditional drawings or even non-immersive 2D and 3D. That is exactly what makes a difference and where VR has a potential to surpass a static retinal architecture. In this case, the visual world is not a grand illusion (Noë, 2002), but the visual representations can combined with our sensorimotor skills provide a usable experience of perception. This sort of movement is exactly what can be supported by the clever use of VR simulations. Instead of striving for a photorealistic virtual paradise we suggest that the virtual reality simulations are opened to imagination by actively removing some of the visual effects and adding more possibilities for interaction. In this way, interaction becomes crucial in simulating the unseen cohesion of architecture.

That our brains are combining many different areas to create an experience does not necessarily mean that we need much more than a few indications to imagine a scenario. The crucial part is to find those indications which are needed, and those which are just noise in the model. This is presumably highly
dependent on the profession of the people who experience the simulation. We need to establish a sufficiently solid general foundation for assessing where a VR representation, on a specific level of detail, can convey a realistic, and still imaginative, scenario for a future architectural vision. Then the next step is to look closer at the different professions in the construction sector and establish a parametric adjustable VR scenario responder system, which can be applied and adjusted for the viewer, when needed throughout the whole lifecycle of a project.

We have seen that architectural virtual reality exists, and believe that a collaboration between architecture, neurology, and technology can be a promising path towards better understanding of perception of architectural space. That is why we find it appropriate to suggests that virtual reality representational architectural models can significantly improve the imaginative role of architectural representation, and thus eventually a better architectural quality.

References

A Workflow of Data Integrating and Parametric Modelling in Urban Design Regulation

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Abstract: This paper presents a computer-aided workflow that supports data integration and parametric modelling in urban design regulation. The recent urban regulations are criticised regards the inefficient data exchange, ungearing across two-dimensional provisions and three-dimensional constructions, as well as unpredictable development results. Although various attempts have been made to utilise parametric design instruments in urban scale, most of them are only for modelling fast. This paper proposes a parametric methodology on algorithm platforms to offer a rational workflow for urban design regulating. The workflow includes three phases: (1) data integrating, (2) form-based regulation modelling, and (3) object-oriented regulation modelling. Rhinoceros 3D™, Grasshopper 3D™, and related plug-ins are employed as modelling and data analysing instruments. The proposed workflow is examined and evaluated through experimenting with real-world contexts. This paper further demonstrates that parametric methodologies provide a high-quality contribution to decision-making and urban regulating in next 50 years.

Keywords: Data integrating; parametric modelling; workflow; urban design regulation.

1. Introduction

An urban design regulation is to create design standards, codes or guidelines to specific districts for ensuring urban space quality and site development. Various types of urban regulations have been created upon particular concern with various strategies, but zoning has played a significant role in shaping the built environment (Kim, 2014). Among numerous zoning types, the representative and distinctive zoning approaches are Euclidean, Performance, Incentive, and Form-Based (Barnett, 2011). Euclidean and Form-Based zoning are broadly utilised in contemporary urban planning and design.

Critiques on zoning and urban design regulations are broad. One is the inefficient data exchange from designing process perspective. The regulating plan is one of the essential files in both Euclidean and Form-Based zoning. For formatting the regulating plan, the planning team consists of urban planners and architects creates zoning maps with the spatial and geography data from Geographic Information System (GIS); the regulating team provides text-based regulations; the construction companies and engineers require CAD files. Data exchange has become a problem because of the various requirements and
extended the working process. Another critique is ungearing across two-dimensional provisions and three-dimensional constructions from practising perspective. The urban design regulations are described commonly by using words, tables, and two-dimensional figures. It is queried that the paper files simplified the urban morphology control and hardly regulate the construction of the whole urban site. Besides, the current urban regulations cannot offer directly visualised outcomes which easily lead to unpredictable development results. The benefit to visualise urban regulation is supplementing the word-based codes and reducing misunderstanding.

This paper hypothesises that parametric methodologies and algorithm platforms can provide a high-quality contribution to urban design regulation. Computer-based urban modelling enables urban design stakeholders to describe existing urban future developments, in large part replacing the conventional use of drawing and physical models (Brail, 2008). The capabilities of computer-aided tools have been applied broadly in architecture, engineering, and construction (AEC) industry, while, their application of urban regulation is still in infancy. This paper explores the workflow of data integrating and parametric modelling in urban-scale regulation.

The workflow consists of three phases. The first is data integrating. Spatial and attribute data are the essential materials. Elk, a plug-in of Grasshopper, works as the tool to integrate geography information by connecting with .osm format maps. It provides more accurate feature types than GIS like land use, building, transportation and subtypes like busway, walkways, etc. The second is form-based regulation modelling. A series of transect types and subtypes are addressed to generate the transect matrix of Form-Based Code. This research utilises *Rhino* and *Grasshopper* as modelling platform to visualise the form-based provisions in the urban scale. The third is object-oriented regulation modelling. We extend the urban design regulation into micro scale. Galapagos provides a generic tool to apply evolutionary algorithms for object-oriented modelling in microscale regulation.

We experiment Tsim Sha Tsui (TST) region of Hong Kong to examine the methodology and workflow. The motivations of choosing TST as the context are: (1) density should be highly considered in the urban regulation process; (2) mixed use of land-hungry metropolitan regions prompts the urban regulation transformation from figure-based to model-based. In *Death and Life of Great American Cities*, Jacobs identified the city as complex layers and proposed four generators of diversity including mixed uses; walkable block size; variety of building age and condition; and higher density (Jacobs, 1961). Hong Kong is a typical place to meet the diversity standards of Jacobs and well-placed for test the parametric planning methods. The experiment results are a workflow framework of parametric regulation of TST region and examples of provision model in different scales.

2. Background: Parametric Urbanism and Smart City

Since the beginning of the first experiments of using parametric tools in architecture design process, it has become clear that these tools could bring similar benefits to urban design projects, having even effectiveness in higher scale urban cases (Nagy, 2009). With parametric urbanism, the design of solution is no longer conducted by axial forces or position of urban objects, but is guided by the distribution of densities of constructed urban fabric, by the sensitivity to deformations along the territory or by the development of compositional gradients, understanding space individualities that define the city (Pinto, *et al.*, 2013).

Parametric Urbanism is of great interest for reasons that are both technical and theoretical (Ryan, 2013). One representative example of Parametric Urbanism is Thames Gateway Project by Zaha Hadid
and Patrik Schumacher. Digital design instruments worked in the project for presenting differentiated form patterns and exhibiting diverse scenarios. The parameterisation adopted in urbanism provides a novel method to create dynamic and interconnected built environment. Computer-based tools have been consistently produced to support the increasing parametric urban design ideas. For instance, SOM proposed Parametric Urban Design as a theoretical framework and created Blackbox Studio as a software prototype (Kim, 2014). Users can model buildings and blocks with the Blackbox Studio through the lens of parameters.

Parametric Urbanism contributes to making and remaking a Smart City. The concept of Smart City is often thought of as the utilisation of networked infrastructure to improve both economic and political efficiency and to enable social, cultural, and urban development (Hollands, 2008). Parameterization work as a methodology to integrate physical data and merge the data into Smart City information system. As Toppeta (2010) argues, a smart city is a place where information and communications technology (ICT) and Web 2.0 technology are combined with other administrative, design and planning efforts to speed up bureaucratic processes and help to identify new, innovative solutions to city management complexity, improving sustainability and livability.

In the aspect of place shaping, parametric urban design regulation is an alternative approach for Parametric Urbanism and Smart City generation. It is proposed that by building spatial databases of urban performance and analysing the patterns within these databases using simulation, it should be possible to provide service planners and government authorities with timely information to guide the planning process (Batty, 2012; Oliveria et al., 2015). Although many attempts have been conducted to apply parametric concepts into urban design, very limited research and projects are about regulation simulating. In this research, we aim to fill this gap and explore the interrelationships across parametric methodology and urban design regulation.

3. Methodology

In this section, we analyse the methodology. It consists of three phases, data integrating, form-based regulation modelling, and object-oriented regulation modelling (Figure 1). The result of data integration is a map of geography information on algorithm platform. Based on the information map of step one, step two is to generate a parametric regulation model in large scale. Step three is to model regulation in small scale.

Figure 1: The research workflow and methodology framework.
3.1. Data integrating

We utilise OSM data as the data resource and Elk the plug-in of Grasshopper as the data integrating platform. OSM and GIS are both common map data resources. GIS data has worked as the main database for tons of projects on the urban scale. In recent years, some scholars and designers doubt GIS's capabilities in form-based urban planning and design. For instance, Kim and Clayton (2010) argue that many GIS data, such as parcel, road, and building footprint, may not be directly used in the urban design process due to the inaccuracy. The difficulty of regulation interpretation and the inaccuracy of GIS data converting process have been criticized (Kim and Clayton, 2010).

Compare with GIS, OSM data is more accurate in spatial forms of streets. Produced by UCL and Bytemark Co., OSM data can connect with Elk without exchanging data type in different regulation files. Elk organises and constructs collections of point and tag data so that people can begin creating curves and other Rhino/Grasshopper geometry (Logan, 2017).

3.2. Form-based regulation modelling

Form-based regulation, also called Form-Based Code (FBC), is used to substitute conventional land use-based regulations. As the main approach of New Urbanism, FBC has proven to prescribe the urban form, implement mixed-use development, and address place-based characteristics of sites (Ben-Joseph, 2005; Parolek et al., 2008; Kim and Clayton, 2010).

Algorithm methods work in parametric modelling for form-based regulation. The integration components of algorithm methods simplify the regulating process both in composition and review stages. By taking advantage of computer-aided instruments, urban codes become directly visualised models instead of paper-based text files. An efficient multiple-scenario review is possible through changing the parameter values. After retrieving the map data in the last phase, a form-based regulation model can be generated within Rhino and Grasshopper platforms. Two elements should be involved in this process. One is the transect matrix. FBC uses transect types and subtypes to hierarchize zones from natural to artificial. These transect types constitute the transect matrix of form-based regulation. The other is parameters. A series of parameters should be set to determine the urban and building forms in large-scale regulation modelling.

3.3. Object-oriented regulation modelling

In this phase, an object-oriented regulation model is assembled for microscale urban design. Conventional urban-scale regulation is insufficiently pitched at the small scales such as street-level open space, buildings’ façade, and front openings. Given the problem of discrepancy between urban design regulation files and street-level construction, we utilise evolutionary computing method to explore the parametric urban design regulation in microscale.

From the street-level perspective, the form of low buildings or accessory constructions of high buildings and pedestrian lanes/footprints are both essential design regulation points. The parameters of controlling buildings include height, width, ground floor ceiling, upper floors ceiling, and stories. These variables support parametric modelling on algorithm platforms. Galapagos of Grasshopper analyses the pedestrian lanes and footprints rationally. It provides a generic platform for the application of evolutionary algorithms to be used for regulating street buildings’ front opening and predicting people’s movement.
4. Experiment

We conduct an experiment in Hong Kong to indicate how to implement parametric urban design regulation in a working prototype of the algorithm platforms. TST area works as the research context for the empirical examination. This site located in the southern part of Kowloon Peninsula. Today TST is a major tourist hub and event venue of metropolitan Hong Kong (Zhang and Schnabel, 2016).

4.1. Phase 1: Data collection

The OSM map data source consists of a web-based user interface. We define the TST mapping area coordinates as N22.3078, S22.2925, W114.1641, and E114.1822 then receive a geography information database with manifold layers. The map data comprise four types: Standard, bicycle, transportation, and humanitarian. People can specify the data type as they want. In this research, we choose the standard map and import it into Elk and Grasshopper (Figure 2a).

The Location component of Elk pre-processes all node or point data from OSM file. Through connecting the Location to OSM Data component, there is a small menu to specify feature types (Figure 2b). It defaults to selecting Building, more types and subtypes like apartments, church, or commercial can be added or removed easily. The result of this phase is a geography information file of TST based on Grasshopper platform (Figure 2c).

4.2. Form-based model generation (urban-scale)

Before the generation of form-based models, two essential issues should be considered. One is the transect matrix; the other is the regulation parameter group. Naturalists use a concept called the “transect” to describe the characteristics of ecosystems and the transition from one ecosystem to another; Andres Duany has applied this concept to human settlements, and since about 2000 this idea
has permeated the thinking of new urbanists (Congress for the New Urbanism, 2016). A standard transect matrix of FBC consists of seven transect types including natural zone (T1), rural zone (T2), sub-urban zone (T3), general urban zone (T4), urban centre zone (T5), urban core zone (T6), and special districts (SD). As Zhang and Schnabel (2017) have pointed out, TST Hong Kong has only two transect types, natural zone (T1) and urban core zone (T6), because of the limited land and super high-density population. They extended the urban core zone (T6) with six sub-types from T6-1 to T6-6 to elaborate FBC in high-density performances.

Table 1: Building regulation sample of T6-3, TST.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Regulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table data</td>
<td></td>
</tr>
<tr>
<td>Depth</td>
<td>200’ max.</td>
</tr>
<tr>
<td>Width</td>
<td>150’ max.</td>
</tr>
<tr>
<td>Ground Floor Ceiling</td>
<td>17’ max.</td>
</tr>
<tr>
<td>Upper Floor(s) Ceiling</td>
<td>10’ max.</td>
</tr>
<tr>
<td>Storey</td>
<td>36 max.</td>
</tr>
<tr>
<td>Height to Eave/Parapet</td>
<td>367’ max.</td>
</tr>
</tbody>
</table>

A regulation parameter group is utilised to control the building units. The parameters are depth and width of building coverage, ground floor ceiling, upper floor(s) ceiling, building storeys, and height to eave or parapet (Figure 3a). The building coverage is defined in former phase. We get a base map of building coverage surfaces on Rhino platform by connecting the node data and adjusting the inaccurate points. This research uses T6-3 as a modelling sample (Table 1). We generate a group of building models and colour them for differentiating them with other transect subtypes (Figure 3bc). Urban design regulations become directly visualised to approach and gain insights about a predictable morphology simulation.

4.3. Phase 3: Object-oriented model generation (street-scale)

The elements influencing on street-scale urban design regulation are manifold, but there is a consensus among urban scholars that walkability is increasingly valued at street canyon and neighbourhood scale. As Southworth (2005) has presented, not only does pedestrian transportation reduce congestion and have
low environmental impact, it has social and recreational value. He argues that six criteria for the design of a successful pedestrian network: connectivity; linkage with other modes; fine-grained land use patterns; safety; quality of path; and path context (Southworth, 2005). In this phase, we explore an evolutionary process towards regulating walkable street atmosphere in TST.

Figure 4: The process of evolutionary computing.

Figure 5: A sample of motion simulation.

The research context is a commercial neighbourhood for pedestrians of T6-6, TST. We designate nodes as the surrounded buildings’ front doors. The node numbers can be adjusted in the Count Component. Through processing Galapagos component group (Figure 4 left) of Grasshopper, the pedestrian’s activity path has been simulated. Figure 4 right is a solvers window of Galapagos. The yellow part represents the tolerance degree; the thinner the closer to the optimum solution. In the underneath part, the point and
line figures represent the measures of variability; the numbers represent the tolerance values. Use a simulated scenario as an example (Figure 5). Pedestrian’s movement track shows as the dotted lines. Designers can locate the front doors based on the calculated results and set urban furniture along the predicted tracks.

5. Results and discussion

The research results consist of two aspects. One is a workflow of urban design regulating taking advantage of computer-based data integrating and parametric modelling. The other is an examination of this workflow in the real-world context TST Hong Kong. The workflow contains three phases:

- **Data integrating.** Elk, the plugin of Grasshopper, works as the working platform with the support of OSM map data resource. In this way, a relative accurate database is prepared for the urban regulation modelling process.

- **Form-based regulation modelling.** A series of parameters regulate the building unit forms instead of using land use provisions regulate block functions. Urban regulation is reformed from text-based to visualised and model-based.

- **Object-oriented regulation modelling.** A simulation model of pedestrians’ movement is explored towards a walkable urban environment at the street canyon and neighbourhood scale.

The practice in TST Hong Kong experimentally examines the proposed workflow. The parametric methods are used towards an efficient urban design regulation process both in macro and micro scale. The experiment steps are data collection; form-based model generation; and object-oriented mode generation.

Applying the parametric concepts to the approach of envisaging urban regulation of future cities changes the way to analyse, perceive, and express. Conventional urban zoning and regulation is land use-based which must be expressed in a two-dimensional method. People cannot predict what an urban atmosphere looks like simply through texts, tables, and imagination figures. Model simulation is increasingly valued to offer up predictable and controllable regulation outcomes. Data integrating and parametric modelling make it possible to visualise directly building forms, public space, street canyon, and rational analysis individuals’ movement tracks. The computer-aided approaches can provide a high-quality contribution to urban regulation especially for the high-density environment.

From the perspective of working efficiency, the proposed workflow is proved to be more efficient than the current urban regulation. In the data collecting step, the existing data exchange process is criticised because of the various file formats and redundant departments. In this research, we assemble the regulating process on a unified platform. All steps can be completed through Rhino and Grasshopper. A group of designers can conduct regulation workflow from data collection to provisions modelling.

The case study is used to describe how to merge the regulation workflow in high-density cities. By conceptualising the TST area as a dynamic system, two transect types and six subtypes intervene the zoning approach for change and reconfigure the whole morphology structure. For next 50 years, we argue that high-density will be one of the main urban development trends. The parametric modelling workflow provides an alternative way to regulate the future city towards walkability and sustainability.
6. Conclusion

In this research, we demonstrate that applying parametric methodology within algorithm platforms has the positive potential for digital urban design regulation of future cities. The concept of parametric analysis has been proven broadly in AEC industry. There are however rare considerations of using this novel approach in the field of urban design regulation. We use an experiment to examine the parametric workflow in the urban regulation of Hong Kong. The experiment results consist of an efficient data integration process; avisionalised form-based regulation model in urban scale and a movement simulation in street canyon scale. Combing form-based regulation with parametric tools encourages people to analyse urban space as a dynamic system and urban regulation a continuous workflow.

For further research, we recognise that the workflow of data integrating and parametric modelling may introduce new problems. For example, the zoning regulations are manifold in different contexts. The way to combine parametric methods and local zoning process is still not clear. Besides, the presented regulation framework is simplified urban planning procedure. In reality, urban regulating is a complex system relating to different departments and inter-discipline experts. This research argues an architect-led urban design regulation. The feasibility of the workflow still needs deeper discuss.

References

Kim, J.B. (2014) Parametric urban regulation models for predicting development performances, Texas A&M University, College Station.


How important is Insulation in the Modern Office Building?

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Abstract: Adding insulation limits the rate at which heat is transferred between the internal and external environments. Consequently, there is an expectation that the presence of insulation will reduce energy consumption as less heating and cooling will be required. For internal dominated buildings located in certain climates, an excessive amount of insulation may prevent heat loss through the wall, increasing the energy required to cool the building. Real New Zealand office building calibrated energy models are used to explore how the energy use of a building interacts with load densities, climate and insulation level. It is found that the internal load level has a significant impact on the overall energy consumption, in all the explored New Zealand climates. An increase in cooling energy requirements was observed to occur in heating dominated buildings with a low load level and patterns of use.

Keywords: Insulation; building simulation; heat trapping; energy saving

1. Introduction

International data suggests office buildings are significant, and largely inefficient users of energy. The key energy uses in commercial office buildings are office equipment, light and space conditioning (Amitrano et al., 2014). The laws of physics are clear that adding insulation limits the rate at which heat is transferred between the internal and external environments. Consequently, there is an expectation that the presence of insulation will reduce energy consumption as less heating and cooling will be required.

However, it has been identified that in internal dominated buildings (such as office buildings) in certain climates, excessive insulation may prevent heat loss through the wall, increasing the energy required to cool the building. Internal heat gains (heat given off from lights, equipment and occupants) generally dominate office buildings, unlike residential buildings where most heat gains and losses occur through the building envelope.

Previous studies have identified high internal gains, over-insulation, solar gains, modern construction which eliminates thermal bridging, heating and cooling set points and the climate to be factors which may lead to insulation having an adverse effect on energy use (Boyano, Hernandez, & Wolf, 2013; Friess, Rakhshan, & Davis, 2017; Guan, 2010; Masoso & Grobler, 2008). Internal heat gains (heat given off from lights, equipment and occupants) generally dominate office buildings, unlike residential buildings where most heat gains and losses occur through the building envelope.
The New Zealand Building Code Acceptable Solution H1/AS1 references NZS4243: Part 1 2007 which sets out the minimum acceptable energy efficiency performance requirements that new large (> 300 m²) non-residential buildings, including offices, must meet. The thermal performance requirements for the building envelope were not revised from the preceding NZS4243:1996. The given levels of thermal insulation for the building envelope are based on an economic cost benefit analysis, being the least cost option for the building owner. The NZS4243 Part I is not a code of good practice, so increased levels of insulation above the set minimum requirements are thought to be likely to achieve improved results.

While load densities in office buildings have soared in the past, recent technological advancements and the increase in use of laptops (only consume fraction of the energy of desktop computers), has resulted in load densities being driven down (Menezes, Cripps, Buswell, Wright, & Bouchlaghem, 2014). This change in load density will have a significant impact on the energy behaviour of office buildings—determining how much heating and cooling energy is required to maintain comfortable temperatures. The importance of internal heat gain (in terms of purchased energy consumption) varies with the building location, size and specific building processes (Isaacs, Lee, & Donn, 1995).

2. Analysis Method

Building energy simulation with EnergyPlus has been used to explore the effects of thermal insulation on the energy performance of a range of real New Zealand office buildings. A total of 10 buildings have been modelled and the results examined. One building was selected based on its performance to carry out detailed analysis for this paper. The buildings were modelled with three internal load levels in four New Zealand cities to identify how the energy use of a building interacts with internal load level, insulation and climate.

2.1 Simulation Models

Ten real office buildings were modelled. The models were a part of a representative sample of New Zealand office buildings that were developed into calibrated energy models to represent energy consumption for all commercial buildings in New Zealand (Cory, 2016). Real building data collected on each building during the BEES study ensured adequate calibration of the models (Cory, 2016). Detailed models were created by ensuring they were matched as closely as possible to the materiality, construction, window size, building loads, patterns of use and HVAC system of the real building. The monthly meter data (10 minute monitoring data collected by BEES) and the building’s annual EnPI (Energy performance Index) were used to compare the simulation results in the calibration process.

A national sample of office buildings was divided into 5 size groups (strata), with each strata having approximately the same total floor area (Amitrano et al., 2014). Buildings in the largest three size groups were used in this study (strata 3-5) 1,500–3,499 m², 3,500–8,999 m², over 9,000 m²). Table 1 displays the specifications for the selected building. All building parameters, except for those discussed in the following section, remained unchanged in the study. This includes all the building’s occupant densities and patterns of use.
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Table 1: Specifications of the selected building, (Source: Recreated from (Cory, 2015))

<table>
<thead>
<tr>
<th>Geometary</th>
<th>Temperature Setpoints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Orientation (Degrees - Clockwise from North, 0=North)</td>
<td>N</td>
</tr>
<tr>
<td>Total Building Floor Area m²</td>
<td>E</td>
</tr>
<tr>
<td>Total Number of Storeys #</td>
<td>S</td>
</tr>
<tr>
<td>Building Height m</td>
<td>W</td>
</tr>
<tr>
<td>Glazing Percentage %</td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>N</td>
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<tr>
<td>%</td>
<td>E</td>
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<td>%</td>
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<tr>
<td>%</td>
<td>W</td>
</tr>
<tr>
<td>Construction</td>
<td></td>
</tr>
<tr>
<td>Primary Building Fabric</td>
<td>Façade Material</td>
</tr>
<tr>
<td>Secondary Building Fabric</td>
<td>Façade material</td>
</tr>
<tr>
<td>Roof Construction</td>
<td>Material</td>
</tr>
<tr>
<td>Foundation / Ground / Basement floor</td>
<td>Material</td>
</tr>
<tr>
<td>Glazing Type</td>
<td></td>
</tr>
<tr>
<td>Glazing Framing Material</td>
<td></td>
</tr>
<tr>
<td>Glazing Tint</td>
<td></td>
</tr>
<tr>
<td>Glazing Reflective Tint</td>
<td></td>
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<tr>
<td>Loads</td>
<td></td>
</tr>
<tr>
<td>Occupant Density (person/m² per one floor area)</td>
<td></td>
</tr>
<tr>
<td>Geometary</td>
<td>Temperature Setpoints</td>
</tr>
<tr>
<td>Building Orientation (Degrees - Clockwise from North, 0=North)</td>
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<td>Glazing Percentage %</td>
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<td>%</td>
<td>S</td>
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<td>%</td>
<td>W</td>
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<tr>
<td>Construction</td>
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</tr>
<tr>
<td>Primary Building Fabric</td>
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<td>Secondary Building Fabric</td>
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<tr>
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<tr>
<td>Foundation / Ground / Basement floor</td>
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<tr>
<td>Glazing Type</td>
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<tr>
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<td>Glazing Tint</td>
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<td>Glazing Reflective Tint</td>
<td></td>
</tr>
<tr>
<td>Loads</td>
<td></td>
</tr>
<tr>
<td>Occupant Density (person/m² per one floor area)</td>
<td></td>
</tr>
</tbody>
</table>

2.2 Parameters and Variations

A parametric study was undertaken to determine the influence internal load and insulation level had on energy use for space heating and cooling. Three lighting and equipment load levels and patterns of use were applied to the calibrated energy model. The load densities and patterns of use were those determined by the Building Energy End-Use Study to be the typical (50th percentile), low (10th percentile) and high (90th percentile) values across the sample of office buildings used in the study. The purpose of BEES was to monitor and analyse non-residential buildings around NZ to gain knowledge of energy use patterns for the entire NZ commercial building stock. For each load level scenario, the building was modelled uninsulated or with one of three levels (R1.2, R2.4 and R3.6) of wall insulation. Every model with non-zero wall insulation was modelled with R1.9 roof insulation (the minimum required level in NZS4243 Part 1 for Z2 and Z3).
Figure 1: Percentage Lighting Load “On” (Source: (Cory, Donn, & Pollard, 2015))

All buildings were simulated in four major New Zealand cities - Auckland (Zone 1), Wellington (Zone 2), Christchurch (Zone 3) and Dunedin (Zone 3). The NZ Building Code Compliance document H1/AS1 Energy Efficiency sets out the required thermal performance. The three climate zones (based on average temperature data) are used to determine the thermal resistance values. (Bannister & Guan, 1996) identified that for climates similar to and/or warmer than Auckland, the benefit of additional wall insulation in commercial buildings is marginal. This led to the requirement that no wall insulation is compulsory for commercial buildings located in Climate Zone 1.

<table>
<thead>
<tr>
<th>Lighting (W/m²)</th>
<th>Equipment (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>3.5</td>
</tr>
<tr>
<td>Typical</td>
<td>11</td>
</tr>
<tr>
<td>High</td>
<td>21</td>
</tr>
</tbody>
</table>

| Low             | 4                |
| Typical         | 8                |
| High            | 24               |

3. Results and Discussion

The model results from the ten buildings provide a basis on which the single building was selected for more detailed analysis.

3.1. All Buildings

The results of all the modelled office buildings showed that increasing thermal insulation level in combination with low internal load levels, can increase the cooling energy consumption. However, in only one building was the cooling energy increase large enough to increase the total HVAC energy use i.e. the sum of the heating and cooling energy. With the typical internal load, every building model showed an
increase in cooling energy consumption—whether it was only for the minimum NZBC level or increased levels of insulation. The largest increases in cooling energy were found for the two northern locations (Auckland and Wellington) as would be expected due to the higher average temperatures. An increase in total heating and cooling load was only found in about 40% of the buildings. With the high internal load scenario input, all (100%) of the buildings had an increase in total HVAC energy requirements. However, the size of increase was so small in three of the buildings that it did not have an impact on the building’s total energy consumption.

3.2. Single Building

One building has been selected for a more detailed analysis in this paper. It was selected as it showed a consistent impact of increase thermal insulation in all locations and for each internal load level.

3.2.1. Insulation effect on cooling energy

The effect of change in insulation level on the building cooling load is shown in Figure 4. The percentage of change is relative to the non-insulated building, for each load and climate scenario. Increasing the insulation level is shown to always cause a reduction of cooling energy for the low and typical internal load scenarios, but an increase in all cases modelled with high internal loads.

![Figure 2: Building cooling energy change](image_url)

In every case, the largest increase in cooling energy is between the uninsulated buildings to R1.2 insulation. This is expected as the first step in insulation level will always provide the largest thermal resistance. The increases in cooling energy use are between 8-12% in Auckland, 30-37% for Wellington, 12-17% for Christchurch, and 37-46% for Dunedin.
Increases in cooling energy have typically been identified in previous studies to only occur in scenarios with high levels of insulation. Figure 2 shows that an increase in cooling energy occurs in all scenarios with high internal load levels.

The Table 3 below, displays the annual cooling energy in kWh for each scenario with typical loads, and the percentage difference between each addition of insulation level. While the energy use of all of the insulated models can be seen to never increase above the energy use of the uninsulated model in three locations (Auckland, Wellington and Dunedin), the cooling energy use increases for each additional thermal insulation step beyond the R1.2 level, albeit very minimally.

Table 3: Building cooling energy kWh and percentage reduction, for building modelled with typical loads and schedule.

<table>
<thead>
<tr>
<th>Location</th>
<th>Cooling Energy(kWh)</th>
<th>Percentage Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUCKLAND</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R1.2</td>
<td>16,038</td>
</tr>
<tr>
<td></td>
<td>R2.4</td>
<td>16,049</td>
</tr>
<tr>
<td></td>
<td>R3.6</td>
<td>16,080</td>
</tr>
<tr>
<td>WELLINGTON</td>
<td></td>
<td>10,901</td>
</tr>
<tr>
<td></td>
<td>R1.2</td>
<td>7,647</td>
</tr>
<tr>
<td></td>
<td>R2.4</td>
<td>7,740</td>
</tr>
<tr>
<td></td>
<td>R3.6</td>
<td>7,784</td>
</tr>
<tr>
<td>CHRISTCHURCH</td>
<td></td>
<td>14,719</td>
</tr>
<tr>
<td></td>
<td>R1.2</td>
<td>8,687</td>
</tr>
<tr>
<td></td>
<td>R2.4</td>
<td>8,606</td>
</tr>
<tr>
<td></td>
<td>R3.6</td>
<td>8,589</td>
</tr>
<tr>
<td>DUNEDIN</td>
<td></td>
<td>7,970</td>
</tr>
<tr>
<td></td>
<td>R1.2</td>
<td>5,053</td>
</tr>
<tr>
<td></td>
<td>R2.4</td>
<td>5,101</td>
</tr>
<tr>
<td></td>
<td>R3.6</td>
<td>5,133</td>
</tr>
</tbody>
</table>

3.2.2. Insulation effect on total energy use

Only in Christchurch are the decreases in heating energy consumption greater than the cooling increases, therefore all insulation levels reduce HVAC energy requirements. In all the other locations added insulation causes the total heating and cooling requirements to increase. While the increase in HVAC
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Energy increases by up to 27%, the impact the increases have on the building’s overall annual energy consumption is very minimal—between 0.3% to 1.6%. Effectively the high internal load energy is providing an increased proportion of the space heating requirements.

Figure 3: Building heating and cooling energy.

Table 4 displays the monthly heating and cooling energy requirements for two scenarios modelled in Christchurch with high internal load levels for both uninsulated and R3.6 insulation. The R3.6 model is shown to require less heating year-round. An increase in cooling energy is required in the R3.6 insulated model in the colder months due to the greater amount of heat produced by the high internal load of lighting and equipment. However, as was shown in Figure 3, the heating and cooling energy for the R2.6 scenario still results in an overall decrease in HVAC energy consumption as the decrease in heating energy is so great.
Figure 4 displays the building EUI’s (Energy Use Intensity) for each internal load, insulation level and climate. It is clear that the load level and schedule has a significant impact on the energy use of the building. NZS4220:1982 lists energy consumption targets for existing and new office buildings. These targets are 200 and 100 kWh/ m² respectively. The building modelled with typical loads is shown to perform just below this new building target, and significantly lower with the low load level. In contrast, the building modelled with high loads has an EUI nearly three times the EUI’s for the typical load. This is due to the large amount of cooling that is required to maintain comfortable temperatures by removing the additional heat produced by the lighting and equipment. In all climates, aside from Christchurch, as the insulation level is increased, the EUI increases. The EUI decreases slightly with R1.2 insulation added, then slightly increases with every addition of insulation level. The models with low internal loads appear to be slightly more responsive to the different levels in insulation between climates, possibly due to the building being effected more by the climate when not dominated by the internal gains.

While the target for new office buildings is 100kWh/ m², the BEES study identified that a building of this size in New Zealand typically has an EUI of 170kWh. m²-yr.
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4. Conclusion

The objective of this study was to explore the sensitivity of HVAC energy consumption to changes in levels of thermal insulation and internal loads in New Zealand office buildings. Although increasing insulation has been shown to reduce total HVAC energy use in all climate zones, this is only true with low and typical internal load levels. Interestingly, it was found that increasing thermal insulation could increase cooling energy requirements, possibly leading to increased total HVAC energy use.

Further analysis of all the buildings included in this study is required. Further research will be undertaken to understand how other building parameters (e.g. heating set points, window to wall ratio and thermal mass) effect the building thermal performance. Additional load densities (between the typical and high values) and patterns of use will be modelled to explore the point at which insulation begins to increase the cooling energy to an extent at which it increases the total HVAC energy requirements.

References

Generating Urban Codes for Neighbourhoods

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Abstract: This research has developed a participatory methodology to generate urban codes to achieve the desired configuration for neighbourhoods in New Zealand. Urban codes are the qualities inherent in the built environment which have either evolved by themselves or have been guided by rules and regulations. The work develops a novel decision-making platform that brings together city level and local neighbourhood data to aid participatory urban design decisions. This platform offers stakeholder collaboration and engagement in complex urban design decision-making processes. The research develops a configurational design method by employing virtual instruments to generate building forms. The research methodology establishes a middle approach between top-down and bottom-up urban design methods where the generated urban forms can be visualised in an online platform for stakeholders to get real-time feedback. In particular, it explores an alternative urban design process as an algorithmic knowledge-based system for neighbourhood design.

Keywords: Urban codes; algorithmic urban design; decision-making platform; investigation rules; virtual instruments.

1. Introduction

New methods in urban design practices have brought about a shift from utopian design approaches to systematic design approaches (Beirão, 2012). Cities have ever increasing urban complexity and dynamics which have influenced a change in conventional urban design decision-making processes. Advances in procedural design approaches have already taken place in the domains of art and science, and such methods are starting to influence urban design (Beirão et al., 2012). With the advancement of computation, particularly in terms of Computer Aided Design (CAD), come rich possibilities to create design tools that address urban complexity. However, currently these tools are mostly used in design production rather than as an instrument in decision-making processes (Schnabel, 2007; Hanna, 2012). Previously, each design decision phases was carried out by hand, but nowadays they are automated (Miao et al., 2017). Such automatic design procedure also has influenced urban designers to seek for new design methodologies.

Shifting from top-down modelling to more generative and bottom-up systems has influenced urban designers to address morphogenetic changes in urban design (Beirão and Duarte, 2005; Ayaroğlu, 2007; Beirão et al., 2011; Verebes, 2013). Such systems can function as a creative design assistant during the conceptual stages of architecture & urban design. Traditional urban design and planning methods have
limited ability to address multiple urban complex rules and cannot able to provide necessary information to predict the urban forms. City Information Modelling (CIM) can automate design options and generate possible new urban scenarios (Gil et al., 2011; Beirão et al., 2012; Stojanovski, 2013). However, this top-down modelling process has the inability to visualise urban scenarios in a dialectic way for stakeholders (Kunze et al., 2012a). Therefore, this research develops an instrument between top-down and bottom-up design methods to engage stakeholders in urban design process. The research employs CIM and generates interoperable rules for neighbourhoods through mathematical and computational models by analysing and evaluating urban forms and spatial configurations. The research develops a configurational design method which can integrate maximum urban complex rules for building forms. The intention is to explore an alternative urban design process; an algorithmic knowledge-based system, in neighbourhood design.

The goal of the research framework is twofold. One is to develop an instrument which supports interactive prediction in urban design, and the second is to demonstrate a better way of communication between different stakeholders including professionals such as urban designers, urban planners, policy makers and lay people. The study presents an approach for how design codes can efficiently steer and redefine procedural city modelling to arrive at detailed urban scenarios (Kunze et al., 2012a), and it also creates an interface to visualise the 3D models for improved dialogue between stakeholders (Kunze et al., 2012b).

2. Methodology

The research methodology is a design exploration based on logical argumentation. The methodology comprises of five steps. It starts with defining the content of urban codes and end with an assessment process (Figure 1). The output of every step feeds into the next step. The first step extracts the content of codes. This step tries to reconfigure the contents of codes from literature reviews and exemplars. The second step configures algorithmic relationships between different urban elements and investigates them through several adapting methods from urban theories. The third step intends to develop a mathematical algorithmic modelling platform as programming scripts on the sets of investigation rules to generate urban forms. These algorithmic rules define the boundaries of design computing. The limits of design computing are indeed nebulous and difficult to define. Unlike pure mathematics, design computing is an application of computing–pattern which demands consistent interpretation and self-critique (Johnson, 2016). In this step, the rules translate to programming scripts. Such translation from physical rules to computation scripts provides an opportunity to operate those complex urban relations in a visual platform. Scripting in this step is an iterative process which engages stakeholders to predict the most desirable urban forms. The fourth step suggests a virtual platform to visualise the iterative outcome. Finally, the fifth step ensures the validation of output by an assessment process with stakeholders in an online platform to achieve the desired urban configurations.
Figure 1: Research Steps
2.1. Step 1 - analysing the content of codes

Step 1 adapts the content of urban codes for this research from literature reviews.

Defining the content of codes

Urban components are associated with urban coding. Stephen Marshall (Marshall, 2012) has developed the framework for coded elements (Table 1) which he admits that the intention is not to produce an exhaustive synopsis of all codes and regulation, but is intended to contain the range of types of different coded elements. Within the scope of the thesis, this study adopts the primary content of codes which have physical impacts on street block formation. The elements are listed from slowest rate of change to quickest rate of change. So far, the coded items are:

- Open spaces
- Street network system
- Street width
- Street Block
- Subdivision of Lands in Blocks
- Plots/sections
- Subdivision of Plots
- Ground coverage
- Buildings height

The research addresses these content of codes to set the boundary of urban investigation rules.

2.2. Step 2 - developing investigation rules

Step 2 tries to establish the operable relation between different urban elements. The elements of urban codes posit an intricate lattice within themselves. Remapping the relationships of specific urban elements can set the boundary condition to operate them on a virtual platform. This section of the research explores multiple ways of remapping the relationship of the quantified elements of urban codes.

Adapting algorithmic investigation rules

The first set of investigation rules supports the parameters related to measuring physical density, which to some extent defines different housing typologies. Later, this stage includes the set of examination rules for street network and connectivity by employing space syntax (Karimi, 2012; Van Nes et al., 2013) and the rules for spatial configuration of dwelling functions by adapting graph theory (Nourian, 2016). Further rules like evaluating solar insolation, shadow analysis, functional mixture, etc. can accommodate in this part of the research framework. Most of these methods are simulation based. All of these investigation rules are purposefully designed to create urban scenarios which can simultaneously get feedback during the process of simulation.
A set of investigation rules for building types and density

Marshall illustrates that the elements of ‘the scopes of building’ and ‘plots & land division’ have the first-degree relation to formulating their physical aggregations. And the density indicators also depend on the value of those elements of codes. By remapping the relationship of coded elements, we can define the measuring criteria of density. Those elements also can determine the types of housing whether it is semi-detached, terraced or apartment.

2.3. Step 3 - mathematical algorithmic modelling

The insertion of mathematical modelling in urban design and planning has opened up a new horizon in design exploration. Mathematical modelling science refers an accumulated nature of knowledge which represents ways to comprehend and make sense of the complex relation (Lucio-Arias and Scharnhorst, 2012). Researchers like Koenig and Schneider (2012) have already started to explore the potentiality of the integration of cognitive computing in urban design and planning. Also, researchers like Schnabel et al. (2017) have already explored the potential applicability of parametric design in urban regulation. This part of the research transforms the previous set of rules in the programming language. Such transformation of rules in the computational platform provides the opportunity to operate the relationships between different urban elements and generate visible outcomes which eventually increase the interrogation with the design options in a real-time feedback.

A set of investigation rules for building types and density

This section of the research develops an integrated script from which one can generate the desired housing typology by manipulating the density indicators. The method is Object Oriented Parametric Modelling (OOPM). The script is written in a programming language either it is visual (i.e. Grasshopper for Rhino/ Dynamo for Revit) or C-style language.

2.3. Inserting the vector map of the street block

The script is linked with the 3D modelling interface by the GIS or Open Street Map (OSM) exported vector map of the street block of the test site. The script also accommodates the information of the topography. The map is available in online and has sufficient information to meet the requirement for this investigation.

2.4. Step 4 - developing a platform-an interface

From the beginning, the study tries to develop communicative Graphical User Interface (GUI). This interface offers a platform to operate and visualise multiple options of urban scenarios which are generated by various inputs. There are existing software like Rhino, Revit, Maya, etc. which can generate 3D models from programming scripts. The scripted rules from the previous stage, importing in such visual platform can create multiple choices for 3D models in an iterative loop. However, these platforms are still in the face of developing to overcome the limitation of engaging with the users. Figure 2 illustrates a GUI interface to generate urban forms in Rhino platform.
2.5. Step 5 - evaluation- assessing in a triangulation loop

This stage of the research validates the level of performance of this proposed system. The validation occurs with the presence of stakeholders. The online real-time visualization engages stakeholders in design discussion. This section suggests a triangulation loop between three different situated conditions (Figure 3). One condition is the input value in the system as density criteria; the second condition is the output of the system—the generated urban forms and the third one is the feedback from the stakeholders—their choices for urban forms. All three steps offer the state of negotiation, where the stakeholders initiate the decision of choices.

Figure 2: A GUI interface linked in an online platform to visualize generated urban forms

Figure 3: The triangulation loop for assessment
A triangulation assessment method provides a way to validate the conclusion of a study. Therefore, the assessment ends by getting the most desired urban scenarios after going through several cycles into the system. The evaluation of the system is concluded by documenting a questionnaire survey.

4. Contribution and discussion

The study is a significant endeavour to promote a participatory urban design system for neighbourhood design. The study develops an instrument to analyse and generate urban forms and present them with information to the stakeholders. The framework of the study also can be explored in the field of architecture and urban design pedagogy as a guideline for design studios or workshops. The steps of research methodology are framed in such a way that the methodology can cater to any location around the world. The sets of investigation rules offer to deal with urban complexity as a holistic approach, and the online platform offers to visualise the outcome in a dialectic way.

Urban professionals try to engage stakeholders in their design process through different approaches. There are already established studies to proof the limitation of perception of scales between top-down and bottom-up urban design approaches. This study doesn’t include the socio economic aspects of those urban design and planning approaches, but seeks a methodology to create virtual instruments to bridge the gap. This study still needs proof to validate the system. The proposed system is on the process to engage stakeholders in real-life scenarios.

Acknowledgment

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References


Acoustic Design for an Auditorium Project

Using Building Performance Simulation to Enhance Architectural Quality

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Abstract: This paper reports a consultancy work for an auditorium project. The consultancy work considers four important acoustic design issues for auditoria: volume and seats; control of reverberation time (RT); diffusion of sound; elimination of defects. Odeon 5.0 was used to simulate the reverberation time and sound propagation and diffusion. Case studies were used to discuss the simulation results and to propose design guidelines. For a small auditorium, the design recommendation is about how to minimize sound absorption and to achieve sufficient reverberation. Sound defects were found in the stage outlet and rear walls. The design recommendations based on the consultancy work helped architects improve their design and enhance architectural quality.

Keywords: Architectural acoustics; building performance simulation; auditorium; design quality.

1. Introduction

Contemporary architectural design is shifting from a prescriptive approach towards a performance based approach (Anderson, 2014). There is an intensive debate about the two approaches (Xie and Gou, 2017). The prescriptive is dogmatic, restricting creativity and cannot guarantee design quality or performance; while the performance based approach is using information technologies to encourage design innovation and predict design performance. On the other side, the prescriptive approach is easy to understand and operable for architects, while the performance based approach required special techniques which is beyond the capacity of architects. This paper demonstrates how building performance simulation helps architects in a heuristic approach. Particularly, this paper uses an interior design project for an auditorium as a case study. Auditorium required special consideration for acoustics. Being part of the design team, the authors used acoustic simulation to estimate the reverberation time and sound distribution. The authors also used case studies to discuss the design implications and to propose design recommendations.
2. The Auditorium Project

The project’s client is Diocesan Boys' School (DBS) Hong Kong (Figure 1). The Diocesan Boys' School is one of the most prestigious boys' schools in Hong Kong, located at 131 Argyle Street of MongKok. Founded in 1869, it is one of the oldest secondary schools in the city. This prestigious private boys' academy in Hong Kong has become renowned for its music programs. The auditorium was to be built to accommodate the emerging needs of music performance. The architect is Thomas Chow Architects (TCA). The project has a very tight schedule so that in the early design stage, acoustics was not fully considered. The architects were not confident about its acoustic performance; therefore, the authors were invited to help them to verify their design and improve the design quality especially on architectural acoustics during the construction stage (Figure 2).

Figure 1: The location of the auditorium and the project under construction (photographed by the authors in 2012)

Figure 2: The project under construction (photographed by the authors in 2012)
3. Design Objectives

The acoustical environment for an auditorium project can be enhanced in following respects (Barron, 1993):

- The floor area and volume of the auditorium should be kept at a reasonable minimum for adequate loudness in every part of the auditorium.
- Optimum reverberation characteristics should be provided in the auditorium to facilitate whatever function is required.
- The sound energy should be uniformly distributed within the room.
- The room should be free from acoustical defects (distinct echoes, flutter echoes, picket fence echo, sound shadowing, room resonance, sound concentrations and excessive reverberation).

First of all, there should be adequate loudness in every part of the auditorium, especially in remote seats. The problems of providing adequate loudness result mainly from the inverse square law and excessive absorption by the audience attenuating the direct sound before it reaches the listener (Egan, 1988). Above all, the floor area and volume of the auditorium should be kept at a reasonable minimum, thus shortening the sound paths. The following table details recommended Volume-per-seat values for various auditoria (Table 1). The volume for the DBS auditorium is 7,324 m³ (The calculation was conducted in SketchUp 8.0). The total number of seats is 800. So, the Volume-per-Seat is 7,324 m³/800 = 9.2 m³. The value falls into the range for Concert Halls. For other criteria, the authors conducted building simulation to verify its performance.

Table 1: Recommended Volume-per-Seat Values (m³) for Auditoria (Source: Egan, 1988)

<table>
<thead>
<tr>
<th>Type of Auditorium</th>
<th>Minimum</th>
<th>Optimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rooms for Speech</td>
<td>2.3</td>
<td>3.1</td>
<td>4.3</td>
</tr>
<tr>
<td>Concert Halls</td>
<td>6.2</td>
<td>7.8</td>
<td>10.8</td>
</tr>
<tr>
<td>Opera Houses</td>
<td>4.5</td>
<td>5.7</td>
<td>7.4</td>
</tr>
<tr>
<td>Catholic Churches</td>
<td>5.7</td>
<td>8.5</td>
<td>12</td>
</tr>
<tr>
<td>Other Churches</td>
<td>5.1</td>
<td>7.2</td>
<td>9.1</td>
</tr>
<tr>
<td>Multipurpose Halls</td>
<td>5.1</td>
<td>7.1</td>
<td>8.5</td>
</tr>
<tr>
<td>Cinemas</td>
<td>2.8</td>
<td>3.5</td>
<td>5.6</td>
</tr>
</tbody>
</table>

4. Building Simulation

4.1. Reverberation Time

Reverberation is the persistence of sound in a particular space after the original sound is removed (Meyer, 1978). Reverberation Time (RT) is the time required for reflections of a direct sound to decay by 60 dB below the level of the direct sound (Knudsen, 1932). For acoustic design, RT remains a prime consideration. Historically values between 1.0 and 1.5 seconds have prevailed (Olson, 1967). For the fullness of instrument playing, RT for symphony concert hall is usually higher than 1.5. For a concert hall, the RT should be between 1.4 and 1.7. The choice of appropriate RT for a recital hall is at the same time more difficult but less critical than for a full symphony concert hall. In a small hall, reflections arrive earlier and this means that maintaining satisfactory clarity should be less of a concern. The suitable choice of reverberation time, as it affects loudness, should therefore be less stringent in the smaller hall (Ham,
1987). For symphony concert halls, the recommended reverberation time is a function of programme only. Different sources in the literature give different recommendations and the final selected values should be influenced by experience of individual halls, as well as the acoustic intentions of the designers (Beranek, 2004). A shorter reverberation time will enhance musical definition. A long reverberation time will give a more sumptuous sound with better blend but less clarity.

Odeon 5.0 was used to estimate RTs in the DBS auditorium. The method estimates a mean absorption coefficient, which is inserted in the Sabine, Eyring and Arau-Puchades formulas to give an estimate of the reverberation time (Christensen, 2009). Instead of simply taking the areas of the surfaces and multiplying by the corresponding absorption coefficients to obtain the total absorption in the room, Odeon also sends out ‘particles’ from the source, assuming diffuse conditions thus reflecting them in random directions, keeping a count on how many times they hit each surface. Surfaces that are hit very often then carry greater weight in the overall mean absorption coefficient of the room. Surfaces, which are not detected at all in the ray-tracing process, are left out of all calculations and surfaces which are hit on both sides are included twice in the calculation. As a result the estimated reverberation time corresponds to the sub-volumes in which the selected source is located. Note however that if a part of the area of a surface, which is present in the sub-volume, is located outside that sub-volume (e.g. if two sub-volumes share the same floor surface) then area and surface estimates for the statistical calculations may not be entirely correct.

In Odeon, two mean absorption coefficients are inserted in the Sabine and Eyring formula to calculate reverberation times. The mean absorption coefficients used for the Arau-Puchades formula are derived in similar ways except that separate values for surface hits, area and the corresponding mean absorption coefficient are calculated as projections onto each of the main axis of the room. The DBS model was based on the architects’ design scheme and the principle of material selection is to minimize the sound absorption (Figure 3). The condition was the auditorium occupied (audience on the wooden chairs); one speaker was located in the center of the stage. The result was shown in Figure 4 (estimated RTs) and 5 (absorption sources). The estimated RT for the DBS auditorium at the mid-frequency (500 Hz) cannot fall in to the range 1.4 - 1.7 seconds. The RTs at the high-frequencies (1000 Hz, 2000 Hz etc.) are even lower than 1.0 seconds. Undoubtedly, the audience absorbed the largest part of sound; the ceiling in the wake of the audience. Considering the absorption due to audience that is hard to change, efforts should be made on the ceilings.

![Figure 3: Material settings for ceiling (top), walls (middle) and bottom (chairs)](image-url)

```plaintext
<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mat. 2320: Ceilings</td>
<td>16 mm pressed mineral fiber board (fissured) 210 mm from ceiling</td>
<td>Ref.</td>
</tr>
<tr>
<td>63 Hz</td>
<td>0.39000</td>
<td>Ref.</td>
</tr>
<tr>
<td>125 Hz</td>
<td>0.39000</td>
<td>Ref.</td>
</tr>
<tr>
<td>250 Hz</td>
<td>0.29000</td>
<td>Ref.</td>
</tr>
<tr>
<td>500 Hz</td>
<td>0.39000</td>
<td>Ref.</td>
</tr>
<tr>
<td>1000 Hz</td>
<td>0.59000</td>
<td>Ref.</td>
</tr>
<tr>
<td>2000 Hz</td>
<td>0.64000</td>
<td>Ref.</td>
</tr>
<tr>
<td>4000 Hz</td>
<td>0.65000</td>
<td>Ref.</td>
</tr>
<tr>
<td>8000 Hz</td>
<td>0.10000</td>
<td>Ref.</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mat. 2329: Walls</td>
<td>panel without slots, on 25 mm studs with mineral wool Ref. Dahlenbäck</td>
<td>Dahlenbäck</td>
</tr>
<tr>
<td>63 Hz</td>
<td>0.12000</td>
<td>Dahlenbäck</td>
</tr>
<tr>
<td>125 Hz</td>
<td>0.17000</td>
<td>Dahlenbäck</td>
</tr>
<tr>
<td>250 Hz</td>
<td>0.32000</td>
<td>Dahlenbäck</td>
</tr>
<tr>
<td>500 Hz</td>
<td>0.12000</td>
<td>Dahlenbäck</td>
</tr>
<tr>
<td>1000 Hz</td>
<td>0.06000</td>
<td>Dahlenbäck</td>
</tr>
<tr>
<td>2000 Hz</td>
<td>0.03000</td>
<td>Dahlenbäck</td>
</tr>
<tr>
<td>4000 Hz</td>
<td>0.02000</td>
<td>Dahlenbäck</td>
</tr>
<tr>
<td>8000 Hz</td>
<td>0.00000</td>
<td>Dahlenbäck</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mat. 503: Audience on wooden chairs</td>
<td>1 per sq. m (Ref. 20)</td>
<td>Ref. 20</td>
</tr>
<tr>
<td>63 Hz</td>
<td>0.16000</td>
<td>Ref. 20</td>
</tr>
<tr>
<td>125 Hz</td>
<td>0.16000</td>
<td>Ref. 20</td>
</tr>
<tr>
<td>250 Hz</td>
<td>0.24000</td>
<td>Ref. 20</td>
</tr>
<tr>
<td>500 Hz</td>
<td>0.56000</td>
<td>Ref. 20</td>
</tr>
<tr>
<td>1000 Hz</td>
<td>0.69000</td>
<td>Ref. 20</td>
</tr>
<tr>
<td>2000 Hz</td>
<td>0.81000</td>
<td>Ref. 20</td>
</tr>
<tr>
<td>4000 Hz</td>
<td>0.78000</td>
<td>Ref. 20</td>
</tr>
<tr>
<td>8000 Hz</td>
<td>0.00000</td>
<td>Ref. 20</td>
</tr>
</tbody>
</table>
```
4.2. Sound Distribution

Averagely distributing sound energy is of importance to achieve a good acoustic design. In an enclosed space, the direct sound decreases in level in the same way as outside. Most of the sound energy we receive in enclosed spaces has been reflected by walls and ceiling surfaces. The geometries of reflection for light and sound are identical. The reflected wave behaves as if it had originated from the image position (Schultz and Watters, 1964). But, for sound, much larger surfaces are required owing to the much longer wavelengths involved. An acoustic mirror is a large, plane, massive surface of, for instance, concrete or timber. Sound reflected by one surface will continue to be reflected between the room surfaces, until its energy is removed by absorption. “3D Billiard” in the Odeon software was used to simulate the sound energy propagation and distribution. Figure 6 shows the result. One of outstanding issues is that the upper part of the stage obstructs the sound propagation to the audience. The direct sound (deep red balls) has not yet reached the rear wall, but some balls have been reflected eight times (green balls) in the stage. It means that the outlet of the stage needs acoustic treatment. Reflectors should be considered.
4.3. Sound Defects

Any time the surfaces of a room focus the sound which is reflected from them, they create spots of high intensity and other spots with low intensity. This is generally undesirable in an auditorium since we want a uniform, evenly dispersed sound to all listeners (Andrade, 1932). The “3D Billiard” again, is used to display sound effects such as scattering, flutter echoes or sound focusing. A number of billiard balls are emitted from the source and reflected by the surfaces in the room. To visualize any sound effect, a large number of billiard balls (10,000 balls) were used. The results are shown in Figure 7. As expected, the real walls of the stage contributed to a sound focusing in the front of the auditorium. The focused sound energy will cause sound distortion, which should be avoided. The main reason is that the real wall is concave. This form should be avoided in auditorium design.
5. Case Studies

Table 2 refers to several famous concert halls in the U.K (Barron, 1988, Barron, 1993). They are Wigmore Hall and Queen Elizabeth Hall in London, Maltings Concert Hall in Snape, and Music School Hall in Cambridge. The DBS case is very similar to the Maltings Concert Hall, Snape (around 800 seats and 7500 m3). The Maltings (a large complex of mid-nineteenth century) was converted into a concert by Arup in 1967. The simple lines and straightforward finishes in generous-size spaces offer a delightful environment for the high-quality music provided in this auditorium. The auditorium is rectangular in plan, using existing red brick walls which were grit-blasted and sealed. To achieve a suitable internal volume the walls were extended upwards 1 m. The roof structure was completely new with a 45° gabled section. For the roof, two layers of 25 mm tongued and grooved timber boarding were used, set at 45° relative to one another. The timber roof trusses and steel ties are all exposed on the auditorium interior, yet the construction is stiff enough to ensure little low-frequency absorption. In acoustic terms, the exposed roof elements can be expected to contribute to good diffusion. Use of seats without upholstery is unusual in modern auditoria, as it results in large changes of reverberation time with occupancy (Barron, 1988). The case study showcases a way for auditoria with small volumes to achieve good reverberation times. The DBS is suggested to increase the volume by enlarging and elevating the ceiling and roof.

<table>
<thead>
<tr>
<th>Concert Hall</th>
<th>Number of seats</th>
<th>Volume (m³)</th>
<th>RT (s)</th>
<th>Interiors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wigmore Hall, London</td>
<td>544</td>
<td>2900</td>
<td>1.5</td>
<td><img src="image1" alt="Wigmore Hall" /></td>
</tr>
<tr>
<td>Queen Elizabeth Hall, London</td>
<td>1106</td>
<td>9600</td>
<td>1.8</td>
<td><img src="image2" alt="Queen Elizabeth Hall" /></td>
</tr>
<tr>
<td>Maltings Concert Hall, Snape</td>
<td>824</td>
<td>7590</td>
<td>1.6</td>
<td><img src="image3" alt="Maltings Concert Hall" /></td>
</tr>
</tbody>
</table>
We also proposed an over-stage reflector used in the selected projects to reflect sound onto the audience. It is due to the concern about inadequate clarity at the rear of the new large concert halls, but some acousticians criticized the harsh quality they imparted to the sound. In the Queen Elizabeth Hall the reflector is movable between a reflecting and non-reflecting position. Subjective tests conducted at the time of opening suggested that the audible effect of the reflector was small but that in general the preference was for the vertical, no-reflection condition. For solo piano, however, the reflector was favoured in its down position. The fact that the subjective effect of this reflector proved to be small is not wholly surprising given the relatively small size and narrow width of the wall, which creates other reflections of similar delay to that of the reflector. With a massive auditorium shell (the walls here are 375 mm thick concrete), the bass reverberation time will rise. For symphony concerts many consider this to be highly desirable but for chamber music the argument for a bass rise is less clear.

We also found sound focus due to the concave stage walls. This sound defect can be avoided by decorating the surfaces (using boundary element methods) of the concave walls to distribute the sound energy (Figure 8). Out of this technique have come ‘wavy’ surfaces optimized for their directional reflection characteristics (D'Antonio and Cox, 2000, Hargreaves et al., 2000). An impressive use of this technology also is shown in Figure 7. It is a scattering wall in a rehearsal hall with circular geometry in plan. The shape of the wall is based on a wave motif optimized for diffusion using boundary element techniques (Architects: Patel Taylor; acousticians: Arup Acoustics; diffuser design and installation: RPG) (Orlowski, 2000).

![Figure 7: Scattering wall in a rehearsal hall with circular geometry in plan.](image)

**Figure 7:** Scattering wall in a rehearsal hall with circular geometry in plan.

![Figure 8: Rationale of focusing and distribution](image)

**Figure 8:** Rationale of focusing and distribution (Orlowski, 2000)
6. Design Recommendations

The research identifies the following key findings and design recommendations.

- The project is a small auditorium with volume at 7,324m³ and seats at 800. The experience learnt from small auditorium is to elevate the roof to increase the reverberation. The openings (holes) for daylight access in the DBS auditorium could be enlarged and elevated to increase the volume and consequently increase the RT.
- Reverberation Time was estimated under occupied conditions. The estimated RT was lower than the expected RT (1.4-1.7 s). The results show that the auditorium needs design on reducing absorption. Sound absorptions from ceilings and walls must be minimized during material selections.
- The sound diffusion in the DBS auditorium is not advantageous at the outlet of the stage. Reflectors should be placed to distribute the sound energy to the audience.
- Sound energy focusing was found in the front of the auditorium. The rear wall of the stage should be designed to avoid sound focusing. A scattering wall in a rehearsal hall was studied as a good example to shape the wall to “wavy” surfaces to suppress focusing caused by concave walls.

Based on the consultancy work the authors conducted, the architects completed the fit-out and interior system (Figure 9). First, the architects kept the interiors simple to maximize the volume, minimize the sound absorption and achieve appropriate reverberation time. There are no excessive decorative elements in the ceiling system or on the walls. The roof is exposed to the audience. This also benefits daylighting. Second, the architects changed the stage outlet to make it open and reflective. Over-stage reflectors were used to maximize early reflection towards audience. Third, the architects use timber panels to reshape the rear walls of the stage to minimize the sound focus and diffuse sound from the stage to the audience.

Figure 9: The completed project (courtesy of Thomas Chow Architects)

In this project, reverberation time is one of key design criteria for auditorium acoustics. A significant portion of the consultancy task is to achieve optimal reverberation time. Both prescriptive design
approaches such as checking seat-volume ratio and performance-based design approaches such as simulating reverberation time are used. Prescriptive design, as a traditional design method and rule of thumb, is of great important and useful in the very beginning of the design stage. Performance-based design using computer simulation can be instrumental in schematic design, especially material selection and interior installation and construction optimisation. In this study, the quality of the acoustics of an auditorium also covers the shape and size of the enclosure and related acoustical defects such as concentration and focus. Through the visualization of sound distribution, these defects can be detected. Actually, prescriptive approaches for acoustic design such as room geometrical analysis can also help architects to avoid sound defects such as echoes, dead spots and flutter. Preferably, the performance based approach can produce more evidence-based outcomes to convince architects and clients to improve their design and construction.

7. Conclusion

The performance studies in this project came to a late stage; so, some acoustic defects (such as sound focus due to the concave shape) were not avoided in the early design stage. Anyway, this project demonstrates how building performance studies can help architects enhance design quality. In response to the debate raised in the beginning of this paper, the authors believe that the building performance simulation indeed is an important instrument which should be used in architectural design and that the way of using building simulation should be heuristic instead of dogmatic, to truly help enhance the design quality.

Acknowledgements

Many thanks are due to Thomas Chow Architects for inviting authors to participate in this project. The authors also like to thank DBS.

References

Optimization of Complex Fenestration Systems using an Artificial Neural Network

Considering Energy and Daylighting Performance of Office Buildings

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Abstract: The use of artificial neural networks (ANNs) in building performance problems has been widely studied by different authors in the last years. ANNs can decrease the computational time when the building design is complex due to high number of variables. In this research, an ANN was developed in Python and used to optimize an office space with exterior and fixed complex fenestration systems and dimmed luminaries in three different climates of Chile considering variables such as window-to-wall ratio, solar heat gain coefficient, U-value of windows, shading device, walls’ thermal resistance and insulation position. The office performance metrics considered in the objective function of optimization process are total energy consumption (sum of lighting, heating and cooling energy consumption) and two visual comfort criteria, spatial daylight autonomy (sDA) and annual sunlight exposure (ASE). A total of 5,400 lighting simulations and 12,800 energy simulations were performed to train the ANN. The simulations were carried out using mkSchedule, a tool that integrates energy and lighting simulations. The results show the capability of the ANN to be incorporated to an optimization process of office buildings based on energy performance and visual comfort metrics.

Keywords: Complex fenestration systems; artificial neural network; energy performance; visual comfort; optimization.

1. Introduction

Buildings are responsible for about 32% of the energy consumed in the world and generate one third of greenhouse gases (GHG) (OECD/IEA, 2013; Lucon et al., 2014; Borgstein et al., 2016). In Chile, energy consumption in the building sector was 21.3% of the total energy consumption in 2015 (CNE, 2017). The building sector needs to design, build and operate buildings to provide a healthy, comfortable and productive indoor environment in balance with strategies towards energy efficiency (Kang et al., 2017). This is particularly important in office buildings that compromise fully-glazed facades that might significantly increase the cooling energy consumption and contribute to visual discomfort (Kuhn, 2006; Bustamante et al., 2014).
An increasing amount of literature has been published recently on the optimization of buildings to minimize their energy consumption as well as to achieve the indoor visual comfort using complex fenestration systems (CFSs). CFSs include a non-specularly transmitting layer within the façade assembly, thus different shading devices such as fabric shades, louvers and blinds are considered CFSs (Laouadi and Parekh, 2007; McNeil et al., 2013; Vera et al., 2016). For example, McNeil and Lee (2012) applied a genetic algorithm and Radiance to design a slat-type shading. Manzan (2014) designed a shading device using ESP-r and DAYSIM. In this case, a multi-objective optimization was used to minimize the energy consumption. On the other hand, Futrell et al. (2015) also used multi-objective optimization to design a light shelf to maximize the daylight transmission and minimize energy consumption. More recently, Vera et al. (2017) have demonstrated that optimization of CFSs needs to take into account not only energy performance of office spaces but also visual comfort. However, automated optimization process via coupling energy, lighting and optimization tools can be time consuming due to the large number of parameters to be optimized. Therefore, the use of artificial neural networks (ANNs) can help reducing the complexity of simulation processes and computing time.

An ANN can learn from simulation results for some variables and provide optimal solution for certain parameters that need to be optimized. The use of ANNs to solve building performance problems has been widely studied by different authors (Wong et al., 2010; Fonseca et al., 2013; Afram et al., 2017; Pino-Mejías et al., 2017). The literature review demonstrates that ANNs can decrease the computational time when the building design is complex due to high number of variables.

Based on an extensive literature review of Uribe et al. (2017), the most important variables that impact the thermal and lighting performance of office buildings are U-value of the building envelope components, the position of the insulation, window-to-wall ratio (WWR), size and form of the office space; type of windows and type of the CFSs. Therefore, the main objective of this paper is to evaluate preliminarily the ability of an ANN to be integrated to the optimization process of an office space with north-oriented glazed façade with a large number of design parameters in three cities of Chile with very different climates. The office space counts with exterior and fixed CFSs and dimmed luminaries.

2. Methodology

2.1. Overview

An ANN was developed in Python and used to optimize an office space with exterior CFS and dimmed luminaries in different climates of Chile. The office performance metrics considered in the objective function of the optimization process are the total energy consumption (sum of lighting, heating and cooling energy consumption) and two visual comfort metrics: spatial daylight autonomy (sDA) and annual sunlight exposure (ASE) (IES, 2013).

A total of 5,400 lighting simulations and 12,800 energy simulations were performed to train the ANN. These simulations were carried out using mkSchedule, an integrated energy and lighting simulation tool presented in Vera et al. (2016). This tool integrates SketchUp to create the office and CFSs models, Groundhog which is a plug-in for SketchUp to export the geometry in Radiance readable format, Radiance for lighting simulations, EnergyPlus for energy simulations, and GenOpt to perform the optimization.
2.2. Building Model

The space to be studied corresponds to an office with north oriented glazed-façade of 4.0 m x 6.5 m x 2.8 m, as shown in Figure 2. The walls, ceiling and floor are considered adiabatic. Only the glazed façade is exposed to the outside. The surface reflectance of the floor, ceiling, and walls are 20%, 70% and 50%, respectively. The HVAC system consists of an electric heat pump with COP 3.0 with heating and cooling thermostat set points of 20°C and 24°C, respectively. The internal heat gains of people and electric equipment are 6.7 W/m² and 15 W/m²(CIBSE, 2006), respectively. The office space includes two sets of dimmed luminaires, which are controlled to achieve 500 lux at the workplane. The internal heat gain due to lights is 13.85 W/m². The schedules for people, lights, equipment and HVAC are set from 08:00 to 18:00 hrs.

Figure 2: Office space model with louvers: (a) Isometric view, (b) Side view, (c) Plan view. Source: (Vera et al., 2017)

2.3. Design Variables

Table 2 shows the variables studied and their values, ranges and steps. Three Chilean cities with very different climates are studied: Antofagasta (S 23.43°, W 70.45°), Santiago (S 33.38°, W 70.78°) and Punta Arenas (S 53.00°, W 70.97°). According to the Köppen-Geiger classification, Antofagasta shows a desert climate with low-latitude (BWn); Santiago corresponds to a semi-arid climate (Bsk); and Punta Arenas presents a subpolar oceanic climate (Cfc). Three different windows are evaluated:

- Single clear glazing with U-value of 5.82 W/m²K and SHGC of 0.9.
- Double clear glazing (DCG) with U-value of 2.7 W/m²K and SHGC of 0.7.
• Low-e DCG with U-value of 1.68 W/m²K and SHGC of 0.43.

Four exterior CFSs were evaluated: venetian blinds with slat angles of 0° and 45°, generic woven shade and perforated screen panels. The combination of windows and CFSs gives 12 cases and windows without CFSs were evaluated, which give 15 cases of whole-fenestrations.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Step</th>
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<tr>
<td>City</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Window</td>
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<tr>
<td>CFS</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>SHGC of the whole-fenestration</td>
<td>0.07</td>
<td>0.90</td>
<td></td>
<td>15</td>
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<tr>
<td>WWR (%)</td>
<td>30</td>
<td>100</td>
<td>5</td>
<td>15</td>
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<tr>
<td>R-value of the walls (m²K/W)</td>
<td>0.1</td>
<td>1.5</td>
<td>0.1</td>
<td>16</td>
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<tr>
<td>Location of the wall insulation</td>
<td>Inside</td>
<td>Outside</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

### 2.4. Thermal and Lighting Simulation

The lighting and energy simulations were performed in *mkSchedule*, a time-efficient tool that was recently developed by Vera *et al.* (2016). This tool performs integrated thermal and lighting simulations for fixed and movable CFSs using the three-phase method developed by McNeil and Lee (2013). *mkSchedule* uses Radiance for the lighting domain and EnergyPlus for the thermal domain. Using a simple case study, Vera *et al.* (2016) demonstrated that *mkSchedule* efficiently integrates Groundhog, Radiance and EnergyPlus, producing results within a short period of time and allowing flexibility to incorporate different design alternatives. Vera *et al.* (2017) also used this approach for optimizing exterior venetian blinds using a hybrid algorithm of particle swarm optimization and Hooke-Jeeves (PSO-HJ); whereas, Bustamante *et al.* (2017) showed that this tool can be used to take decision about control algorithms of CFSs at early-stages of building design.

Using *mkSchedule* tool, an hourly annual schedule with the CFS position and the power fraction of the luminaires is generated for each city for each combination of parameters shown in Table 1. This schedule is used as an input to the lighting and energy simulations performed with Radiance and EnergyPlus, respectively.

The performance of the building was evaluated in terms of the following parameters:

• Total energy consumption (kWh/year), which represents the sum of lighting, heating and cooling energy consumption.
• sDA<sub>300/50%</sub> is defined as the percentage of an analysis area that meets 300 lux for 50% of the operating hours per year. An sDA<sub>300/50%</sub> above 50% has been considered as the acceptable daylight level according to Illuminating Engineering Society (IES, 2013).
• ASE<sub>2000/400h</sub> is defined as the percentage of an analysis area that exceeds 2000 lux more than 400 hours per year. An ASE<sub>2000/400h</sub> lower than 20% has been considered acceptable to reduce visual discomfort according to Illuminating Engineering Society (IES, 2013).

Both, sDA and ASE represent a complete evaluation for visual comfort in office buildings. sDA is related with the daylight availability in the space, and ASE aims to limit the direct sunlight exposure by occupants (IES, 2013).
2.5. Artificial Neural Networks (ANNs)

ANNs are information processing systems. They learn the relationship between the input and output variables by studying previously recorded data. An ANN resembles the biological neural system, composed by layers of parallel elements unit, called neurons. The neurons are connected by a large number of weighted links, over which signals or information can pass. Basically, a neuron receives inputs over its incoming connections, combines the inputs, performs generally a non-linear operation, and provides the final results (outputs) without performing complete and detailed simulations.

In this study, an ANN was developed in Python and then used to estimate the energy and daylight performance of the office space. A total of 5,400 lighting simulations and 12,800 energy simulations were performed using the methodology explained in the section 2.4. Figure 2 shows a diagram of the basic architecture of an ANN. It has three layers, the input, hidden and output layers. Each layer is interconnected together by the connection strengths.

![Diagram of Basic Architecture of an ANN](image)

Figure 3: Topology of the multi-layer artificial neural network.

2.6. Optimization

The optimization was carried out in GenOpt using a hybrid algorithm between particle swarm optimization and Hooke-Jeeves (PSO-HJ). The algorithm begins by performing PSO on a coarse mesh for 10 generations. The course mesh is used to increase the speed of the simulation process; thus, the process does not ensure that a global minimum is reached. To refine the search, the HJ algorithm is used to find the particle with the lowest cost function value within the searching region. Thus, the hybrid algorithm combines the
global features of the PSO algorithm with the probable convergence properties of the HJ algorithm (Wetter, 2011).

The objective function is presented in Eq. (1). As shown in Vera et al. (2017), it includes metrics related to the building energy performance as well as metrics related to visual comfort. $sDA_M$ and $ASE_M$ are the penalty functions defined by Eqs. (2) and (3), to considerer the visual comfort criteria as a restriction.

$$OF = E_T \cdot sDA_M \cdot ASE_M$$  \hspace{1cm} (1)

$$sDA_M = \begin{cases} 
1 & \text{if } sDA_{30050\%} > 0.5 \\
(1.5 - sDA_{30050\%})^4 & \text{otherwise}
\end{cases}$$  \hspace{1cm} (2)

$$ASE_M = \begin{cases} 
1 & \text{if } ASE_{2000-4000} < 0.2 \\
(ASE_{2000-4000} + 0.8)^4 & \text{otherwise}
\end{cases}$$  \hspace{1cm} (3)

Figure 3 shows the optimization workflow. GenOpt use the ANN previously trained to estimate the energy performance and visual comfort metrics. With this information, GenOpt run the optimization process.

Figure 4: Optimization workflow (The subscript $i$ represent each possible combination of the simulations to train the ANN).

3. Results and Discussion

This section displays results of the optimization process using the ANN developed. The results are in terms of visual comfort metrics and total energy consumption for each city evaluated. Table 2 shows the optimization results for each city.

<table>
<thead>
<tr>
<th>City</th>
<th>Variable</th>
<th>Optimum</th>
<th>Energy consumption (kWh/year)</th>
<th>Visual comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

Table 2: Optimization results.
Results of the optimization process using an ANN evidences results that are reasonable for the conditions of the cases. In the three cities studied, the WWR values are over 90% because they increase the daylighting availability, which turns in reducing the lighting energy consumption. The latest seems to be the most influential energy consumption due to the high internal gain of the luminaires. In Antofagasta, the optimum window is single clear glazing that has the poorest thermal insulation because in this climate heating is not needed. Otherwise, CDG is the optimum for Punta Arenas that shows a heating dominated climate. It should be notice that solutions close to the optimum have Low-e CDG in this city but this type of window causes higher lighting energy consumption that is not compensated in the same magnitude by lower heating energy consumption. In Santiago, the optimum window is also CDG despite heating is very low; however, this window has a SHGC of 0.7 that contributes to reduce the solar heat gains in combination with the CFS, which causes lower cooling energy consumption.

About the CFS, the optimum solutions are venetian blinds at 45° and generic woven shade because they allow providing visual comfort. The cases with perforated screen panels show too low daylight transmission through the fenestration system thus they not accomplish sDA criterion, while cases without CFS and cases with venetian blinds at 0° show too high daylighting transmission thus ASE was over 20%.

Finally, the optimum solutions show that the thermal insulation of the walls and its location are not relevant because of the high WWR. However, in Punta Arenas, a heating dominated climate, it would be expected to have optimum solutions with lower WWR because of the much higher R-value of the wall. However, the need of daylight transmission to reduce lighting energy consumption might cause optimum solution with higher WWR.

These study evidences that the use of ANNs allow obtaining optimum solutions for office buildings based on energy and visual comfort metrics. Although it is not shown in this paper, the optimum solutions via ANNs are very close to the optimum solution for the whole simulations.
5. Conclusions

An ANN was developed in Python and used to optimize an office space with exterior CFS and dimmed luminaries in three different climates of Chile (BWN, Bsk and Cfc). The office performance metrics considered in the objective function to be optimized are total energy consumption (sum of lighting, heating and cooling energy consumption) and two visual comfort criteria, spatial daylight autonomy (sDA) and annual sunlight exposure (ASE).

Preliminarily, this paper demonstrates the capability of ANNs to be incorporated in the optimization process of office spaces based on energy consumption and visual comfort criteria. ANNs have the ability to take into account variables of the complex fenestration systems, envelope characteristics and climates.

The results and conclusions presented in this paper are specific for the CFSs and location studied. Further studies are recommended in order to evaluate other shading systems, locations and optimization algorithms. Future work must consider the validation of ANN and evaluate the time efficiency of ANN versus regular optimization process using simulations.

Acknowledgements

This work was funded by the National Commission for Scientific and Technological Research (CONICYT) under research grant FONDECYT 1141240. The authors also gratefully acknowledge the research support provided by CEDEUS under the research grant CONICYT/FONDAP 15110020.

References


IES (2013) *Approved Method: Illuminating Engineering Society (IES) Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)*.


House Retrofits and Comfort Measures to Reduce Heat Stress and Carbon in a Warmer Future

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Abstract: Australia has one of the highest carbon emissions per person for buildings in the world. Record-breaking summer temperatures were experienced in 2017. So there is an urgent need for designers to reduce carbon emissions and temperatures to ensure the health and comfort of occupants in existing buildings. This paper reports on research on climate change modelling, thermal simulations of retrofits for the main three representative Australian house types as well as for a ‘cool retreat’, and an alternative comfort approach. The results indicate that the most cost-effective single carbon reducing retrofits are partial house air conditioning, ceiling insulation, external wall cavity insulation, and an optimal level of sealing the house. Then they depend on the type of house e.g. insulation under timber-floored houses and an internal brick wall for concrete-floored houses. The most cost-optimal carbon savings of combinations of retrofits across all house types were those with do-it-yourself (DIY) simple payback periods of between 5 and 8 years. Measures to reduce heat stress and cooling energy include bulk ceiling and roof insulation with added roof foil, external wall cavity insulation, a parasol roof and ceiling fans as well as occupants adopting a Standard Effective Temperature (SET*) comfort approach.

Keywords: House retrofits; carbon emissions; cool retreats; standard effective temperature (SET*)

1. Introduction

Australia has double the OECD average of carbon emissions per person (Garnaut, 2008) and one of the world’s highest carbon emissions for buildings per person (WRI, 2005). Since brick houses can endure for around 100 years in Australia (Snow and Prasad, 2011), there is an urgent need to retrofit buildings to reduce their carbon emissions, which comprise 25% of all Australian emissions (ASBEC, 2016).

Australia has also experienced record-breaking summer temperatures in 2017, with Sydney recording one night of 30°C after midnight (Blumer and Mayers, 2017). Residential air conditioning ownership is now almost universal, from a low base of 40% in 1994, around the time of the introduction of Australia’s Nationwide House Energy Ratings Scheme (NatHERS) (DEWHA, 2008; Ryan and Pavia, 2016).
Meanwhile, the little research that has been carried out into residential retrofits usually follows star rating protocols to reduce overall conditioned energy, and has not considered affordable do-it-yourself (DIY) retrofits (Shiel, 2017) suited to the active renovation movement in Australia (HIA, 2016). It also rarely focuses on reducing temperatures, other than some notable exceptions (Palmer et al., 2013; Saman, NCCARF and UniSA, 2013; Roaf, 2016).

NatHERS uses the new Effective Temperature (ET*) comfort approach. Researchers cited in Shiel (2017) have proposed various alternative schemes but few have considered the Standard Effective Temperature (SET*) which may be able to save over 90% of conditioned energy (Shiel, Aynsley, et al., 2017). So, with global warming there may be an opportunity to rethink the comfort approach in the ratings scheme and move back to the future to provide occupants with more personal and building controls over their comfort.

More air conditioning use is not an option as it is a positive feedback mechanism to greater global warming and Australia has committed to keeping global temperatures below 2 Kelvin (K) (ASBEC, 2016).

The aim of this paper is to report on research into reducing carbon emissions and heat stress of occupants living in typical Australian houses from the results of a PhD programme (Shiel, 2017).

2. Method

Climate change was modelled for 2050 using CSIRO’s Australian Climate Futures online tool (CSIRO, 2015) with the latest Fifth Assessment Report (AR5) Global Climate Change (GCM) models. Belcher’s “morphing” technique (Belcher, Hacker and Powell, 2005) was used to down-scale, or regionalise, the projected climate parameter changes to the Adelaide area, for two scenarios:

- Extreme Climate Change - the current greenhouse gas emissions trajectory (IPCC-AR5-WGI, 2013, p. 104) and represented by RCP8.5 where RCP is the Representative Concentration Pathway (van Vuuren et al., 2011), and
- Scarce Resources - a future with lower economic growth and therefore carbon emissions due to resource depletion by the rapidly growing middle class (Rubin, 2012; Mohr et al., 2015; Kharas, 2017), and represented by RCP4.5.

We used the NatHERS-accredited AccuRate software package to conduct thermal simulations of retrofits for three existing houses, which were selected as they represented the Australian stock with similar wall and floor types and lot and house size characteristics over eras (DEWHA, 2008; Shiel, 2017):

- House 1 - a light-weight weatherboard house with timber-floor (1950s era);
- House 2 - a heavy-weight cavity brick house with timber-floor (1980s era); and
- House 3 - a medium-weight brick veneer house with a concrete floor (2010s era).

Houses since 1950 were chosen since some will reach their lifespan in 2050 (Snow and Prasad, 2011), and Adelaide was chosen for the simulation location as it is an example of a warm temperate climate where 50% of Australians live, and because it has a history of heatwaves. We used a reverse-cycle air conditioner to calculate carbon emissions, with a do-it-yourself (DIY) costing approach (Shiel, 2017).

Around 50 affordable DIY single retrofits were simulated across the three house types for their ability to lower temperature or conditioned energy, not just improve star ratings. This meant that some retrofit modelling (e.g. vegetation, aquariums) did not comply with the NatHERS protocols. Also, some retrofits were assumed to have zero cost if they were hobbies or already part of the house.
Carbon emission savings were calculated for combinations of retrofits for three payback periods to suit the budget of various household categories:

- small (less than 3 years) to suit tenants or those with low wealth or disposable income;
- medium (between 3 and 10 years) for owners with medium wealth or disposable income; and
- large (between 10 and 20 years) for householders who would like to carry out deep retrofits.

Combining retrofits involved selecting several of the most cost-effective retrofits for each component such as the floor. This created very effective thermal barriers per component e.g. under-floor foil batts, underfloor bubble insulation with double-sided reflective foil and carpet.

We developed an innovative approach to create ‘cool retreats’ (Saman, NCCARF and UniSA, 2013; Roaf, 2016) in existing houses. A database was designed (Shiel, Aynsley, et al., 2017) to manage the detailed NatHERS hourly results of temperature and conditioned energy, for retrofits and their combinations, for each room of the house. Reports from the database can show the effect of retrofit combinations on the temperature for the hottest day spatially for all rooms for one time (see Figure 4), or over 24 hours on a time basis across living and bed rooms (Shiel, Moghtaderi, et al., 2017).

3. Results

3.1. Climate Change

The HadGEM2-ES Global Climate Model (GCM) was selected as the most suitable GCM. So the 1990 to 2050 projected climate parameter changes for the Scarce Resource (RCP4.5) and Extreme Climate Change (RCP8.5) scenarios were found to be:

- a mean annual surface temperature increase of 1.2 K and 1.8 K respectively, and
- a relative humidity change of -1.1% and +0.9% respectively.

3.2. Retrofit Carbon Savings

The most cost-effective carbon emission-reducing single retrofits for all three house types are partial house air conditioning, ceiling insulation, external wall cavity insulation, and optimal sealing (Shiel, 2017), and then depend on the house type e.g. adding an internal brick wall to concrete-floor houses.

Figure 1 shows the carbon emissions saved for each retrofit against the DIY simple payback period (SPP) for the Scarce Resource scenario in 2050 for the 1950s timber-floored weatherboard House 1, and the floor plan is shown in Figure 4. The most cost-effective retrofits are those in the top left corner, and include roof and under-floor insulation and carpet.

Figure 2 shows the relationship between carbon emission savings for retrofit combinations for each of the three house types for Adelaide under the Scarce Resource scenario in 2050. The retrofits that make up the combination of retrofits with a large payback period for House 1 (with a label of $12.5k DIY cost in Figure 2) are listed in Figure 3. Details of the other retrofit combinations are provided by Shiel, Moghtaderi, et al. (2017).

Figure 2 allows estimation of the carbon savings for the payback period of combinations of retrofits for each type of house, to suit individual householders. The medium SPP level for all house types in Australia can be seen as cost-optimal e.g. the retrofit combination with the medium SPP of for House 1 saves around 2.6 t CO2 equivalent per annum (CO2-e/yr) for a DIY cost of $7,300 while for $12,500 around 2.8 t CO2-e/yr, or only 0.2t CO2-e/yr extra is saved for $12,500 (i.e. an additional $5,200 cost).
Figure 1: Carbon emissions saved per annum for each retrofit against the DIY SPP, with points labelled by SPP and a table with retrofit descriptions, ranked by SPP with arrows locating the points. This is for the 1950s weatherboard timber floor House 1 for the Scarce Resource scenario (RCP4.5) in 2050. The retrofits are colour coded for thermal mass (dark blue bolded), roof and ceiling insulation (light blue), sealing (bolded black), floors (brown), cavity walls (purple bolded), wall cladding (purple), vegetation (green), and other (black). (Source: based on Shiel, Moghtaderi, et al., (2017))

3.3. Retrofit Cooling Effects

Figure 3 shows the savings in heating and cooling energy for each retrofit that makes up the combination with the largest payback period (R501) for the 1950s weatherboard House 1, for the Scarce Resources scenario in 2050. The most effective cooling retrofits are:

- bulk ceiling insulation
- bulk and reflective foil insulation in the roof,
- foil batt insulation in the roof,
- external wall cavity insulation,
- parasol roof,
- ceiling fans, and
- insulation under the timber floor.
3.4. Room Temperatures

Figure 4 shows a temperature spatial analysis for House 1 in Adelaide when the hottest internal temperatures were occurring in 1990 for the base case, in 2050 for the Extreme Climate Change scenario with no retrofits (base case) and after the combination of retrofits with the large SPP (R501).

In the 1950s weatherboard House 1 in Figure 4 for the Extreme Climate Change scenario on the hottest day, internal temperatures range from 39 to 45.9 °C, after the retrofit combination (R501) with the large SPP (Figure 4 (d)), down from 47 to 48.3 °C if there were no retrofits (Figure 4 (b)).

4. Discussion

4.1. Single Retrofits

Important single retrofits for global warming include:

- additional thermal mass to stabilise temperatures in climates with large diurnal temperature variations without air-conditioning e.g. by adding a brick wall if there is a concrete floor, and
- an optimal level of sealing the house around 10 air changes per hour at 50 Pa (10ACH50) since higher levels of sealing have health concerns without having an Energy Recovery Ventilation (ERV) system (Aynsley and Shiel, 2017), which incurs additional costs.
Figure 3: Savings in heating and cooling energy of retrofits making up the large SPP combination (R501) for the 1950s weatherboard House 1 for the Scarce Resources scenario for Adelaide in 2050. The area-adjusted energy savings are ranked by the cooling energy saved. (source: Shiel)

4.2. Combinations of Retrofit

A significant finding is that the cost-optimum level of carbon savings occurs around the medium SPP level for all house types in Australia, as shown in the Result section. This is significant from government and environmental points of view, since the most cost-effective single retrofits can now be found that suit the main types of houses in Australia to make up these medium SPP combinations.

However, without government assistance, tenants may use the retrofit combinations with small SPP to negotiate long term (e.g. 3-year) leases with discounted or no-rent increase clauses, to have the savings in conditioned energy costs pay for those retrofits. This can still assist with the split incentives problem where landlords do not benefit from low carbon housing investments, although caution is needed to estimate actual payback periods because of the NatHERS assumptions, as explained below.

4.3. Cool Retreats

A ‘cool retreat’ can be established on the south side of a one-storey house or in a room on the ground floor of a two-storey house. If a living room is cooler than a bedroom (e.g. if it is on the south side of the
House Retrofits and Comfort Measures to Reduce Heat Stress and Carbon in a Warmer Future

house), swapping the function of these rooms could be considered. A room can be retrofitted using single retrofits that save the most cooling energy.

Figure 4: The plan of House 1 is in (c) at the bottom left, and schematics of its room temperatures (°C) are shown for Adelaide at 2pm on the 13th February when the hottest internal temperatures occur. These are (a) in 1990 for the base case (at the top left), and in 2050 for the Extreme Climate Change
scenario for (b) the base case (top right), and for (d) after the combination of retrofits with large SPP (501) (bottom right). The temperature legend is colour coded as indicated (source: Shiel).

In the 1950s weatherboard house (Figure 4), both Bedroom 1 and the Living Room with lower temperatures are both on the west side. Bedroom 3 has cooler temperatures than Bedroom 1, and so Bedroom 3 could become the main bedroom. The retrofits which could convert Bedroom 3 of House 1 into a cool retreat are shown in Figure 3, and described in the Results section.

4.4. NatHERS Assumptions, Comfort and Heat Stress

The AccuRate simulations for this study use the NatHERS assumptions, which may not be practical (Shiel, 2017), and so adjustments may be needed to the payback period and savings in carbon emissions. These assumptions include: (i) heavy occupancy level with someone home all day, (ii) the large number of conditioned rooms and (iii) the use of the new Effective Temperature (ET*) with a narrow temperature comfort band range to suit 90% of occupants, similar clothing levels to wearing suits, and which underestimates the cooling effect of air movement at high temperatures and humidity (Shiel, Aynsley, et al., 2017).

The Standard Effective Temperature index (SET*) is an alternative comfort approach which can use less conditioned energy for comfort by extending the temperature comfort band to the recommended 80% acceptability level for typical applications (ASHRAE-55, 2010, p. 24), and by taking into account the six parameters - air temperature (°C), mean radiant temperature (°C), air velocity (m/s), relative humidity (%), clothing insulation (CLO), and metabolic rate (met) (Shiel, Aynsley, et al., 2017) - and which takes skin wettedness into account.

Warmer temperatures (around 35 °C) than those indicated by the NatHERS can be tolerated without conditioning as shown by Wyndham et al. (1965) as cited in (Aynsley, 2007, p. 4), and by occupants using the SET* comfort approach as shown in Shiel, Aynsley, et al. (2017), thus saving energy and reducing carbon emissions. The latter research used light clothing and the greater cooling effect of air movement.

However, heat stress can occur for temperatures above 35°C, as heat exchange with the environment is greatly diminished, particularly for infants and the elderly, with a high risk of heat exhaustion, heat strokes or black outs (Parsons, 1993, p. 260; Hanna and Tait, 2015, p. 8050).

After reviewing 45 heat stress indices, Epstein and Moran (2006) found that the Wet Bulb Globe Temperature (WBGT) and the Discomfort Index (DI) have been in use over the last 40 years, with WBGT being the most popular. However, the six SET* parameters are also important in determining heat stress (Fanger, 1972) along with the skin wettedness aspect of the SET* thermal comfort index. However, only the Heat Stress Index (HSI) (Belding and Hatch, 1955; Parsons, 1993, p. 268) and its derivatives include skin wettedness.

So a greater level of retrofits than the combination with the largest payback period for House 1 will be needed to reduce the risk of heat stress for this scenario in 2050, even if the SET* comfort approach were adopted by occupants. However, more research into thermal comfort and heat stress field studies should be conducted to verify these SET* estimates.

4.5. Benefits to Governments

These house retrofits and comfort measures can assist with lowering carbon emissions and internal house temperatures. This can help Australian and local governments to meet their greenhouse targets, the
States to manage their network peak energy loads, as well as assist those vulnerable to heat stress. So there may be a role for government to create more retrofit and comfort education programs.

5. Conclusion

Cost-effective carbon-reducing single retrofits for all house types are partial house air conditioning, ceiling insulation, external wall cavity insulation, and optimal sealing. They then depend on the type of house e.g. insulation under timber-floored houses and internal brick walls for concrete-floored houses.

A significant finding was that specific single retrofit combinations with simple payback periods (SPPs) of 5 to 8 years were cost-optimal in saving carbon for each house type, costing less than AUD$7,500 DIY.

A method was developed to design retrofits for ‘cool retreat’ by swapping a room with one that has lower temperatures in summer e.g. those on the south side or in a basement of the house. Then retrofits can be applied to specifically cool that room e.g. using retrofits for the 1950s weatherboard house such as bulk ceiling and roof insulation, with added roof foil, external wall cavity insulation, a parasol roof and ceiling fans.

The Standard Effective Temperature index (SET*) comfort approach can be used so that occupants may tolerate warmer temperatures, although more research with field studies is needed.

This paper shows that conducting optimal performance retrofits, including establishment of cool retreats, and modifying the occupant comfort approach can help to lower the carbon impact of existing houses. This can also help to lower the risks of heat stress from high internal building temperatures as the climate warms, allowing us to get back to the future with more personal and building comfort controls in a warmer future.

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The authors would like to thank Professor Susan Roaf for discussions on cool retreats and room temperature mappings, Dr Dong Chen for assistance with AccuRate simulation, John Clarke for climate change modelling assistance, Dr Nico Marcar for his review, and the conference panel reviewers for their astute advice.

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A Virtual Reality Experiment to Investigate Optimum High-Density Apartment Parameters

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Abstract: The current study uses Virtual Reality (VR) to experimentally investigate how room shape and volume affect perception of space and perceived size to identify optimal design for densified urban apartments. Optimal parameters are defined as (1) room shape that produces the largest increase in perceived space with the smallest increase of objective space (2) rooms that produce high perceived spaciousness and livability ratings. Participants experienced a series of virtual rooms of different shapes and volumes, and were asked to scale a cubed reference room to match the size of the target room. While room shape determined the accuracy of the spatial perception it is suggested that the optimum parameters of ceiling height and room width affect perceived spaciousness and liveability. Defining optimum parameters of room height, width and shape are foundational to providing strategies in apartment design to produce optimum perceived spaciousness and liveability. This research aims to firstly, develop a new method for studying optimal architectural design parameters, and secondly study the relationship between perceived space, shape and volume to form optimum parameters. Future research can then build on these parameters and introduce more complex parameters to produce defensible architectural strategies for optimizing high-density design.

Keywords: Occupant wellbeing, virtual reality, perception of space, densification.

1. Introduction

1.1. Densification

Densification is an inevitable consequence of growing city populations. Projections estimate that by 2050 75% of the world’s population will be living in cities compared to 50% in 2007, and 10% in 1900 (Nations, 2014). Currently 24% of urban density around the world is between 10,000 – 100,000 people per square kilometre. In 1939 while urbanisation was increasing in Berlin the population density decreased from 29,000 to 5,600 people per square kilometre. The population increased by three million people and 800 square kilometres as the city expanded (Bosselmann, 2012). However, once cities reach a certain size a rate of expansion is no longer sustainable or possible resulting in an increased rate of population density. The 50% urbanisation increase from the 1900’s to the present has resulted in the top 26 largest urban
areas in the world having a population density which is increasing more rapidly than expansion (Cox, 2015). The reduced size of living environments is a consequence of increased population density. Densified living environments can result in discomfort and dissatisfaction, especially in high density housing (Wong et al., 2009). Densification can cause issues in living situations affecting occupant wellbeing which needs to be addressed. Simply creating larger high density spaces is not a viable solution as the available space decreases as population density increases. “It is simply impossible to increase the amount of space available to individuals incarcerated in cities” (Worchel, 1978, p. 28). By taking a scientific approach we can establish the optimum measures to improve spatial responses in high density design. A defensible set of optimal design parameters which challenges the issue of densification are required. These parameters are a crucial development to providing high density architecture which optimise liveability, spaciousness and perceived size.

1.2. Overcrowded Stress

By creating smaller living size conditions there is a potential to affect the overall wellbeing and comfort of the occupants (Kopec, 2006). This can lead to living dissatisfaction and discomfort and in serious cases depression and violence (Solari and Mare, 2012). The most common effect of densification is overcrowded stress. Overcrowding has three main manifestations stimulus overload, behavioural constraint, and ecological orientations, each of which have either a social or physical evoker (Stokols et al., 1973). Densification in an apartment context largely contributes to overcrowded stress with stimulus overload from physical stressors, which the built environment effects. Evans et al. (2003), while discussing the factors of overcrowded stress suggests that reducing it is essential for high density housing which can more positively affect occupant wellbeing. An approach which can increase the subjective or psychological space with minimal objective increase will help to minimise the effects of densification. An increase in psychological space has the potential to reduce the negative psychological effects of overcrowding stress. During an investigation of crowding and density Stokols (1976) suggests that “perceived crowding might be reduced through cognitive or perceptual strategies designed to expand psychological space” (p.69).

This indicates that a designed space could alter an individual’s perception of space and density resulting in an increase of wellbeing and comfort. Baldassare (1979) found that subjective ratings of perceived crowding correlated strongly to the prediction of living discomfort. People were able to determine the environmental quality of a space through perceived density. This suggests that architecturally designed rooms can improve the wellbeing and comfort of occupants in densified environments by altering the perception of space, as supported by Cohen et al. (2013). He discuss the effects of ‘crowding’ to be a largely subjective response to densification. Booth and Cowell (1976) also tested objective and subjective crowding relationships through survey responses. Thirty-three relationships between density and stress were measured. Twenty-one were of subjective measures of crowding, whereas twelve were of objective measures. If perceived density is largely influenced by subjective measures it would suggest that perceived density can be changed with minimal change to the objective measures.

1.3. Perception of Space

People perceive the world around them uniquely on an individual level, but there are fundamental laws that define how people experience the physical environment (Evans and McCoy, 1998). This leads to question how the laws of perceived space can be tested to understand perceived size and subsequently alter perceived space. Hayward and Franklin (1974) discuss the relationship between the built environment to perceived openness or enclosure. They conclude that a lower height of back wall (H)
divided by the distance to wall (D) has an increased openness. “Impression of openness-enclosure of architectural space is determined by size-distance relations regardless of actual scale of space. As the value of the H/D ratio increased, perceived enclosure also increased” (p. 39). The experiment conducted in this research was highly abstracted in practice and does not serve as an adequate equation to challenge densification. Rather this research acts as an insight into the foundational information into perception of space. Additionally as precedent, forming studies involving perception of space. Sadalla and Oxley (1984) also explored this concept with a series of experiments. From these Sadalla and Oxley concluded that ratios of a rectangular room greatly influence the perceived size. The understanding of perception within a rectangular form concluded that a greater ratio of length/width implied a larger perceived space. In both of these experiments the fundamentals of perception of space were tested in regular cubic and rectangular form. However, this leaves a gap in understanding around perception of space in irregular form. Typical apartment design is not of regular form so to improve our understanding of perceived density an exploration of perceived space including irregular form is necessary.

1.4. Conservation of Space

In the current study, subjects were asked to scale a cube to match the volume of another shape; a conservation of space task. Conservation refers to the ability to determine that a certain quantity will remain the same despite adjustment of the apparent size or shape (Siegler et al., 2003). Piaget (1976) tested children’s perceptions of space by testing the concept of conservation by tipping the same amount of liquid into two vessels of the same volume yet different shapes. The exercise illustrated that children would rate the tallest of the vessels to be larger when asked which container had the most liquid. “Children’s perceptions in this stage of development are generally restricted to one aspect or dimension of an object at the expense of the other aspects” (Ojose, 2008, p. 27). This ability develops around late childhood (Piaget, 1976). The proposed experiment will test the ability to apply conservation of space in more complex scenarios to investigate which aspects or dimensions of rooms produce larger perceived spaces. The method of experimentation with VR allows an in depth evaluation of architectural understanding, architectural qualities, and observation of user experience and perception of space. The medium of VR grants a controlled environment to conduct research enhancing perceptual understanding of 3D volumes (Schnabel and Kvan, 2003). The ability to experience the rooms in a first person perspective means a measure of perception of space can be observed and recorded. This would not be possible with another medium with the same level of immersion and reliability. The results of the experiment will suggest how apartments could be designed to feel more spacious and reduce the perceived density of the space. We hypothesise that room shape will have a relationship towards the perceived size of a space, resulting in a positive or negative association (perceived larger or smaller) at a constant volume. This would result in a room shape having a larger psychological space increase than the objective space increase while increasing perceived livability and spaciousness. We also predict that it will be harder for the participant to match volumes as room size increases.

2. Method

2.1. Participants

For the VR experiment 30 subjects participated in the study with a demographic ranging from 20 to 50 years of age with an average of 26.7 years old. The sample of 33.3% females over represents males. The sample size is derived from the application ‘Piface’ power and sample size calculator to achieve 80%
power, or 95% confidence Intervals with an accuracy of 5 or 10%. Subjects were selected if they had not had education in the field of design. Conservation of space is a developed ability which can only improve with education (Judd, 1940). This informed the decision to exclude any participants with architectural education who may have a trained eye or advantage in the experiment.

2.2. Materials

2.2.1. Equipment and Software

The VR equipment used was a HTC Vive, 2160 x 1200, 90Hz refresh rate, with a 110 degrees field of view, and a tracking area of 15x15 feet. Alienware Aurora R5 Processor connected the VR equipment and programs with an Intel(R) Core(TM) i7-6700, CPU @ 3.40GHz, 3401 Mhz, 4 Core(s) 8 Logical Processor(s), RAM 16.0 GB, CPU Intel Core i7 (6th Gen) 6700 / 3.4 GHz Type Core i7, and NVIDIA GeForce GTX 1070. Excel 2013 and IBM SPSS Statistics 24 were used during the data analysis and to produce graphs. Steam VR and Unity 5.5.1 were used to run the experiment.

![Figure 5: VR set up and equipment](image)

![Figure 2: In-experiment VR view](image)

2.2.2. Rooms and Set up

Perceived illuminations affect perception of space so well defined edges are needed to accurately perceive a room (Gilchrist, 1979). A grey scale allowed the wall definitions to stand out more than the white, allowing for a clear understanding of the shape. Without a clear definition of the rooms boundaries the participants would struggle to interpret the space. Lighting and colour also has an effect on perception of space (Manav and Yener, 1999). A single lighting system with constant light and colour was chosen to create a consistent light dispersal over each Room. Room sequence was randomised across all participants to remove any learning trends. Words were programmed to appear at the top of the controller which stated which Room they were in with minimal visual interference. This was to reduce any confusion the participant may experience which could affect the results of the study by putting them off task. Participants were also asked an exit question of whether they had experienced any motion sickness of which zero were reported.
Perception of space is a subjective response which requires a within subject study process to effectively remove subject to subject variation (Seltman, 2012). The dependent variables are the shaped rooms. The rooms were selected for basic shapes which allow a wide range of investigation and of which can be associated with the most typical apartment proportions and shapes. The independent variables are the sizes of a Scalable Room which the subjects manipulate. The scalable Room will be referred to as the Scale Room. The Scale room is a 50m$^3$ cubed room which is scaled at the end of each Room sequence to match the Room’s volume. The Rooms had a baseline of 50 m$^3$, same as the Scale Room before manipulation. However, for each participant the Rooms randomize in size within a range of $\pm$50% (25-75m$^3$). This removes a size effect bias which could affect the data output. After the matching is complete the Scale Room reverts back to 50m$^3$ to allow for a consistent starting point for each participant. The in experiment questions were chosen with the anchor points of enclosed – neutral – open, and strong no – neutral _ strong yes, to understand the perceived spatial qualities of the rooms (table 1).

Table 1: Experiment questions

<table>
<thead>
<tr>
<th>Pre-experiment questions:</th>
<th>Post Room scaling questions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) What is an estimate of the size of your current living room in cubic meters?</td>
<td>1) On a scale to 1 (Strong No) – 5 (Neutral) - 10 (Strong Yes) rate if you would like to use Room #/ Scale room as a living room.</td>
</tr>
<tr>
<td>2) How many people use the living room typically?</td>
<td>2) On a scale to 1 (Closed) – 5 (Neutral) - 10 (Open) rate the spaciousness of Room #/ Scale room?</td>
</tr>
<tr>
<td>3) How would you rate the spaciousness of your current living room? 1 (Enclosed) - 5 (Neutral) - 10 (Open)</td>
<td></td>
</tr>
<tr>
<td>4) How would you rate the comfort of your current living room? 1 (Uncomfortable) - 5 (Neutral) - 10 (Comfortable)</td>
<td></td>
</tr>
<tr>
<td>5) How many hours a week do you play video games?</td>
<td></td>
</tr>
<tr>
<td>6) Have you used VR before?</td>
<td></td>
</tr>
</tbody>
</table>

2.3. Procedure

Participants were individually brought into the VR laboratory and asked to fill in pre experiment questions, see table 1, and subject information. Once the experiment process was explained the subjects were introduced to the Scale Room. The experiment started with a ‘size test’ for each participant to determine the individual’s ability to match volumes. Three cubed rooms, no shape change, with a randomly selected order were set for the size test with sizes of 30m$^3$,40m$^3$, and 60m$^3$. The participant had 30 seconds to explore a Room before going back to the Scale Room to best match the Room’s volume size. The participants were given a 10 second warning before the end of the time limit. When the participant was confident (or as close as) that the volumes are matched they were given another the 30 seconds in the Room after which they were allowed to make any alterations. This process illustrated the individual's and the group's ability to match same shape volumes with reasonable accuracy.

For the next part of the study the subjects followed the same process with a series of different shaped rooms (Figure 3). The subjects had 30 seconds in the Room before returning to the Scale Room to match the volume. Once complete the participants were asked to verbally complete questions describing their perception of both the Scale Rooms and Shaped Room in terms of perceived liveability and spaciousness.
Once the questions were completed the participant repeated the process with the subsequent Room’s, as seen in Figure 3.

![Figure 3: Virtual room shapes](image)

**2.4. Analysis Strategy**

The size (m$^3$) of both the Rooms and the Scale room (after scaling) was recorded after each sequence. This data showed the perceived size accuracy of a room which illustrated a larger or small perceived space. For example a participant scaled the Scale Room to 50m$^3$ where the Room experienced was 40m$^3$. This illustrates that the participant perceived the Room to be +25% or 10m$^3$ larger than its objective size. A positive percentage or size indicates that the volume was perceived larger than the objective size. Likewise a negative result indicates a smaller perceived size. At the end of each Room sequence the subjects were asked to rate the livability and spaciousness of both the Room and the Scale room. Questions on livability and spaciousness were asked to firstly, establish how spaciousness and liveability are effected by room shape and volume. Secondly, to establish whether they had a relationship to the accuracy in perceived size of a room, of which none was established. The data produced were numbers ranging from 1-10 with specific anchor points, see table 1.

**3. Results**

The experiment variables are the dependent variable of Room shape and volume, and the independent variable of the Scale Room volume after manipulation by the subject.

**3.1. Perception of Space**

There is a clear relationship between perceived size accuracy and volume shape (Figure 4). Participants almost always overestimate the size of the room, though the effect was stronger in some rooms. Room D has the largest perceived space and Room A the smallest perceived space with the same objective size (figure 4 and 5). As expected the size tests (Rooms 1-3) show minimal perceived size variance as room shape was constant. The randomization of the rooms had equal distributions around 50m3 (figure 5). There is a slight decrease in average Room size in Room B however there is an insignificant difference.

Average room width follows a moderate correlation of $r = 0.545$ (Figure 6). This suggests a relationship between the two variables but suggests the possibility of other contributing factors. There is also a weak correlation between ceiling height and perceived size accuracy where $r=0.283$. This suggests that multiple contributing factors influence the perceived size accuracy of a room.

As room size increases volume matching accuracy decreases (figure 8). Perceived Liveability and spaciousness is strongly correlated to perceived liveability, $r = 0.872$ (Figure 9).
A Virtual Reality Experiment to Investigate Optimum High-Density Apartment Parameters

Figure 4: Accuracy of perceived space over each Room. A larger perceived space is an overestimation of the room size.

Figure 5: Average room sizes during the experiment, showing no systematic bias.

Figure 6: Moderate positive correlation between average room width and perceive spaciousness, $r = 0.545$.

Figure 7: Weak positive correlation between ceiling height and perceived size accuracy, $r = 0.283$.

Figure 8: As room size increases the accuracy of volume matching decreases.

Figure 9: Positive correlation between perceived spaciousness and liveability $r = 0.872$. 
As room size increases the optimum room shape changes. This suggests that multiple parameters determine an optimum room at a given size. This differs from our original hypothesis that perceived liveability and spaciousness would have a positive relationship to perceived size. Room G is the ideal room in terms of perceived spaciousness and livability at small volumes (20-40m³) and Room B at the large volume (60-80m³). However, around 50 cubic meters (40-60m³) both perceived spaciousness and liveability ratings cluster with similar results. In all room shape examples perceived spaciousness has a positive relationship to room size. However, room shape determined the rate of increase suggesting that optimum solutions can be achieved through optimising room shape and size.

Figure 10: As room size increases perceived liveability also increases at varied rates of room shape.

Figure 11: As room size increases perceived spaciousness also increases at varied rates of room shape.

Figure 12: The rate of subjective size increase over objective size typically decreases as size increases.

4. Discussion

This study used VR to measure the effect of room shape and volume on perceived space. Overall, room spaciousness was correlated with average width, suggesting that people base judgements of spaciousness on room width. These results support research by Hayward and Franklin (1974), who found that room depth and perceived openness had a positive correlation. However, perceived room size was only weakly correlated with ceiling height, suggesting that other parameters could be contributing also. The correlation, though weak, is supportive of research by Piaget (1976), who found that conservation of space was generally restricted to one dimension of an object which was typically height. Alternatively, the increased ceiling height simply increases the difficulty to accurately perceive a room’s size. This interpretation is supported by Figure 8 showing that as room size increases perceived room size accuracy decreases. Research by Sadalla and Oxley (1984), contrary to the results suggesting ceiling height influences perceived size, state that a greater length over width ratio forms a larger perceived space. Room D, which was the largest perceived space, had the smallest length/width ratio. The method used could influence the results produced by Sadalla and Oxley (1984) through a purely two dimensional investigation using perspective lines to gage perceived size. This possibly influenced the results leading to room height as an insignificant contributing factor. Their process differs from a VR experiment in that the perceived space is three dimensional and participants have the opportunity to look up and around.
A negative relationship between perceived size accuracy and actual room size suggests that psychological space is more impactful at smaller volumes. However, as room size increases accuracy decreases (figure 8). This would indicate that as the room increases in size the data associated in perceived size becomes less reliable. Therefore any trends taken from Figure 12 would need to be confirmed by further research. Though Room D met requirement (1) the room did not meet requirement (2) suggesting that an optimum room needs to utilise multiple parameters to meet both requirements. Due to multiple parameters contributing towards forming an ideal room further research is needed to investigate the optimum relationships between them. It is suggested that there are thresholds in parameters which cause significant change in perceived space. It is essential to establish parameter thresholds which vary responses of perceived livability, spacious and size as larger rates. This has been suggested in Room D which, compared to the other rooms, had a comparatively lower average room width resulting in a significantly reduced perceived spaciousness and liveability. Likewise, in Room D with comparatively larger ceiling height produced a significantly larger perceived size. Establishing the crucial thresholds and understanding how they relate is fundamental to developing accurate and useful optimum design parameters. Currently the research illustrates that the height and width of a room influence perceived liveability, spacious and size. With this knowledge the perceived space in high density architecture can be optimised. However, due to the abstract nature of the virtual rooms further studies are needed to determine any additional parameters in more complex environments.

5. Conclusion

Overall, the method achieved the desired output of basic optimum design parameters. The data suggests that ceiling height is a contributing parameter to perceived room size accuracy and that average room width contributes to perceived spaciousness ratings. However, perceived size and perceived spaciousness are attributed to different parameters and did not directly correlate. Further research is required to establish the parameter relationships to form optimum room requirements (1) and (2). This research acts as a foundation for future research which will expand and refine parameters and their relationships to produce optimum design strategies. A subsequent experiment would investigate what proportions of a room shape produces the optimum perceived room increase and optimum perceived spaciousness and livability. High density design can be optimized with this method to find the optimum efficiency of a volume. This research produces foundational parameters of height and width to form architectural strategies which could optimize spatial design. Further research would refine the parameters and method to form a full optimization of high density architecture.

References

Building Performance Modelling

Parametric Study of Energy Optimization for Office Retrofit in the Tropics

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Abstract: Buildings are accounted for approximately 40% of global energy consumption and one-third of global greenhouse gas (GHG) emissions. A significant proportion of energy utilization is due to the spread of heating, ventilating, and air conditioning (HVAC) installations in response to the growing demands for better thermal comfort of the built environment. While the proportion of energy consumption of buildings is an issue, architects have not seriously considered to innovate new solutions to tackle the problem particularly existing office building which is centrally airconditioned and consumed substantial amount of energy. Only few has been research to improve its performance to save energy that can be used as bench mark for post occupancy evaluation for existing buildings. To elucidate this issue, this paper is a result of a case study using building performance simulation tool to optimized energy for an actual office retrofit project in the tropics. Its objectives are to explore an energy optimization strategy using building performance simulation tool (IESVE) and to improve existing office building envelop for utmost energy efficiency. The result revealed that using parametric methodology through building performance simulation tool, an office building has the potential to achieve 26.8 % energy savings.

Keywords: Building Performance Modelling; building envelop; energy efficiency; office building retrofit.

1. Introduction and Background

Increasing concerns about global warming present the building industry with a challenge to cut its energy consumption (Chenvidyakarn, 2010). It was evident that the building sector consumes 40%-50% of the total delivered energy (EPA, 2004), (DTI, 2003). Building environment control systems like ventilation, cooling and heating can be fared as much as 70% of the total energy used (BRESCO, 2000). However, this energy consumption can be reduced significantly by utilizing passive design solutions instead of active mechanically designed buildings. For instance, a building engineered for tropics can only consume one third of the energy consumed by an air-conditioned building (BRESCO, 2000), (Chenvidyakarn, 2010) while providing comparable level of thermal performance. This is because building in the tropics must be designed to adapt climate and take better advantages (Chenvidyakarn, 2010) of natural energy resources
such as wind and thermal buoyancy to help provide acceptable thermal comfort specifically in the tropics where heat of interior environment of a building is a challenge.

The Tropics is regarded as a region where humans evolved and comfort has often been taken for granted, built environments are increasingly becoming issues of public concern (Ossen et al, 2008). The tropical indoor environment and thermal comfort has been regarded as important as outdoor in the life of the populace which is remarkably evident in the vernacular architecture of the region. However, today many cities in the region experienced rapid urban growth often without much reference to the evolving urban environment. This tendency has put increased demand on the comfort requirements in the design of buildings. Comfortable outdoor spaces have a significant bearing on the comfort perception of the indoor ambience (Ossen et al, 2008). The demand for comfort conditions in buildings are significantly increased as a result of exposure to uncomfortable indoors. Achieving thermal comfort for building engineered for tropics in hot humid climates is indeed a challenge (Chenvidyakarn, 2010), (Suebarto, 2006). Point out by experts, tropics is characterized by relatively high temperature and high humidity. These difficulties lead to many buildings relying for air-conditioning. However, range of passive design techniques such as design for minimizing cooling requirement and building massing (Wong, 2010), the use of shading device (Garde et al, 2001), (Laopanitchakul et al, 2007), material, color and texture (Leaurungreon et al, 2005), vegetation (Chen and Wong, 2006) cooling and ventilating techniques (Givoni, 1991), (Tantasavasdi et al, 2007), thermal mass (Hunt and Linden, 2004), radiant cooling (Givoni, 1994), indirect evaporative cooling (Givoni, 1980), (Bourne and Hoeschele, 1992) was already developed and framed but existing office building in the tropics has not been taken into account.

2. Objectives

Advances in digital technologies particularly building simulation environments have focused on algorithm development, data management and interfacing that are analysis based and support independent domain activities (Malkawi, 2004), (Ramilo & Embi, 2013). Currently, there is a broad range of simulation packages (Energy Plus, TRNSYS, Ecotect, IES and COMIS) that evaluate multiple thermal performance for buildings (Ramilo & Embi, 2013) (Luther, 2003). To shift the emphasis of these tools from analysis only to a combined model of analysis and synthesis a renewed research into advances in optimization is underway (Kolarevic et el, 2006). It integrates digital simulation tools to support performance driven design using optimization and partial automation (Pitts et al, 2008). Methods to assist in the coupling of design geometry with building performance simulation and the prediction of the performance of building envelopes (Luther, 2000), (Luther et al, 2007), (Ramilo & Embi, 2016) are being undertaken.

One research that have employed the used of digital technology (Ecotect) was Ossen et al (2010) to evaluate and measure thermal performance in indoor environment in their tropical building design project. The thermal comfort study involved the use of field and combination with Ecotect software. Validation of Ecotect was done by comparing the computer simulation result with the field measurement. Likewise on the research of prediction of thermal performance of facade residential buildings in Singapore (Liping, 2006), a conflation of digital technologies were used such as computational fluid dynamics (CFD and building simulation program (ESP-r) to simulate thermal performance. The coupling program was validated by a series of validation studies, including single zone case, multi-zone cases, and field measurement studies. The result have shown that the coupled simulations can produce much better results that building simulation alone especially in the aspect of indoor air velocity prediction (Liping, 2006).
However while different research of building performance modelling is evaluated during schematic and design phase of a building project, only few has been research for existing office building to improve its performance and save energy particularly for actual office retrofit project that require building simulation tools to evaluate iterations of building envelop for final decision making and provides better understanding of how building performance simulation tool can evaluate façade design and in a way improve its performance. To elucidate this issue, this paper is a result of a case study made from an actual office retrofit project in Singapore to improve energy efficiency through improving existing building envelop. This study elucidates design methodologies that can be used either in design stage of the project or post construction performance evaluation to improve building design using building performance simulation tool (IESVE). Specifically, its main objective is to improve existing office building envelope and explore energy optimization opportunities to improved energy efficiency of 25% to 30% energy savings.

3. Building Performance Modelling for Energy Optimization

Building performance modeling is defined as an expression of measurable variables which affect a process or procedure. Common building performance factors are environmental such as solar gain, aerodynamics and heat loss, structural factors such as load and stress, and social factors such as view and privacy (Gunay et al, 2013). This includes finding sustainable and green strategies using new digital technologies that simulates building performance or 4D digital technologies that is available in the market. 4D digital technologies are commercial software (Ramilo & Embi, 2013) that can evaluated and stimulate daylighting, heat, energy efficiency, air flows, and indoor humidity. It helps and allow the design teams to provide quality information that is needed to quantify iterative choices, so that design teams can develop innovative green solutions at schematic phase of building design.

One notable project which have utilized building performance modelling for energy efficient responsive facade was Hanwha Headquarters in Seoul, Korea designed by UN Studio done to mitigate heat flow, optimized facade assembly and increase thermal comfort of its interior spaces (Figure 2).

![Figure 2: Hanwha Headquarters, Seoul, Korea by UN Studio (Littlefield, 2008).](image)

The high-rise Hanwha’s headquarter building was mainly a renovation and re-modeling of the facade which includes refurbishment of its interior public spaces, meeting floors, theatres and executive areas, along with the redesign of the landscaping. UN Studio’s design concept of the building resulted to be a
responsive facade which valued and integrates important key variables: program (exterior and interior), indoor climate and environmental considerations. The existing facade of the building contains single layers of dark glass and horizontal bands of opaque paneling. UN Studio decided to replace by clear insulated glass and aluminum framing to accentuate views and daylight. It’s framing and geometry is defined by the sun and orientation factors to ensure user comfort inside and to be able to reduce energy consumption. The facade workflow module distribution by UN Studio is presented in Figure 3.

![Facade workflow module distribution](image)

Figure 3: Facade workflow module distribution by UN Studio (Littlefield, 2008).

While the upper portion of the south facade is angled to receive direct sunlight, direct solar impact on the building was reduced by shading which is provided by angling the glazing away from direct sunlight. At south and southeast where there is direct sunlight, photovoltaic cells are placed on the opaque panels on the façade. The challenging part on this process is that even a small variation of the parent geometry of the panel quickly results in an avalanche of child modules, which makes it necessary to develop a tool to automatically generate all possible facade unit variations panel. The idea of developing a “Unit-Maker Tool” through scripting is helpful to takes basic geometric input information such as transom position, mullion dimensions, glass properties, and outputs numerous facade units.

3. Methodology

The scope of the case study dealt with exploring energy saving opportunities through improving building envelop of an existing 9-storey centralized office building located on the west of Singapore with a gross floor area of 18,879 square meters, with north-south orientation and window to wall area ratio of 0.57. The exploration was focused on how to improve the existing facade to minimize heat gain, improve day lighting and to minimize energy consumption. The exploration was done in four modified steps 1) post occupancy evaluation and measurements, 2) 4d modelling through IESVE, 3) building performance evaluation and 4) decision making which is briefly explain in 3.1, 3.2, 3.3 and 3.4

3.1 Post Occupancy Evaluation and Measurements

The first step of the exploration was to evaluate the existing office building. This was done through assessing the architectural plans and evaluating the data such as area of spaces and record of energy consumption. These data (Figure 4, 5 & 6) were collected, analyzed, validated and subsequently used in 4d modeling.
Figure 4: Photo and existing plan of the project

Figure 5: Space areas of the project

<table>
<thead>
<tr>
<th>Space Usage</th>
<th>Air-Conditioned Area (m²)</th>
<th>Non Air-Conditioned Area (m²)</th>
<th>Total Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offices</td>
<td>16,165.1042</td>
<td>0</td>
<td>16,165.1042</td>
</tr>
<tr>
<td>M&amp;E Rooms</td>
<td>0</td>
<td>769.6269</td>
<td>769.6269</td>
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<tr>
<td>Lobbies</td>
<td>913.2435</td>
<td>0</td>
<td>913.2435</td>
</tr>
<tr>
<td>Corridor</td>
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<td>0</td>
<td>801.1225</td>
</tr>
<tr>
<td>Toilets</td>
<td>0</td>
<td>229.5810</td>
<td>229.5810</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>17,879.47</strong></td>
<td><strong>999.2079</strong></td>
<td><strong>18,878.68</strong></td>
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</table>

Figure 6: Existing building energy consumption

<table>
<thead>
<tr>
<th>End Use</th>
<th>Reference Model Energy Consumption (kWh)</th>
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<tbody>
<tr>
<td>Air-Con Lighting energy (kwh)</td>
<td>726,408</td>
</tr>
<tr>
<td>Non-Air-con Lighting energy (kwh)</td>
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<tr>
<td>Equipment energy (kwh)</td>
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<td>Cooling System Energy (kWh)</td>
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<td>AHU/FCU Fan Energy (kwh)</td>
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<td>Lift Energy(kWh)</td>
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<td>Escalator Energy (kWh)</td>
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<td>Domestic Pump (kWh)</td>
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</tr>
<tr>
<td><strong>Total Building Energy Consumption</strong></td>
<td><strong>3,397,534</strong></td>
</tr>
</tbody>
</table>
3.2 4D-Modelling Using IESVE

A 4d model was made using the verified architectural plans, sections, elevations and interior spaces of the existing office building project through IESVE (Figure 7). It was made to simulate the existing building orientation and other site condition.

![Figure 7: 4d model of the existing project](image)

3.3 Building Performance Iterations

When the baseline 3d model was verified, three (3) options of different new facade including the existing office building was modelled as shown in figure 8, made to evaluate the new facade design in terms of energy efficiency. Building performance simulation experiments of three façade options through IESVE was made, evaluated and assessed on the basis of efficiency and accuracy of thermal performance results. Quantitative data was statistically compared on existing building and each proposed retrofitted building envelop and energy consumption was recorded and analyzed (Figure 9). This was done to further improve the facade and explore the possibility of reducing energy consumption.

![Figure 8: 3d Models of existing building envelop and the three proposed retrofitted building envelope 1, 2 & 3 showing its WWR and ETTV](image)
Figure 9: Comparison of energy consumption of proposed building Envelope 1, 2 & 3.

<table>
<thead>
<tr>
<th>Description</th>
<th>Proposed Building Envelope 1</th>
<th>Proposed Building Envelope 2</th>
<th>Proposed Building Envelope 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Envelope</td>
<td>• Reduced WWR to 40%</td>
<td>• Reduced WWR to 40%</td>
<td>• Reduced WWR to 40%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 300mm shading provided to all facades</td>
<td>• 300mm shading provided to all facades</td>
</tr>
<tr>
<td>Lighting Power Budget</td>
<td>• Office LPD – 8 W/m²</td>
<td>• Office LPD – 8 W/m²</td>
<td>• Office LPD – 7.5 W/m²</td>
</tr>
<tr>
<td></td>
<td>• Corridor LPD – 6 W/m²</td>
<td>• Corridor LPD – 6 W/m²</td>
<td>• Corridor LPD – 6 W/m²</td>
</tr>
<tr>
<td>Air-conditioning System (Water-sake)</td>
<td>• No change</td>
<td>• Energy efficient VSD chiller with the system efficiency of 0.646 kW/kton</td>
<td>• Energy efficient VSD chiller with the system efficiency of 0.646 kW/kton</td>
</tr>
<tr>
<td>Air-side</td>
<td>• No Change</td>
<td>• No Change</td>
<td>• Energy efficient AHU with VSD fans (0.34 W/CMH)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Energy efficient FCU DC brushless motor (0.073 W/CMH)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Installation of CO₂ sensors</td>
</tr>
</tbody>
</table>

3.4 Decision Making

After the building performance simulation of the new three (3) proposed façade was made, relevant data related to energy efficiency and daylighting was carefully analyzed, verified and final decision was made as to which among the three (3) options is best to utilized.

4. Results

Considering energy efficiency, the proposed retrofitted building envelop 3 with the WWR of 0.40 and ETTV of 30.90 W/m² as shown in figure 10 was chosen as the final design façade design. It is because retrofitted building envelop 3 has the highest amount of energy savings (26.8%) among the three models that was presented in Figure 8. A comparison of cooling load savings of proposed building between envelope 1, 2 & 3 is presented in Figure 11.

![Figure 10: Comparison of existing building envelope and proposed retrofitted building envelope 3 as final design](image)

It was reiterated that the rate of heat transfer through the building envelop was depended on the difference of value between the outside temperatures and the temperature of the interior of the building.
and the capacity of the facade to control heat flow and heat transfer. Factors that influence heat flow within the facade is mainly the overall thermal resistance, window to wall ratio (WWR), and envelop thermal transfer value (ETTV). It is also worth noting is that building envelop with high WWR is likely to have greater effect of the thermal comfort than with low WWR. The optimal WWR must importantly consider the layout of the space, smaller WWR must be used for spaces where users are near to the penetration for the building envelop facing south.

![Figure 11: Comparison of Cooling Load Savings of Proposed Building Envelope 1, 2 & 3.](image)

<table>
<thead>
<tr>
<th>Orientation of Facade</th>
<th>Gross Area of External Walls and Windows (m²)</th>
<th>Reference Model ETTV (W/m²)</th>
<th>Proposed Model ETTV (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>2782.54</td>
<td>43.5</td>
<td>27.4</td>
</tr>
<tr>
<td>East</td>
<td>1478.33</td>
<td>59.2</td>
<td>35.5</td>
</tr>
<tr>
<td>South</td>
<td>2782.54</td>
<td>44.9</td>
<td>28.2</td>
</tr>
<tr>
<td>West</td>
<td>1478.33</td>
<td>63.9</td>
<td>38.2</td>
</tr>
<tr>
<td>Average ETTV of the Building Envelope (W/m²)</td>
<td></td>
<td>50.2</td>
<td>30.9</td>
</tr>
</tbody>
</table>

![Figure 12: Proposed retrofitted building envelope 3 showing the additions of 4 x 300 mm external shading device and how it affects ETTV.](image)

During the simulation, it was evident that facade elements like windows and light shelves is very significant in as far as thermal fluctuations is concerned. Heat transfer can be dictated the combination of the interior skin temperature of the glazing including the transmitted ultra violet rays through the glazing. This can be significantly influenced by the glazing units, the material properties of the glass, and the
effectiveness of the light shelves used above the window (Figure 12). On the iterations, it is noted that light shelves on the south facing building envelope of building remarkably increases the daylighting quality and quantity. It reduces cooling cost, efficient daylighting approach by means of light, increases light penetration and therefore decrease artificial lighting during day time. It is the most effective in south facing envelope, improves daylight penetration, creates shading near the window, and helps reduce window glare and ultimately decreases the cooling load.

5. Conclusions

Building performance modelling play a crucial role in the decision making for designing an energy efficient building retrofit because it help investigate design options prior to construction. It is good tool to assess energy efficiency, environmental and energy impacts of design decisions. Without a doubt, it is an essential part for designing sustainable performative building envelope. In an office retrofit building project where energy is a concern, building performance simulation tool can quantify and predict energy consumptions and can be further reduced through building envelope iterations. It helps establish metrics that can be utilized to measure improvements by using different design strategies. In the case of this study, it is concluded that building performance simulation has an ability to quantify the impact of a design solution like the performance building envelop that can be investigated with actual quantifiable data, not just through theories, and able to analyse, predict energy consumption and saving, and lastly improve architectural design with multiple design alternatives.

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Less and More in Aotearoa New Zealand

More Houses and Less CO₂ Emissions

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Abstract: This paper outlines the case for further research into an expanded use of bio-based materials for housing construction in Aotearoa New Zealand. Not only are large numbers of houses required to address ongoing shortages, but there is also an urgent need to address climate change. The embodied CO₂ emissions of the materials used to construct the future housing stock are, therefore, critical and warrant further investigation. Bio-based materials have very low CO₂ emissions, and some of those grown in Aotearoa New Zealand, are currently underutilised. Over 40 percent of straw, a byproduct of grain production, is currently burned in the field but it has the potential to be used on the scale necessary to satisfy current and future housing needs. Engagement with grain growers and researchers is necessary in order to further the research, as is gaining an understanding of overseas developments in prefabricated straw construction. Public perception is also important. Seventy years ago and facing a similar housing crisis, an attempt was made to introduce an alternative construction method, soil cement, into mainstream building practice. The reasons for Terracrete’s forward-thinking but ultimately unsuccessful venture are considered when speculating on a contemporary response using an uncommon material.

Keywords: Bio-based; housing; straw; embodied energy.

1. Introduction

“Housing is to-day a major issue. This is as true of New Zealand as it is of most other countries. Probably never before have so many houses been wanted so quickly. And perhaps never before has the problem been so complex.”

One could be forgiven for thinking these words were written yesterday. In fact, they were penned by architect Cedric Firth in 1949. Firth’s book, State Housing in New Zealand (1949), is an account of the New Zealand Government’s response to a chronic housing shortage in the middle of the twentieth century. Seventy years later, in 2017, housing is still a major issue in Aotearoa New Zealand. Not only is there a shortage of new houses, but also of skilled tradespeople; much of the existing housing stock is in poor condition, and housing has become unaffordable for many lower and middle-income earners. But the problem has become even more complex: there is also the urgent need to address climate change.
Thirty years ago, global attention was drawn to the serious issue of climate change by the Brundtland Report, *Our Common Future*(1987). In a July 2017 report, New Zealand’s Parliamentary Commissioner for the Environment, Dr Jan Wright, describes climate change as “the ultimate intergenerational issue” and urges the government to enact climate change legislation, including the setting of greenhouse gas (GHG) emission targets, a key mechanism for mitigating global warming (Wright, 2017). For the construction industry, this means looking at ways to reduce CO₂ emissions, both in the operation of buildings and in their material make-up.

Bio-based materials, including timber, absorb CO₂ and sequester carbon as they grow, making them an important resource to consider when looking for ways to reduce the carbon footprint of an ever-expanding built environment. Timber is the predominant structural building material in Aotearoa New Zealand, particularly for housing, but there are other bio-based materials worthy of consideration by the construction industry. Hemp from the fledgling industrial hemp industry, wool from sheep farming and straw from grain growing all have the potential to be fashioned into building products and manufactured at scale, enabling further reductions to national GHG emissions. Straw is a useful place to start in considering the potential of such materials. It is already grown in large quantities as a byproduct of grain production, and currently has little value. Over the last 24 years a small number of straw bale houses have been built in Aotearoa New Zealand, predominantly by owner-builders in rural locations, but overseas advances in the use of prefabricated systems suggest that a broader uptake is viable.

### 2. Aim

The aim of this paper is to present the case for further research into using a broader range of bio-based materials, specifically straw, for construction in Aotearoa New Zealand. It is predominantly a literature review providing the background for more detailed research and for speculation on how a new low carbon building material, might be integrated into mainstream construction over the next 50 years. Reflection on a previous attempt to introduce an uncommon building material, soil cement, into mainstream construction 70 years ago aims to provide insight into factors beyond the scientific that could affect the success or failure of a contemporary proposition.

The proposed research would follow the lines of enquiry introduced in this paper:

- interrogation of the different methodologies involved in measuring embodied CO₂ emissions,
- engagement with researchers and farmers to gain an understanding of the grain growing methodology in Aotearoa New Zealand,
- analysis of overseas prefabricated straw construction techniques.

Engagement with the prefabrication industry in New Zealand is not covered in this paper but would be part of the proposed research.

### 3. Methodology

The paper begins by examining Firth’s 1949 report on the New Zealand Government’s response to a chronic housing shortage in the middle of last century. The short history of Terracrete Construction, provides an example of the government’s willingness to consider new construction methods, but also illustrates the political and social factors that influence their success or failure. This is investigated using published books, archival journal and newspaper articles, and personal interviews.
A contemporary response to the current housing crisis requires the issue of climate change to be addressed, in particular via the control and reduction of CO₂ emissions. This is investigated via an analysis of research by Hammond and Jones (University of Bath), and Alcorn (Victoria University of Wellington) on the embodied energy and emissions of building materials. Differences in methodologies are reviewed, particularly regarding carbon sequestration, an important factor when considering the use of bio-based materials.

Focusing on straw as a case study, further interrogation of Alcorn’s research follows with a view to investigating the feasibility of using straw for building large numbers of houses. To gain an understanding of the role of straw in the process of growing grains, close reading of a report prepared by the Foundation for Arable Research (FAR) for Environment Canterbury in 2013, was undertaken, revealing detailed information about current farming practices. Interviews with the CEO of FAR provided further clarification. A brief history of straw bale construction and current building practices is provided, and leads into a desktop overview of two prefabricated systems, Modcell® from the UK and Ecococon from Lithuania.

Speculation follows as to how lessons from the past, current developments in straw building technology, future government legislation on climate change, and potential changes to grain growing methods, might inform a strategy to successfully introduce a new low carbon building system.

4. Back to the Future in 1949

4.1 State housing in New Zealand

Firth’s *State Housing in New Zealand* was a response to “inquiries received from overseas and local sources” about the First Labour Government’s housing programme (Firth, 1949, p.2). The extract quoted in the Introduction outlines the situation the government was responding to, a situation that sounds all too familiar. In 1949, in an attempt to respond to a worsening housing crisis, exacerbated by the six years of WW2, the government ramped up the intensive house building programme which it had begun in 1936. Statistics provided by Firth show that during the first twelve years of this radical new housing initiative, the government built 20 to 40 percent of all new dwellings constructed annually (1949, p.67).

The State Advances Corporation (SAC) and the Housing Division of the Ministry of Works carried out the housing program, acting as developers, property managers, architects, planners and financiers. They were keen to encourage innovation:

“The Division is on the look-out for ideas – for new materials and systems of construction that may be useful in speeding up the supply of houses, or in reducing costs. Anyone interested is invited to submit prices for houses involving any type of construction at all” (1949, p.44).

4.2 The terracrete experiment

In 1952 an enterprising family of builders from the Wellington suburb of Wainuiomata put the Housing Division's invitation to the test. John Anker heard about engineer P.J. Alley’s pioneering work in soil cement at the University of Canterbury (Alley, 1949). Anker and his brothers, Chris and Peter, saw potential for the material and sent soil samples from Wainuiomata to Alley for testing (Alley, 1952). The outcome was favourable and the brothers began by building houses for their own families. They formed a company, Terracrete Construction Limited, designed and patented machinery for wall placement, and
designed a method they believed could compete with the prevailing timber-framed construction (Evening Post, 1954). Their system was sanctioned by the SAC who approved loans for Terracrete houses (Parade of Homes, 1958).

In 1958 Terracrete won a contract with the SAC to build six state rental houses on Wainuiomata Rd, the main road into town. The Housing Division thus proved that they were open to “new materials and systems of construction,” and it seemed that the vision, shared by Alley and the Ankers, for soil cement as a material with a future, could become a reality. The houses, along with nine other Terracrete houses in Wainuiomata, have been continuously occupied for sixty years, but after 1959 no more were built.

According to Miles Allen, “Although Terracrete successfully built houses slightly cheaper than their competitors, their contract [with SAC] was not renewed” (Allen, 1997). He suggests that the government was more interested in promoting the use of timber from its own forests than supporting the commercialisation of soil cement. Maureen Anker, wife of Peter, also suggests that most people were still too conservative to consider soil cement and perceived building with earth a backward step (Anker, 2017).

5. Climate Change and the Embodied Carbon of Building Materials

Since 1987, the effects of climate change have become increasingly obvious, and it is now widely accepted that anthropogenic GHG emissions are increasing the rate of change (MFE, 2014). Globally, much attention has been focused on energy efficiency as a way of mitigating the effects. Current building regulations in Aotearoa New Zealand reflect this focus by requiring increased levels of insulation for most types of building. The GHGemissions embodied in the building fabric, however, are also significant, particularly when global demand for housing continues to grow and operational emissions are falling because of tighter building regulations (Rawlinson and Weight, 2007).

Andrew Alcorn interrogates the makeup of GHG emissions in his 2010 thesis, Global sustainability and the New Zealand house, and finds that if operational emissions are broken down into categories such as hot water heating, space heating, cooking, and refrigeration, then the emissions associated with building materials become second only to hot water heating. He concludes that

“The ratio of construction CO₂ emissions and absorptions to total emissions for average and currently constructed New Zealand housing is significant, at approximately 1:4” (2010, p.317)

Values for the embodied energy and CO₂ emissions are available from several sources, including the University of Bath’s Inventory of carbon and energy (ICE) (Hammond and Jones, 2011), Embodied energy and CO₂ coefficients for NZ building materials (Alcorn, 2003) and Alcorn’s PhD thesis (2010). However, differences in methodologies mean that it is difficult to compare findings, and it is the CO₂ emissions associated with the possible end-of-life scenarios that complicate matters. An important difference between the UK and New Zealand sources concerns timber, the most prevalent bio-based construction material in both countries. Hammond and Jones do not factor in the negative impact of carbon sequestration on embodied CO₂ calculations, stating that to do so “requires a fundamental understanding of the carbon cycle, which is still a developing science” (Hammond and Jones, 2008, p.11). Alcorn includes sequestered carbon in his calculations, assuming landfill as the end-of-life scenario. He maintains that the carbon locked up in buildings for decades or centuries is a crucial mechanism for mitigating global warming (2010, p.218). Despite this difference, widespread acceptance of the importance of embodied carbon of building materials is reflected by the interest shown in the ICE database (Hammond and Jones, 2008) and Alcorn’s New Zealand equivalent.
Bio-based materials like timber have low embodied CO₂, whether carbon sequestration is factored in or not. A 2008 study by John et al investigated the impact of different materials over the life cycle of four similarly designed buildings. They concluded that the timber-rich buildings “have significantly lower net emissions over the full 60-year life-cycle of the buildings,” regardless of whether the end-of-life scenario was landfill, material recycling, or the permanent storage (sequestration) of the carbon in the timber (John et al, 2008, p.128).


6.1. General

Timber is already widely used in construction; it is the predominant structural component of the national housing stock, and provides a strong starting point from which to continue exploring low or ultra-low carbon bio-based building options. Primary industry, specifically agricultural primary industry, has the potential to provide further raw materials, like hemp, wool and straw, for manufacturing building elements. Both hemp and wool are worthy of further research, but straw, the low value byproduct of grain production, has more obvious potential as a low carbon building material option for future housing needs.

6.2. Straw and grain production

6.2.1. Grain production

Grains were first grown in Aotearoa New Zealand by European missionaries (Zydenbos, 2008) and by 1855, when grain production was first recorded, there were 4,000 hectares of wheat grown nationwide (BIRT, 2017). Between 2008 and 2012 the average area under cultivation for all cereal grain production, wheat, barley and oats was 123,720Ha (FAR, 2013). New Zealanders are good grain growers; two farmers from Canterbury, where 70 percent of cereal grain is grown, currently hold world records for barley and wheat yields (Stuff 2017). The industry is well supported by research carried out at the two agricultural universities (Lincoln and Massey), Crown Research Institutes, and the Canterbury-based Foundation for Arable Research (FAR).

6.2.2. The role of straw

Along with world record grain yields, there are correspondingly high yields of straw - around 900,000 tonnes annually (FAR, 2013, p.12). It is the main component of what is termed ‘crop residue’ by the industry and the annual yields are nearly twice that for the same crops in Australia (FAR, 2013, p.16). Yet, despite the large quantities produced, straw has a low value. Between 2008 and 2012 an average of 41 percent of straw was burnt in the field; the rest was used for landscaping, horticulture, animal bedding, the occasional straw bale house, and as a supplementary food source for the dairy industry. This last use has risen since 2012, with increased dairy farming in Canterbury, but the price the straw commands is very low because of its low nutrient value (Pyke, 2017).

Every year the post-harvest burning of straw, or stubble, by grain farmers in Mid Canterbury raises concerns about air pollution and fire risk, so much so that in 2013 Environment Canterbury commissioned FAR to review the role and practices of stubble burning in New Zealand (FAR, 2013). The resulting report is comprehensive, explaining the rationale behind current farming practices and investigating the pros
and cons of other options for dealing with the residue. It considers the English precedent, where similar amounts of straw per hectare are produced but where the practice of post-harvest burning has been banned since 1992 (2013, p.13).

The FAR report argues that differences in farming practices, specifically the preferred crop rotation cycle, make it unfeasible to ban burning in New Zealand (2013, p.16). Crop rotation is a significant element of grain growing practice in New Zealand. Typically grain rotations are followed by small seeded crops like ryegrass and clover, and burning the crop residue, the straw, from the preceding crop is considered the most beneficial method of preparing for the next crop (2013, p.24). The report investigates four alternative methods of managing crop residues, including “Baling and removing straw” (2013, p.6) which rates as third best out of the five options. Consequently, it appears that unless the value of straw increases and/or a ban is placed on burning crop residues, the current practice is likely to continue.

6.2.3 A short history of straw construction in New Zealand.

New Zealand has a history of using straw in construction, albeit in a limited way. In the 1950s an imported compressed straw wall and ceiling panel, Stramit, was available in New Zealand (Home and Building, 1955), and its contemporary equivalent, Durrapanel, is still imported for specific acoustic treatments, for example in Auckland’s Vector Arena (Ortech,2008). Towards the end of the twentieth century straw bale houses made with locally grown product began to appear.

Straw bale construction began in the late nineteenth century in Nebraska, USA (Steen, 1994) but it was not until 1995 that New Zealand’s first straw bale house was completed (Hall, 2012). The relatively simple construction method makes it attractive to owner-builders, and for the last 24 years a small number of straw bale houses have been built around the country each year. National figures are not available but in the Nelson/Tasman area there were 32 in existence by the end of 2010 (Hall, 2012). It is reasonable to speculate that there may be 300 straw bale houses nationwide. Assuming the Nelson/Tasman sample is indicative of the national position, 69 percent of the houses were built with a high degree of owner participation, and 85 percent are in rural locations. These findings support the general perception of straw bale as a material suited specifically to owner-builders on lifestyle blocks.

There is no building code for straw bale construction, and building consent applications must be made as alternative solutions. Design professionals and building practitioners with straw bale experience use documentation based on overseas codes and guidelines to support their applications, specifically King’s Design of Straw Bale Buildings (2006) and the more recent Appendix S of the 2015 International Residential Code (ICC, 2015).

Straw bale houses have been built with a variety of timber supporting structures, straw bale infill walls with cement, lime or earth plaster coatings, and timber framed roofs. This method allows the roof to be constructed first, providing cover while the moisture-sensitive straw bale walls are built. In some cases, the infill walls have been engineered to provide lateral bracing. While the framing and straw bale raising components are relatively fast to construct, the plaster finishes are slower. To speed up the process, a Geraldine-based design build company, Sol Design, have been experimenting with prefabricated straw bale panels, a system which allows much of the time-consuming plastering process to be carried out off-site in controlled conditions (Hall et al, 2014).
7. Straw as a material for the future

7.1 Straw as a low carbon building option

Alcorn’s research highlights the importance of reducing embodied carbon in building materials as a major strategy when envisioning a sustainable future. For Alcorn, “Sustainability meets the needs of the present without annual CO₂ emissions exceeding what the planet can absorb” (2010, p54). He calculated a negative value, -210Kg/m³, for the embodied CO₂ emissions of straw bale, based on a building lasting for 90 years (2010, p280, 329). His House 14, with timber and straw as major carbon sequestering building components, combined with on-site wind generation was the only house in his study that met his definition of sustainability. Bodegar et al’s UK study, *The carbon reduction potential of strawbale housing* (2011, p.17), also concludes that straw has a negative value for embodied CO₂ emissions when sequestration is factored in.

7.2 Straw as an insulation material

Along with its low carbon credentials, straw is also a good insulator. Testing of full-scale straw bale walls at Oak Ridge Laboratories in the USA and at the Technical University of Nova Scotia provide conservative estimates for thermal resistance of 450mm thick straw bale walls as being in the range R 4.5-5.3 C°m²/W (King, 2006). Additionally, the use of bio-based insulation with R values greater than R 5 of itself results in an overall reduction in CO₂ emissions by way of the reduced heating requirements. This is not the case for other insulation materials, like fibreglass or polystyrene, where the extra embodied emissions present in the thicker material outweigh the savings in heating emissions (Alcorn, p.297).

7.3. Prefabricated straw panels

Sol Design’s experiments aside, building with straw in Aotearoa New Zealand has not moved beyond on-site construction of one-off houses. However, off-site prefabrication has been developing in other parts of the world. The most advanced of these are Modcell® Straw Technology, based in the UK, and Ecococon, based in Lithuania. Both companies construct wall panels off-site, but their methods are different.

Modcell® has been developing its wall systems since 2002 in an on-going collaboration with the University of Bath. The Balehaus at Bath, constructed on campus in 2009, has provided the opportunity for continuous monitoring of the Modcell® system in use. Large wall panels, consisting of full-width engineered timber frames with straw bale infill, are constructed in controlled conditions off-site. Finishes vary according to panel type and range from traditional lime plasters inside and out, to breathable sheet linings both sides, and cavity battens to the exterior supporting a variety of rain screen options. The Modcell® Core+ panel meets Passivhaus standards. Built projects to date include schools, business centres and housing projects (Modcell, 2017).

Ecococon, operating since 2008, also constructs wall panels off-site, but its panels are smaller. Sawn timber is used to construct double frames spaced 400mm apart to contain the full wall thickness. Rather than using straw in bale form, loose straw is rammed tightly within the frame. As with Modcell®, a variety of interior and exterior finishes can be applied. Walls have been successfully tested for fire, structural integrity, air-tightness and thermal and moisture performance, and meet Passivhaus standards. The built examples shown on the Ecococon website indicate that the system has been used predominantly for standalone houses (Ecococon, 2017).
Both the Modcell® and Ecococon systems could be replicated or adapted for New Zealand conditions, the scale of the prefabricated panels being determined by the target market. The large Modcell® panels require heavy machinery to lift in place and are well suited to larger projects, a medium density housing project for instance. On the other hand, the smaller Ecococon panels can be manipulated by hand or small-scale lifting machinery and are therefore better suited to single house projects. The decision to use straw in bale or loose form would be affected by preferred harvesting methods, which requires engagement with the grain growers.

8. Discussion

Nearly 70 years have passed since Firth’s report. During that time, the government’s role as a housing provider has changed dramatically, but the dire housing situation described by Firth has not. In 1949 over 25,000 houses were needed nationally (Firth, 1949, p.48); in 2016 a report prepared by ANZ for the Treasury estimated a national shortfall of 60,000 houses (Newshub, 2017). Since 1949 successive governments have systematically altered their visions for the future, from one where the state felt a responsibility to provide houses for all citizens to one where provision of housing is largely left to the private sector. The role of government may well change again over the next 50 years, not by returning to the 1949 position but by legislating to reduce CO₂ emissions, thereby creating an environment where low carbon building technologies would become highly relevant.

Life-cycle analysis, including embodied CO₂ emission calculations, of proposed construction systems will be an important aspect of the research proposed in this paper. Experts agree that bio-based materials have relatively low CO₂ emissions, regardless of the end-of-life scenario. However the carbon sequestered in the fabric of buildings is a key factor in the case for using more bio-based materials and it is imperative that those end-of-life scenarios be included in the calculations.

The agricultural sector contributes nearly half of New Zealand’s GHG emissions, mostly via methane emissions from livestock (MFE, 2016), but the sector also has the potential to mitigate the effects of climate change by growing low carbon building materials. New Zealand farmers are very good at growing grains, but current farming practices, specifically burning straw after the grain harvest, mean that the potential benefits gained by sequestering carbon while the plants grow are offset by the act of burning, where most of the carbon stored in the stalk is volatised, releasing CO₂ back into the atmosphere (FAR, 2013, p.18). In the UK, burning straw and stubble has been banned since 1992 and if a similar ban were to be enforced in Aotearoa New Zealand, the prospect of using straw to manufacture construction materials may provide an attractive option for grain farmers. The 2013 FAR report did not consider other markets for straw when investigating alternatives to burning. The analysis and subsequent recommendations assume a low value based on straw’s low nutritional value. If, however, it was highly valued as a vital raw material for an innovative prefabricated wall system, it is reasonable to speculate that farmers would be open to adapting their farming methods to suit.

It is useful to reflect on the Terracrete venture and speculate how an unconventional construction system might be successfully marketed in 2017. In the 1950s, when building with earth was considered a thing of the past, Alley called the material ‘soil cement’ and the Anker brothers branded it ‘Terracrete’, both parties making conscious decisions to present earth as a modern material for modern times, and achieving a limited degree of success. The general perception of straw building as a marginal activity practised by owner-builders presents a similar problem. As well as committed support from government and the private sector in relation to research, regulation and the development of standards, and buy-in from the construction and grain growing industries, a sophisticated programme aimed at educating the
public about the environmental benefits of straw, and dispelling negative associations, is likely to be necessary. The branding and marketing employed by Ecococon and Modcell® portray both products as being environmentally responsible and technically innovative. Both companies use the results of their scientific testing and Passivhaus ratings as marketing tools, and Modcell® uses built projects as case studies to illustrate the adaptability of their product to suit a range of building types and styles. Further interrogation of the effectiveness of both companies’ marketing strategies would inform an appropriate approach to introducing straw as a future building material for Aotearoa New Zealand.

9. Conclusion

This paper set out to present a case for further research into the viability of using locally grown bio-based materials to manufacture building materials and develop associated construction systems capable of being utilised at scale. If timber, the country’s predominant structural material, is combined with other bio-based materials such as straw, it is possible to significantly reduce the CO₂ emissions embodied in the fabric of the large number of new buildings required to satisfy current and future housing needs.

In order to explore this proposition, a number of factors require further investigation. Firstly, it is important to engage with growers and researchers to gain an understanding of the farming methods and economics of grain production. Currently straw is treated as a low value byproduct, 40 percent of it is burnt in the field following harvest, and unless the value of straw increases or a ban is placed on burning, current practice is likely to continue. Secondly, a thorough analysis of international straw prefabrication techniques and how these might inform a New Zealand system needs to be carried out. Proposed systems would require life-cycle analysis, including embodied emissions that are specific to the New Zealand environment. Finally, reflecting on the ultimate failure of Terraccrete Construction’s attempt to introduce soil cement as a building material for the future in the 1950s, it is clear that while gaining support from industry and regulatory authorities is essential, public perception is also an important factor to be considered.

The future imagined 70 years ago was quite different to one imagined today. The housing shortages in 1949 were similar to those in 2017, but any vision for 50 years ahead did not consider climate change. As public awareness grows and pressure mounts on governments to take affirmative action on reducing GHG emissions as well as addressing housing shortages, the benefits of using bio-based materials may be recognised as a way of building more houses with less CO₂ emissions in Aotearoa New Zealand.

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Boler’s Pedagogy of Discomfort

Examining a Turn of the Century Idea for Contemporary Architectural Education

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Abstract: Within the architectural design studio we have the opportunity to employ Boler’s (1999) Pedagogy of Discomfort in two dimensions; both to disrupt students’ ways of seeing and also their habits of making – the way they execute design as a practice. By challenging students to work with theoretical ideas and methods of creation beyond those they are comfortable with, a transformation in their understanding of the role of architecture and how it operates within the world can result. This paper will reflect on two design studios recently conducted at the University of Melbourne that sought to broaden students’ perceptions of architecture’s potential to influence perceptions, discourses and behaviours. Furthermore, to enable them to recognise their own capacity to challenge convention and, by extension, their own agency to demonstrate leadership within the built environment. This paper will reframe Boler’s pedagogy of discomfort through Markauskaite and Goodyear’s (2016) more recent theory of epistemic fluency to establish the enduring relevance of Boler’s pedagogical approach for contemporary architectural education.

Keywords: Epistemic fluency; research through design; architectural citizenship; design leadership.

1. Introduction

According to Boler (1999) a pedagogy of discomfort aspires to transform a student’s habits of seeing. It should teach students the skills to listen to others more attentively and without judgment; to examine their own value systems and how they came to hold those; alongside the courage to inhabit a more ambiguous sense of self (the ability to actively resist comfortable binary positions such as right and wrong, innocent and guilty). The relevance of this pedagogical approach for architectural practice is that it requires students to consider the needs of clients whose value systems may vary, and thus threaten, their own pre-existing value system. This can result in a willingness to respect and incorporate the ways that others see and make sense of the world – an ability that is also critical to the practice of epistemic fluency.

Epistemic fluency is a more recent pedagogical approach advanced by Markauskaite and Goodyear (2016); it recognises that tomorrow’s professionals, when faced with increasingly complex twenty first century problems, will require the capacity to work collaboratively, innovate and adapt to changing conditions.
demands in their field of practice. Epistemic fluency is the ability to perform the following five skills synchronously: to connect theory with practice; to learn to act as a professional (with regard to competency and identity); to practise relational expertise (the ability to communicate and collaborate); to exercise a capacity for innovation; and to be attuned to the affordances and constraints of the environment in which one is acting in order to reconfigure this environment as suited to the task at hand (Markauskaite and Goodyear, 2016). Employing a pedagogy of discomfort within the design studio can enhance specific skills necessary for developing epistemic fluency. The first is to foster a willingness to understand and incorporate the disciplinary practices or value systems of others. This is central to a pedagogy of discomfort and requisite to enable deep (as opposed to surface) collaboration across disciplinary boundaries. The second is a willingness to experiment; the confidence to occupy a space where failure is likely to occur. Boler’s aspiration that students develop the confidence to occupy uncomfortable, ambiguous positions aligns with the epistemic fluency because, as Gorman (2015) points out, a willingness to fail productively is necessary for innovation itself (Gorman, 2015).

Within the architectural design studio we have the opportunity to employ a pedagogy of discomfort in two dimensions in order to disrupt a student’s way of seeing and also their habits of making – the way they execute design as a practice. Applying discomfort in these two dimensions intensifies the space of uncertainty within the design studio and enhances opportunities for students to become more comfortable, and thus confident, occupying and working within uncertain problem spaces. Challenging students to work with theoretical ideas and methods of creation beyond those they are comfortable with can lead to a transformation in their very understanding of the role of architecture and how it operates within the world. This is way of working will be important for the future of the architectural profession, particularly relative to an ageing population and the increasing expectation that our built environment should contribute more in support of physical and psychological wellbeing. How does an architect design for a client with dementia, or terminal illness, for example, if they’ve not experienced that themselves? The studio discussed herein sought strategies to help students understand that architecture is not simply a product, reflection or spectator of social values, but that it plays an active role in the lives of those who inhabit it.

2. Confinement, infidelity and disrupted notions of home in the design studio

Boler published her pedagogy of discomfort in 1999 while at the University of Auckland. A year later architect Mike Barns appeared to employ this approach within an architectural design studio focused on prison design at the same university. While this was not made explicit at the time, and although the authors have been unable to confirm whether this was deliberate, Barns’ studio provided a textbook example of the application of this pedagogy. Students were subjected to learning resources (texts and guest lectures) that challenged their pre-existing value systems. It was McLaughlan’s experience of this studio that subsequently informed a recent University of Melbourne design studio that asked students to challenge conventional notions of the house as a typology. To alter a student’s worldview a conflict or tension must be generated to inspire a transformation to occur. As Pratt has asked:

Why and when does a person willingly undertake change, especially if one is materially and ideologically safe and comfortable? (1984, 16)

Barns achieved this within his prison design studio at the University of Auckland (2000) by employing a series of learning resources that created an ideological rollercoaster for the students undertaking this
studio. He began this process by specifying Foucault as mandatory reading alongside contemporary criminology theories including ‘strain theory’. This is the theory that criminal behaviour is a consequence of people not being given the same opportunities in life; the idea that crime arises in response to the frustration of progress this system creates for individuals (Merton, 1938). For students with the studio, this material disrupted prior assumptions that ‘criminals were bad people’ and resulted in the adoption of the position that ‘criminals are normal people who find themselves in tough situations.’ A view further reinforced through a discussion with a group of former inmates who were actively trying to turn their lives around. Boler (1999) advises that the tendency to occupy a binary position in response to new knowledge that illuminates the error of one’s pre-existing value system is a characteristic reaction for students. Next Barns invited a prison guard from a high security facility along to the studio. By the end of that conversation, within which the class gained an understanding of the creative and unceasing efforts of inmates to inflict violence on prison staff, all positions of binary refuge had been abandoned. This student cohort was now on a path, as Boler would term it, to occupying a more ambiguous sense of self. The precarious, subjective nature of the value systems that students arrived to studio with had been shattered in light of a world far more complex and confounding than was formerly appreciated. Yet Barns continued to push the class, requiring students to dwell in this discomfort. He would not allow acceptance of the difficulties that plagued this system but asked students to focus instead on the needs of the prisoners themselves. To think about what a prison could be and to question the role this institution performed in society, including the discourses it upheld, alongside the consequences of the behaviours this system perpetuated.

Barns’ approach facilitated a transformation in the way that students perceived architecture’s capacity to shape our experience of the world. To make evident that while we might accept that certain typologies embody certain characteristics and/or functions, these are socially constructed and, in turn, play a role in influencing human values, expectations and behaviours. This approach resonated with the following conception of the purpose of a curriculum within higher education, as provided by Fraser and Bosanquet, whereby this document should enable:

Teacher and student act as co-constructors of knowledge... the structure of the learning experience is not predetermined ... it emerges from the needs of the students and between the interactions between students, teachers and colleagues... The overarching goal is to empower students ... [to become] effective members of the public ... (2006, 274).

A primary learning objective of the housing studio was to enable students to rethink housing in non-conventional ways and to enable them to develop the ability to conduct a process of research through design. The studio was run with a mixed cohort of fourth and fifth year students with the Master of Architecture programme and was positioned with the intent of providing a comprehensive introduction to research through design as preparatory learning for the capstone subject. Unrequited love provided a lens for interrogating design across three scales: wearable architecture, exhibition design and a residential dwelling. Students were asked to choose a piece of literature that dealt with unrequited love in order to generate their studio clients. This resulted in multiple projects that considered three inhabitants across an array of non-conventional relationships, many that were morally confrontational.

Within the gamut of novels students chose to explore were Milan Kundera’s Unbearable Lightness of Being, David Ebershoff’s The Danish Girl, Patrick Suskind’s Perfume: The Story of a Murderer and F. Scott Fitzgerald’s The Great Gatsby. Among the projects produced were a residence to enable a stalker; a number of houses that utilized architectural strategies to intensify the power imbalances between the characters within these relationships; a house for a narcissist; a cliff slide dwelling to stage a spectacular
suicide; a museum to facilitate murder and conceal the taxidermy and display of human bodies; two sets of terrace houses designed to keep lovers apart; and a house designed to ensure that two women sharing the same man were constantly aware of each other’s presence through the responsive performativity of the architecture itself.

We anticipated some interesting value conversations going into the semester, however, many of these conversations mined ethical depths beyond what we had imagined. The house designed to respond to Kundera’s Unbearable Lightness of Being provides one example of how students’ ways of seeing were disrupted through this studio process. Within Kundera’s novel a wife unhappily resigns herself to sharing her husband with a mistress. The student who selected this novel struggled to come to terms with why anyone would accept a third party into their marriage and this posed a significant, enduring obstacle to the completion of her house design. We were clear that, having chosen this novel, we expected this student to confront this narrative properly. We would not accept a house designed to ameliorate the pain of this relationship, to fix the situation altogether or to shy away from the difficulties the characters were facing. This resulted in subsequent conversations where we argued for a position of non-judgment and questioned whether we necessarily needed to understand, or even remotely comprehend, the life choices of our clients in order to design for their needs. The final project was exceptional but it was one of the hardest won studio successes we’ve witnessed owing to the ideological challenge it presented for the student in question.

While we did not in any way influence the individual selection of novels employed within our studio, only once did we allow a student to step away from the choice they had made. Changing clients mid-semester would have hindered their progress but, moreover, we wanted this to be difficult. Was our position justifiable? Boler states that:

An ethical aim of a pedagogy of discomfort is to willingly inhabit a more ambiguous and flexible sense of self… Learning to live with ambiguity, discomfort, and uncertainty is a worthy educational ideal (1999, 176-197).

Our aim was not to convince our student that infidelity was somehow acceptable but that whether or not we share in the value systems held by others we should try to develop the skills to respect those differences and to engage with them openly and in good faith. Markauskaite and Goodyear (2016) have suggested that the ability to be flexible will be an increasingly valuable skill for tomorrow’s professionals. A willingness to respect, understand and engage properly with the way that others create and understand knowledge will be integral to solving the kinds of complex, global problems we are faced with. Reay et al offer a recent example of this. In a co-created research project between designers and medical practitioners they found that collaboration was hindered by ‘a number of boundaries and challenges’:

Different areas of expertise often have profoundly different methods, values, theoretical approaches, even conceptions of what counts as knowledge. The difficulty arises not from differences in expertise so much as differences in culture (2017, 66).

Student feedback was obtained on the design of the housing studio curriculum via voluntary questionnaires administered at mid-semester (12 responses from 17 students) and semester-end (8 responses from 17 students). Student responses to the studio’s employment of fictional clients and, furthermore, ones who found themselves in challenging situations, suggested this achieved what the brief intended. Students reported that the use of literary characters helped them to ‘engage better with the users of the space’ and ‘added depth to the[ir] understanding of the client [they were designing for]’.
Students also commented that this encouraged different ways of thinking about how to create architecture and enabled them to gain an appreciation of how ‘human behaviours and emotions ... are affected by architecture.’ One student wrote that the use of the novel as a catalyst for making work helped them to see buildings:

Not just as a space for the activities of the occupants but also as a psychological and emotional stimulant.

Another commented that: ‘the narrative dimension forced an architectural position’ and that ‘this translation created complexity.’

As Hogan and Cranton (2015, 11) have observed, narrative can ‘allow for the trying on [of] different points of view.’ This is valuable in fostering critical engagement and reflection. Within the studio, the characters and their varying predicaments served as stimuli for strong levels of personal connection and emotional response. To borrow Turkle’s (2007) term, the characters were ‘evocative objects’ – serving as intellectual and emotional catalysts. This aided students in making abstract concepts concrete and in making sense of the relationships, behaviour settings, values and assumptions they were translating from the narrative into architectural space. Fiction was the vehicle through which students were pushed into the realm of discomfort and a tool to help them make these uncomfortable situations ‘comprehensible’ (Nussbaum, 1997, 10-11). Jarvis (2006) has similarly observed that fiction can be used to encourage transformation. Within this studio narratives became the means through which students began to unpack and examine larger social and cultural issues. Narratives were the vehicle for critical reflection, re-examination of paradigms and preconceived ideas of the self and one’s environment.

3. Towards a collective inhabitation of discomfort

The danger of a pedagogy of discomfort is that in the process of rendering a student’s sense of self more precarious they can become angry or defensive. This occurred, somewhat surprisingly, not through the moral contentiousness of the material but because we forced students to work with methods of production and representation that caused discomfort. As Boler points out (1999, 191) ‘it is often easier to react angrily rather than feel one’s vulnerability.’ We required students to explore architecture relative to the emotional tensions that domestic spaces contain, rather than from a position of function, structure and materiality. Furthermore, we required that they do so through exercises that seemed far removed from the process of architectural design – film making, writing, exhibition design and creating wearable pieces of architecture. This meant that many students were working well outside their comfort zone and was a deliberate strategy of forcing experimentation across mediums through formative, low-risk summative tasks (each not worth more than ten per cent of the final grade).

The wearable piece of architecture students were required to create had to somehow alter the wearer’s physical experience of the world in a way that resonated with the emotional state of the character they had chosen. The wearable was then to be tested, to establish its success relative to helping the wearer establish empathy with this character, and documented via a short film. This was followed by a precedent study of unconventional houses. The cumulative aim of these three exercises was for students to assemble a repertoire of architectural strategies to influence human behaviour through subtle disruptions designed to alter how spaces are inhabited and, thus, how relationships might play out within them. The final six weeks of semester was allocated to the design of the residential dwelling. Experimentation across mediums inevitably sounded more inviting to students when we pitched the
studio than the reality of being stuck in the midst of this process. We fielded more than one indignant accusation that these methods could not possibly bear any relevance to the design of a building.

A clear agenda of our studio was to find a way to push students past a shallow understanding of a client’s needs and thus facilitate a richer and empathetic architectural response. This was informed by our collective knowledge of mental health facilities design. Traditional approaches that prioritised functionality have given way in recent years to ‘patient-centred’ and ‘co-design’ approaches that seek to better understand and address the design of these facilities based on the patients’ experience of them. This aspires to show greater sensitivity to patient needs and empathy for the physical and / or psychological challenges they may be facing (McLaughlan 2014; Liddicoat 2017). We also learnt lessons from observing a Love Hotel studio run during the summer semester by two of our colleagues, Laura Martires and Virginia Mannering. Their experience highlighted the challenges that arise when students are asked to work with clients and life experiences well beyond their own.

While the Love Hotel studio was the vehicle through which students explored a broader agenda of responding architecturally to the urban context, students were asked to write fictional narratives to create a set of clients for three small-scaled proposals. This aspect of the process was of the most interest to us as it made apparent the differences in the way that a typical student cohort might view the complexities of human relationships relative to their studio leaders. In short, the depth of understanding between someone who was in their early to mid-20’s and someone a decade older (i.e. those setting the brief) became quickly apparent. Several students within the Love Hotel studio appeared to have a Hollywood-film or romance-novel idea of how human relationships played out that hindered what could have been much richer, grittier architectural schemes. This was particularly evident in cases where students had chosen to design for clients with an interest in BDSM and polyamory but provided conventional hotel rooms, complete with kitchenettes and living room furniture, without pausing to question the fit of this functionality.¹ Correspondingly, our formative learning tasks were conceived with a view to enabling students to engage more deeply; to enhance their ability to:

Think what it might be like to be in the shoes of a person different from oneself, to be an intelligent reader of that person’s story, and to understand the emotions and wishes and desires that someone so placed may have (Nussbaum 1997, 10-11).

We approached the formative design tasks with a view to disrupting conventional thinking and engendering the subtle paradigm shifts we felt would be required to enable the students to tackle the house design from an informed position. We believed these exercises had value but were concerned that the time devoted to these non-architectural tasks would come at a direct cost to the quality of the final submissions.

Survey responses (only made available to us at the end of the semester) identified that the film exercise polarized students with only half of the students finding it useful. This highlighted that, although we had successfully employed the film exercise in a previous semester, we had not properly articulated the value and purpose of it within the context of this brief. However, this also revealed that the film exercise was the most demanding of the formative tasks that may have influenced its reception. Reactions

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¹ The Love Hotel studio was run as a six-week summer intensive studio which limited the degree to which these schemes could be developed. As noted, however, client engagement was not the primary pedagogical purpose of the Love Hotel studio or the basis on which studio outcomes were assessed. The purpose of citing it here is to give background to our own process of development; not to criticise the quality or outcomes of this studio.
to the wearable exercise were more positive. Students wrote that ‘the wearable helps you sync your thinking with the novel’s character and empathise with them’, that this was a ‘quick’ and ‘easy’ way to understand the predicament their client was in, and that placing oneself in the client’s shoes enhanced the house design. One student commented:

I started to think in terms of the architecture of the body and how it feels and began thinking in terms of materiality – how the architectural experience could be experienced emotionally.

Our approach hit a deeper nerve with one student who responded, at the mid-semester point, by threatening to take us to task for what was felt to be an inappropriate approach to a master’s level studio. This led us to question if we were taking risks with our curriculum that were potentially harmful to our students’ success. By that stage, however, we were seeing remarkable results that we assumed (and student feedback would later confirm) was owing to the challenges we were setting down and to the degree of autonomy we were allowing students to exercise over the direction of their own projects. But we also questioned, on a personal level, whether this could damage our own credibility as teachers and if pulling back to a more comfortable and conventional approach was worth consideration. We faced an ethical dilemma: did we give into our fears and prioritise the desire to protect the teaching reputations we had worked so hard to establish or continue along a path that we intuitively felt to be in the best interests of our students? Without intending to we found ourselves embracing Boler’s discomfort, living the ‘mutual transaction’ she advises should take place:

It is important that the educator explore what it means to ‘share’ the student’s vulnerability and suffering (1999, 178).

This turn of events prompted us to be upfront with our students about the uncertainty within which we were operating. Wolgemuth and Donohue have made the point that both participant and researcher (or student and educator in our case):

Must feel comfortable to share their beliefs, assumptions, and vulnerabilities, acknowledging that comfort creates a space for fully experiencing discomfort, ambiguity, and transformation (2006, 1033).

We realized there were two things we’d not been entirely honest with students about. The first was the degree to which this studio was underpinned by a personal research agenda and the second was the slightly hands-off approach we had developed in response to this particular group of students. Our learning objectives, as explicitly stated, included the ability to rethink housing design in non-conventional ways; to understand how design has the potential to influence behaviour; to use fiction to inform the generation of architecture; to experiment across a range of mediums in the generation and representation of architecture and; to gain an understanding of the process of research through design. But we were also driven by a desire to understand how architecture can be imbued with tension - something that had been bugging McLaughlan since her own capstone studio more than a decade prior. We had effectively enlisted students to help with this research question, using unrequited love as a mechanism to generate tension, but we’d forgotten to inform them of it. So we came clean about the fact that this was a design interrogation for which we didn’t possess any clear answers. Of course we had a fall-back position in place - if tension wasn’t achieved then each student would still have an appropriately developed scheme for a non-conventional house.
We also explained that our seemingly hands-off approach was a demonstration of active resistance on our part, and although uncomfortable for us, seemed to be in the best interests of the group. We had a high percentage (perhaps 40 per cent) of students who were capable of critically self-directing their output and because our interest lay in developing more confident, resourceful designers, we were offering only minimal feedback and direction with regard to their work. We still had students that needed our direction and we gave this but having this high-achieving group model what a relatively autonomous design process looked like enabled us to extend this expectation more widely across the studio. While we had come to the studio with certain expectations regarding how the brief might be addressed, we had been repeatedly surprised both by the level of sophistication and the left-field responses students were bringing to it. We proposed two ways of dealing with this. We could haul the students back to where we envisaged the studio would have gone – a space of relative comfort for us, where we knew exactly what to teach and how. Or we could continue to work as we had been – slightly hands off and in a space of discomfort because we had no way of predicting what turn the studio would take next. We acknowledged that we knew the latter was a more demanding and stressful way to work, for the students as much as for us, and we gave them the choice to make. They chose to persist with the more autonomous approach. Despite the stress, the students were enjoying the freedom our studio allowed. While our surveys were not designed to capture a response to this element of the studio, since it evolved organically, we have since received emails from several students confirming that they felt this approach was valuable. As personal correspondence falls beyond the terms of our ethics agreement we are unable to cite those comments here.

Tillman-Healy’s (2001, 212) ‘ethic of friendship’ provides a possible explanation for why our honesty was so well received. In research ‘an ethic of friendship’ means that research participants are treated with respect and their stories honoured by researchers and used for ‘humane and just purposes.’ Wolgemuth and Donohue borrow this idea when discussing the employment of an inquiry of discomfort within emancipatory narrative research. They state:

If empathy is the ethical stance by which inquiry of discomfort researchers approach participants, then friendship is the overriding structure for that stance... researchers must concern themselves with the whole of participants’ lives, privileging participants’ feelings, experiences, and the needs of data and information gathering (2006, 1033).

An ethic of friendship can equally be applied to teaching within higher education. This should include an honest acknowledgement of ethical paradoxes that is also integral to Boler’s approach:

[recognising that] our ethical dilemmas are ‘intrinsically paradoxical’… that contradictory beliefs and desires may coexist, provides creative spaces to inhabit (1999, 197).

Paradoxes exist within the design studio because educators and students bring their own, varying desires for a project outcome. As Deamer has suggested these should be openly acknowledged:

an environment in which the assumptions behind the illusions [can be] discussed can only make the student’s critical faculties sharper. It also ensures that... architectural education goes beyond the production of an artefact… we are educating people who will put their designs out in the world... with vigilance and intelligence (2005, 16).

E lecting to make our own vulnerability explicit within this studio necessitated that we place trust in our students to respond in a mature and respectful manner. But also to have the fortitude to maintain faith in our abilities as teachers even with our uncertainties exposed. Unintentionally, this offered the
students a valuable opportunity to put into practice the openness to difference that we wanted them to learn from engaging with this studio. What we did not foresee what that this action would engender a degree of trust and openness within the studio that facilitated a richer, more experimental set of architectural investigations than in any previous studio we’ve taught.

4. Conclusion

The ability to listen to others more attentively and without judgement is as important in designing for clients whose values and life experiences are different to our own as it is to collaborating across disciplinary boundaries. Both require a willingness to respect and meaningfully engage with the ways that others see and make sense of the world, whether that relates to a value system that is personal or related to broader disciplinary ways of seeing and understanding knowledge. Central to a pedagogy of discomfort and the facilitation of epistemic fluency is to enable graduates to become more comfortable occupying spaces of uncertainty and ambiguity. The studio can be focused to better enable students to develop the confidence to work within uncertain spaces and the willingness to let go of pre-existing ideas about how knowledge is formed, including how research and design processes are pursued. This allows multiple understandings to co-exist while resisting the need to place these within a hierarchy that values one form of knowledge production (usually that which is familiar) over other forms. A willingness to fail productively becomes an important strategy in developing this confidence.

Within the design studio we can intensify the space of uncertainty by employing discomfort in two dimensions - to disrupt students’ ways of seeing, through the material they encounter, and to disrupt their habits of making. There are clear benefits to this pedagogical approach including the confidence to occupy and work within uncertain problem spaces and the recognition of one’s capacity for agency and leadership. This requires and provides opportunities for students to develop an appreciation of the value of trusting themselves and others, and the skills both to work autonomously but also to accept and offer help within a creative working environment. A pedagogy of discomfort should be accompanied by an ethic of friendship that is honest in acknowledging the conflicting values and ethical paradoxes that exist within the context of the design studio. This is an approach that does not assume what is in the best interests of a student’s development but extends trust that they are capable of making important decisions about their own learning.

Understanding that architecture is not simply a product, reflection or spectator of social values, but that it plays an active role in shaping and upholding perceptions, discourses and behaviours is critical to enable students to engage meaningfully with these architectural typologies and the clients they cater for. Student feedback provided evidence of students becoming more open to alternative points of view, of greater engagement with user’s needs, values and perspectives, and increased self-awareness through their own negotiations of discomfort. Bolger’s pedagogy of discomfort provides a mechanism for cultivating this understanding. This can assist educators in empowering graduates to provide leadership though the disciplinary skill set specific to the architectural profession; to employ their skills in design thinking to advance agendas broader than the simple production of buildings; and to create graduates who are resourceful, independent thinkers, with a capacity for collaborative, integrative thinking.

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References


Exploration of Indoor Tracking Systems as an Architectural Research Tool for the Study on the Housing for the Elderly

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Abstract: With the increasing elderly population, there is a heightened demand for knowledge about housing that best fits their needs, particularly in the event of increased impairment. More specifically, greater understanding is required of those with limited mobility and reduced spatial usage. This research examines the use of indoor tracking systems as an architectural research tool, to investigate the spatial use of the elderly in their private house. Data on equipment performance specifications, cost and operability was gathered through a literature review, through a review of technical specifications and eliciting further information by emails to the suppliers and finally the physical testing of one system. This data was subjected to a comparative analysis. The research found that there were a complex set of requirements for accurate recording of spatial use, which are derived from housing setting, research design and the required scale of movement to detect. The systems that meet all requirements for tracking the elderly indoors are scarce. Improvements to currently available indoor tracking systems would enhance the potential for using them as part of user focused architectural research and provide a more precise and effective knowledge for the design of housing for the dependent elderly.

Keywords: Architectural research methods; Indoor tracking devices; spatial use; housing for the highly-dependent elderly.

1. Introduction

The population of older people in New Zealand, as is the case in many other countries, is growing rapidly. Among this population, the proportion with high care needs are projected to increase more rapidly than the population at large (LiLACS NZ, 2017). As people experience greater difficulties with mobility, they typically spend more time in their home, and as a result, the home becomes more important for creating meaning (Hale et al., 2010; Cooney, 2012). However, as people become more dependent, they often experience a decrease in quality of life (Hale et al, 2010). To maintain a highly impaired body at home usually requires ‘the reorganization of space,’ such as; the re-modelling of a kitchen; the closing off of spare rooms that are no longer accessible; the placing of necessary items conveniently to hand such as on small tables on either side of the individual’s chair; and to facilitate as little movement as possible. However through spatial reorganization, material possessions which mark social identity are often removed and control over space is eroded. Consequently, as needs for assistance and external care increase, the private spaces of highly dependent people are often violated (Hale et al., 2010).
There is a requirement for housing that better fits the needs of the elderly people, as the degree of their impairment increases. In order to effectively design supportive spaces greater information is needed on the requirements of space that maintains elderly people’s privacy and identity as well as their independence. The increased knowledge of detailed special usage of the elderly with high-care needs in their homes could provide valuable insights for the design of housing that enhances their well-being.

1.1. Use of an Indoor Tracking System for an Architectural Research Tool

In order to obtain intimate knowledge of spatial use by those with high dependency, an impersonal tracking system is desirable to avoid the influence of an observer and to practically collect data over long periods of time. The system must be capable of collecting detailed information on daily activities such as the time taken and the location. To obtain the qualitative aspects of use such as the individual’s feelings and perceptions, a mixed-method strategy is required to complement their physical movements. As such, a three-part survey was also included, consisting of time-diaries to be kept by the elderly relating to their activities; researcher’s observation of the care practises; and a follow-up interview to collect their perceptions. Time-dairy maintenance has proven a useful method to provide information on activities as well as their perceived duration, frequency and location; and has been used for a range of analytic purposes directly related to well-being (Gershuny and Robinson, 1988). A researcher’s direct observation in private space while useful, can influence the natural behaviours of the elderly (Sommer and Sommer, 1991). Follow-up interviews provide the means for collecting information that is not adequately obtained or not well understood through the other techniques. To obtain an accurate record of physical movement a number of devices were investigated. Instruments that could record activities as well as location and time such as video cameras were considered; however, most had the potential to influence behaviours, not to mention ethical concerns, particularly when installed in spaces that require higher levels of privacy such as the bathroom (Kayser-Jones and Koenig, 1994). To collect the most accurate information with the least influence on behaviour, a mixed-method strategy using an indoor-tracking system was deemed the best possible method.

1.2. Indoor Tracking Systems

There have been remarkable developments in positioning systems during the last decades, especially, in outdoor positioning systems, which are typified by the Global Positioning System (GPS). However, GPS is not suitable for indoor positioning as the attenuation caused by roofs and walls affects the localization estimation (Schutzberg, 2013; Karimi, 2015). Systems designed for indoor environments, known as indoor positioning systems (IPS), have also become very popular and in demand for a variety of uses; such as applications for ‘navigation,’ ‘wayfinding,’ ‘proximity,’ ‘geo-fencing’ and ‘people and asset tracking.’ IPS for the ‘navigation’ and ‘wayfinding’ are commonly used in hospitals and malls, and there are applications for ‘proximity’ such as providing real-time information via audio for tours in museums and connecting people of interest in proximity to one another (Schutzberg, 2013; IndoorAtlas Ltd., n.d.). ‘Geo-fencing’ enables you to set-up triggers when a mobile device enters or exits the defined boundary, as is commonly used in the healthcare sector (IndoorAtlas Ltd., n.d.).

IPS is most commonly used for people and asset tracking in two main areas: the accurate, automated, and error-free tracking in transport and logistics organizations (as well as healthcare organisations) and streamline asset tracking to eliminate loss and improve supply management; and for use tracking people in healthcare and life sciences organizations (IndoorAtlas Ltd., n.d.). Other uses for people tracking systems include customer analysis for better marketing (Spink et al., 2013; Hwangbo et al., 2017) and
tracking location of players in sports to inform and aid coaching (Lee and Lee, 2009; Mäkinen, 2015). The applications of IPS for research focusing on people’s spatial use include tracking outpatient movement (Singapore International Chamber of Commerce, 2016) and tracking wandering patients in hospitals or nursing homes (Kearns et al., 2008). However, few cases were found using IPS as an architectural research tool to investigate people’s spatial usage, particularly when focusing on small movements in a confined house setting.

Due to the limitations of the literature, a number of challenges were anticipated when considering IPS use for tracking impaired elderly people indoors. These included the suitability of the device for the proposed settings, the ease of application and its user friendliness. Moreover, there were operator concerns for system accuracy; requirements for specific technical knowledge such as that needed for programming, and budget considerations. There was need to explore IPS that were best suited for the practical use for this specific research.

1.3. Aims and Methods
This paper aims to explore the possible IPS which are most suitable for practical use in the study of detailed spatial-use by the elderly with limited mobility living in their own homes. Data on equipment performance specifications, cost and operability was gathered and the requirements and the possibility of the IPS meeting them were examined through the two phases of the study. First, six products with different sensor systems were examined for suitability through a literature review and eliciting further information by emails to the system providers. Next, physical testing of the system that had been identified as most suitable was conducted to examine the operability and the tracking accuracy. Finally, the findings in two phases were integrated to examine the requirements for the IPS for the accurate tracking and the practical application for the specific research. Improvements and possible IPS suited for the study are then discussed.

2. Findings

2.1. Comparison and identification of possible IPS through literature review

2.1.1. Sensor systems and selection of IPS products
An IPS is characterised by the sensor technology it uses, such as magnetic fields, radio waves and sensory signals relayed through mobile devices, which can detect the locations of objects or people within buildings (Schutzberg, 2013). The systems based on magnetic field detect variations of the magnetic field caused by building structures to estimate the location (Sterling, 2014; IndoorAtlas Ltd., n.d.). Radio waves used for IPS include radio frequency identification (RFID), Ultra-Wideband (UWB), Bluetooth Low Energy (BLE) and WiFi signals. RFID refers to the technology that uses radio waves to automatically identify people or objects, and unpwapped RFID tags (Passive RFID) are not suited for obtaining detailed location information (Kearns et al., 2008; Frequently Asked Questions, n.d.). UWB is a variant of RFID, which is radio frequency signal with specific frequency spectrum. Its features, such as penetrating a wide variety of materials including the human body and walls and low power consumption, make it highly desirable for applications in location tracking as well as other uses (Kearns et al., 2008; Alarifi et al., 2016). Due to the widespread adaptation of the Bluetooth standard, BLE solutions are cheap and easy to integrate into other systems and everyday devices such as phones (Augur, 2017). IPS based on WiFi signals are now well-established due to the ubiquity of WiFi (R. Faragher, 2014). Near-field electromagnetic ranging (NFER), an
emerging IPS technology. Its features include the use of low frequencies, which diffract around the human body rather than being blocked by the body experienced in microwave systems like UWB, which makes tracking people possible (Schantz, 2007). Other sensory systems include those based on the ultrasound signal, such as the high accuracy and a low cost of the transducers compared to radio-frequency-based systems (Medina et al., 2013).

One product was selected from the IPS using each sensor system described above except for Passive RFID, which was identified as not suited for obtaining detailed location information. A high level of accuracy is required for tracking the elderly’s small movement in the small space. Due to the lack of similar precedents, the precise accuracy required for this study was not clear from the literature. However, the products which provide accuracy of approximately up to 2m was included for the consideration. The products that could provide enough accuracy were selected. Using these criteria, six potential systems (A-F) were identified (Table 1).

Table 1: Selected products

<table>
<thead>
<tr>
<th>Product</th>
<th>Manufacturer</th>
<th>Main sensor system</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Estimote</td>
<td>BLE</td>
<td>0.5-1m</td>
</tr>
<tr>
<td>B</td>
<td>Accuware</td>
<td>WiFi/ble</td>
<td>up to 2m</td>
</tr>
<tr>
<td>C</td>
<td>IndoorAtlas</td>
<td>Magnetic field</td>
<td>1-3m</td>
</tr>
<tr>
<td>D</td>
<td>DecaWave</td>
<td>UWB</td>
<td>up to 10 cm</td>
</tr>
<tr>
<td>E</td>
<td>Q-Track Corporation</td>
<td>NFER</td>
<td>Better than 30-40cm</td>
</tr>
<tr>
<td>F</td>
<td>Marvelmind</td>
<td>Ultrasound</td>
<td>1-2 cm</td>
</tr>
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2.1.2. Requirements for IPS products

The requirements for the tracking system that can enable tracking the movement of those with limited mobility in their houses, are identified as below, which include work environment, ways of putting the device on, requirements of special knowledge and cost.

- **Work environment**: The settings to be studied are houses specifically designed for the elderly such as housing units in retirement villages and public-sector housing complexes, which include detached, semi-detached and apartment-type houses with 1-3 bedrooms and bedsit/studio types. All settings are expected to have inner walls that separate rooms such as those between the bedroom and the bathroom. The system should be able to work in multi-room sites. It should also be able to function in a variety of construction types, as the construction systems may vary and include timber, steel and reinforced concrete.

- **Practical ways to wear the** device: It is essential that the highly-dependent elderly with mobility impairments can wear the device in a practical way, for long-duration surveys.

- **No technical IT knowledge being required**: Some devices required high levels of technical IT knowledge (including programming skills), that a general architectural researcher would not normally have acquired.

- **Cost**: The system should be affordable, with a budget ceiling of 1,000 NZD.
2.1.3. Evaluation of products

Six IPS products were evaluated in terms of the requirements identified above. The results are summarised in Table 2.

- **Product A:** This system requires iBeacons which costs approx. 500-900 NZD depending on the number required for the size of the site, which meets the requirement of cost. A smartphone was also required, which was not included in the purchase price. The sensor works Non-Line-of-Sight, which makes it possible to track in multi-room sites. The person being tracked must hold an iPhone parallel to the floor, in front of the body at chest height. Even if it was fixed parallel to the floor in front of the body on a harness, this would likely affect daily and social activities. Moreover, it requires knowledge in programming for mapping manually using Xcode and the SDK provided by the company, which is required for the system to work in multi-room sites (Estimote, n.d.).

- **Product B:** It only requires a suitable smartphone in the setting with dense WiFi coverage in the venue; where there is not enough WiFi, extra equipment such as a portable WiFi and WiFi extenders is required. The software platform is offered by the provider at the monthly cost of approx. 250 NZD/month (Accuware, n.d.), which would be within the budget, depending on the duration of the survey, even including the extra equipment. The device, can be placed in a pocket or attached to a belt.

- **Product C:** This product requires a smartphone and provides the basic operation for free. However, the environments that suit this system are limited to those with a steel or concrete structure. Another disadvantage is that the product does not provide a visualising system suited for tracking; it only allows the user’s location to appear on their own smartphone (IndoorAtlas Ltd., n.d.), which then requires the programming skills to develop a suitable visualising system.

- **Product D:** The system works both in multi-room sites and in various types of structures. The device allows various ways of holding it while being tracked. However, the most basic kit costs over 1,000 NZD, which doesn’t meet the requirement in cost (DecaWave Ltd, n.d.). It also requires technical knowledge to deal with the special modules that can be used as anchors and tags (that mounts an IEEE802.15.4-2011 UWB compliant wireless transceiver IC, an antenna and so on).

- **Product E:** It works both in multi-room sites and in various types of structures. The tags allow the user to carry it in various ways. However, the system costs over 20,000 NZD (Q-Track Corporation, 2016), which was acritical disadvantage.

- **Product F:** The basic set is approx. 500 NZD, which is within the budget (Marvelmind, n.d.). However, because it requires unobstructed sight for the sensor system to work, it doesn’t work in multi-room venues without deploying substantial number of devices, which would impose very high costs. The mobile device requires to keep ‘direct line of sight to 2 or more stationary beacons,’ which forces the person to hold it in the high part of the body; however, this affects their behaviour and is therefore not realistic.

<table>
<thead>
<tr>
<th>Product</th>
<th>Requirements</th>
<th>Technical IT knowledge not being required</th>
<th>Cost (up to 1,000 NZD)</th>
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<tr>
<td>A</td>
<td>Yes</td>
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### 2.1.4. Conclusion: the possible product

Some sensor systems do not allow the use of the system in multi-room settings or in certain types of building structure. The technical IT knowledge is required in most products. The IPS designed for ‘asset/people tracking’ provides a visualising system best suited for tracking, as compared with those designed for ‘navigation’, which require users to develop the visualizing system themselves. The products which could provide both adaptability to work in various types of venues and most other requirements, such as those based on NFER, were characterised by very high cost.

Product B, which use BLE and/or WiFi for the main sensor system, were identified as the most suitable systems. However, there are concerns in the accuracy as well as usability and operational issues, which were examined in the following physical examination of one system.

### 2.2. Physical Testing

Physical tests were conducted on the system identified as best suited to personal tracking with high accuracy in order to evaluate their operability and performance (accuracy etc.). For the tests, information was elicited by emails from the system providers to supplement online documentation, due to the complexity of the systems and to evaluate their user friendliness for an architectural investigator. The test was conducted in a typical timber-structured house of approximately 80 m² with 2 bedrooms. This location was deemed typical in terms of the size, layout and structure.

This IPS works with radio signals (WiFi and/or BLE), and requires WiFi access points and/or iBeacons, a certain type of smartphone (on which the special app is installed) and the software platform provided by the company at a monthly cost. Both WiFi access points and iBeacons, which were available at the test site, were used for the test. It was anticipated that some survey sites may not have WiFi access points; however, mobile WiFi access points (WiFi hotspot and WiFi extenders) could be used. This system is suited for inside the building with walls (Accuware, n.d.).

- **Operability in Set-up:** Prior to the configuration of the space, a floor plan should be prepared in an image file and uploaded to the server (Figure 1 left). In the deployment of radio signal source devices, the devices should be placed along the perimeter of the area; however, the exact location can be decided to suit each case (Figure 1 centre). The devices may be placed on the ground as well as on the ceiling. Spatial calibration is made by walking along the defined routes twice, once in each direction, tapping the points on the app on the smartphone (Figure 1 right). However, walking speed must be constant even when turning corners and tapping the device, which is physically difficult. Training for this process is essential.

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Figure 1: the house plan (left), deployed devices (centre) and walking routes for spatial calibration (right)

- **Performance in tracking (accuracy etc.)** The difference between actual position and that on the map was approximately 2 m at most, and the tracked person was often located in a different room to the one that they were in (Figure 2). However, the tracking was unstable; for example, there was movement in the displayed position even if there is no change in the actual position. This accuracy and stability would not allow to track small movements.

Figure 2: Evaluation of performance in tracking

- **Other:** It was made clear through emails from the supplier that the size of the fingerprinted area is recommended as at least 100 m² for better tracking accuracy, which means the test environment as well as most sites for the study might not provide the best results.

**3. Discussion: Application of IPS for Spatial-Use Study on Housing for the Elderly**

The application of IPS for spatial-use case studies for housing for the elderly is complicated by a complex set of requirements. Evaluation was undertaken through examinations in two phases. Considerations for specific spatial-use in the confined context of housing for the elderly, the possible IPS best suited for this type of study, and the possible improvements are discussed following a comparative analysis.
3.1. Required IPS specifications for the use in the older person’s house setting

The performance requirements derive from various features of the setting in a typical elderly person’s residence. The system should be able to work in various types of construction types, rather than specific types such as those based on magnetic field, which are only well suited for steel-structure buildings. As a house is typically made up of more than one room, the system should be work in multi-room setting, which is affected by the type of sensor system and systems such as those based on ultrasound are not suitable. There should be consideration of the minimum space the system can perform in, as well as the maximum space. The performance of some systems is compromised in smaller settings. Consideration should also be given to the operability of set-up.

3.2. Required IPS specifications to suit the research design

Research of this nature typically includes many individual case studies. It is desirable for the set-up procedure to take as little time as possible and to be simple enough to accommodate a variety of situations. The devices must allow for repeated use and be easily attached and detached from typical wall surfaces. The iBeacons used for the tests were designed to stick to walls permanently and had the potential to both damage wall surfaces on detachment and subsequently lose the ability to refix to another surface. The system must also permit practical application by the user holding the device. Rigid requirements for use such as being held at the fixed angle in front of the body throughout the survey are not appropriate for this type of study.

3.3. Required accuracy for tracking the movement of the elderly indoors

Tracking the movement of the elderly with limited mobility in the small room in a house requires high degrees of accuracy and stability. The tested system, reported a 2m accuracy; however, the results identified insufficient stability producing false results—detecting movement in an inaccurate direction and locating users in a different room than the one they were in. This level of accuracy, combined with its instability, did not provide useful information for location and movement of a person. Considering the effect of instability/technical error, as high degrees of accuracy as possible would lead to the best results. As such, systems which could provide the accuracy of 1m or less would be required.

3.4. Possible improvements

Systems that meet the accuracy requirements as well as all other requirements for tracking the elderly indoors are scarce. There is need for higher degree of accuracy. Tracking accuracy is greatly affected by any inaccuracy in the configuration of the space during set-up (Accuware, n.d.; Estimote, n.d.). Improvements in accuracy could include improved operability in set-up, enabling configuration of spaces with multiple obstacles, thereby reducing operational errors. The systems which provide high levels of accuracy are characterised by high cost; a reduced cost would widen the application of IPS.

There should be improvements in the device to be held by the people who are tracked, in terms of flexibility in how to wear or carry the device to best suit high-dependency elderly people. For long-duration surveys, consideration should be given to putting it on the wheelchair or putting it in a pocket or a pouch. There should be consideration of the weight of the device; even the weight of smartphones can tire the elderly, depending on how they hold it. Benefits of using smartphones include the improved accuracy by the use of their internal sensors; however, they typically require impractical methods of
holding them as well as relatively heavy weight. Lighter devices that provide enough accuracy would be more suitable.

A lack of operator technical knowledge limits the options for types and models of IPS; the systems that provide higher accuracy typically require IT knowledge, such as competency to work with programming languages and modules. Acquisition of specialised knowledge or inter-disciplinary collaboration between teams specialised in the system development and those with other specialities would widen the possibilities application of IPS. There is a product which was not included for comparison in this paper, that is an integrated solution in which the device, software and the service are provided to achieve the implementation, would be ideal; however, at present it is cost prohibitive (over 40,000NZD) (SDR Scientific, 2016).

Some UWB-based systems such as Product D, which can meet all the requirements except for requirement of technical knowledge and the cost, which is slightly above the budget, have possibility to be used in the research, given the reduced cost and acquisition of or support in technical IT knowledge (DecaWave Ltd, n.d.; Pozyx Labs, n.d.).

4. Conclusion

This research has examined the use of indoor tracking systems as an architectural research tool, to investigate the spatial use of the elderly with limited mobility in their house. The research found that there were a complex set of requirements for accurate recording of spatial use and practical application of IPS, which are derived from housing setting, the research design and the required accuracy to track the individual’s movements. Careful selection of the IPS to match the specific application is necessary.

Improvements to currently available indoor tracking systems would include improvements for accuracy, operability and cost. These improvements would enhance the potential for using them as part of user focused architectural research in general and provide a more precise and effective knowledge for the design of housing for the dependent elderly.

The limitations of this study include that the physical testing was not conducted for the duration which is required for the real surveys (8 hours), which would have hindered the examination of the aspect of battery consumption of the device. The tracking in the house with interior walls made of concrete or bricks, which would affect performance of some sensor systems, was not considered, because most of the interior wall linings were assumed to be plaster board, softboard or hardboard; however, consideration of the wider variety of wall material types would widen the possibility in application of indoor tracking systems in architectural research.

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Facilitating Transformative Experiences

Case Studies for School Design

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Abstract: Our rapidly changing world, current environmental crisis and calls for regenerative approaches to development evidences the need for change. To achieve sustainable change a transformation in the way we understand and conduct relationships in and with the world is required. The environment is not something at arm’s length, but rather a complex system, of which built, natural, and social systems, among others, are all part. As a profession architecture must have approaches that are reflexive, responsive, longitudinal and inclusive. This paper draws together two illustrative case studies to demonstrate such approaches. These case studies underscore the potential to facilitate continued transformation within approaches to the design of space and the discipline of architecture. The two workshops discussed in this paper enabled architects, teachers, policy-makers and others, to look at their own roles within the broader systems that shape the built environment of schools. Transformative learning is taken as a theoretical model through which to reflect on the two case studies. Transformative learning experiences are those that are most likely to prompt, support and sustain change in worldview and behaviour. They can be catalyst events that are uncommon, unusual or uncomfortable, and challenge assumptions and beliefs. This paper focuses on three aspects that modified the participants’ ability to engage more or less fully in the workshops as a transformative event. These aspects are discussed here as key factors which those seeking to develop events to help provoke change could use to guide workshop development and reflection. These three aspects are the role of unfamiliar context as provocation; agency as capacity and ability to change, and making connections to the everyday. These three aspects are discussed for their potential to contribute to transformation as part of the continuing development of the architecture profession.

Keywords: Workshop design; transformative learning; professional development.

1. Introduction

This paper draws together two illustrative case studies to underscore the potential to facilitate continued transformation within approaches to the design of space and the discipline of architecture. There is a pressing need for architects to engage more broadly in the world (Salama, 2012), and to recognise the place-making and design-by-use actions of the many others who shape our social, physical and cultural
environments. Architects develop the knowledge and skills necessary to design responsibly by learning about the nature of the environment, the needs of the client and the potential impact and contribution of design. In response to our ever-developing understandings of the world—and changing construction, occupation and use of the built environment—the need for evolution in the architectural profession continues (Brown and Holder, 2013). Calls for professional change, initially focused development on technological knowledge, are now focused on the skills necessary to develop environmental, social and cultural understanding. In the last 50 years, during a period of rapid advancement and environmental and societal change, the call for change in architectural education has been persistent (Llewelyn-Davies, 1960); (Dutton, 1987); (Buchanan, 2012). This paper adopts a life-long approach to learning that considers ongoing professional development part of architectural education.

Transformative learning experiences can occur when a collaborative process of design requires critical reflection and the sharing of different experiences through meaningful communication (Atkin, 1999). These experiences can help professionals understand how they view their world, and the world of others, and make sense of their own post-tertiary learning experiences. In this paper two facilitated cross-disciplinary professional workshops that problem-solve design elements of school environments are selected as a focus area. The design of schools presents a ripe ground for critical reflection on the role of the built environment in shaping and contributing to our social-ecological systems, in particular because the learning that happens in schools informs the fundamentals of our understanding of our place in the world which informs and influences behavior and actions (Miller, 2005).

2. The Case Studies: Workshops Designed to Prompt Transformation

In this paper we take as case studies two workshops designed to provoke transformative thinking about school design. The aim of Workshop 1 was to enable participants to explore the future of learning and learning environments. Workshop 2 invited participants to reconsider the design of school environments to support children’s physical activity. These two workshops have been selected because they were designed to challenge the participants—architects, teachers, policy-makers and others—and because they are well known to the authors as the facilitators. The case studies offer rich sources of information about the workshop intention, design, participant groups, interactions and outcomes. The workshops produced artefacts such as design objects, written participant reflections, and verbal presentations of participant design enquiry. Recordings of the events through video, photograph and the participant-generated artefacts form the material base of this reflection. The workshops were documented through photography and video by one person, who was both non-participant and non-facilitator.

This paper forms part of an ongoing critical reflection on the authors’ professional facilitation practice. The lens used to undertake reflection in this paper is a transformative learning model which has emerged from recent research by one of the authors into architectural education (Mackintosh, unpublished anticipated 2018). This model, originally focused on learning experiences in formal architectural education, has been modified to suit professional learning. The following descriptions of the workshops are structured to facilitate understanding the participants, the multiple contexts in which the learning occurred and nature of the inter-actions that took place.

2.1 Case Study 1: Learning Environments WA

Learning Environments WA, a professional body of school architects, facility managers and teachers, has developed a symposium-workshop model as a central part of their professional development activities.
These activities inform the education community and provide an avenue for members to extend their professional development. The symposium that preceded the workshop described here focused on the future of education, prompted by recent discussions held nationally about the future of work (Tori and O’Connell, 2017). At the preceding symposium it was suggested that an ‘ideas-boom’ will follow the mining-boom and implied the need for education to look beyond literacy and numeracy as critical thinking, creativity, and emotional intelligence become increasingly important qualities for our societies. The questions this workshop sought to explore were: What is the new educational focus post-boom?; How will the way we shape our learning environments need to adapt? The workshop was structured to provide a sequence of activities that foregrounded discussion about how learning occurs.

The three-hour workshop was held in small art gallery, temporarily fitted out with school furniture supplied by the event sponsors. Tables and chairs were set up in groups of 6-8, modeling the way many new classrooms are organised. At the front of the room a projection screen was used by the keynote speaker and the facilitator in the introductory session and by the groups for their concluding presentations. The participants, architects, designers, school principals, teachers, and high school students, were invited to choose their own seats as they were introduced to the topic of the workshop. After being guided through a series of questions that set the scene and encouraged participants to focus, participants were asked to reflect upon their personal approach to education and learning. The facilitator used participant responses to questions asked about what they felt the future of learning held to organize groups of around six people each. This resulted in groups of like-minded people whose thoughts on curriculum and learning were aligned, as opposed to groups of colleagues or those from similar backgrounds. The groups were guided through the process of designing a 20-week cross-curriculum learning experience for year 11 and 12 students, exploring alternatives to conventional learning and how the core skills are developed. The workshop concluded with another individual reflective exercise as participants shared how their practices might change as a result of this experience.

Figure 1. The initial map (left photo: Robertson 2016) was inspired paintings by remote Australian Aboriginal artists hung in the gallery, and a search for innovation (right photo: Miller 2016).

Over the course of the session, the groups were encouraged to post photos, websites and resources on Instagram. This served not only to document the processes and progress made during the workshop but also provided small milestones within the larger task, and prompted moments of reflection. These

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postings were also to be used by the groups when presenting their work, providing insight as to how they had come to their final outcome, and the path they took. During the two-hour session, a break was provided, in which participants stepped outside and spoke to friends and colleagues who inevitably were in different groups. This served to provide yet another moment of reflection.

For one group, for whom progress was slow, explaining their experience to another group served to shift their thinking, and seemed to provide the catalyst needed, as this group made rapid progress when they returned to their task. The student in their group was also more carefully listened to, and his contributions led to an increased pace of progress. Another group, inspired by the surrounding artwork, focused their project on exploring a sense of place in the 21st century through an Aboriginal understanding of landscape and place. This group looked beyond the knowledge of those in their group, drawing from technological innovation and other cultures to resolve their final project (Figure 1). Many in this group chose not to have a break, and the student was actively engaged in the group discussions.

2.2 Case Study 2: CSRR Active Schools Workshop

The second case study was a design workshop led by the Centre for Sport and Recreation Research, for invited representatives from policy, teaching, industry, academia and design. Participants where guided through a facilitated session in response to the central question: How can the school built environment be re-imagined as a place that stimulates and supports physical activity? The structure of the workshop adapted several design-thinking exercises and built on the authors’ experience in design practice, design teaching and industry workshop facilitation. The 4-hour workshop pushed beyond idea generation and had interdisciplinary teams prototype and test some of their ideas.

The workshop was framed in four parts: Immersion, Synthesis, Ideation and Prototyping. The Immersion phase was structured to take participants into exploring their experiences and memories of traditional classroom settings. In the Synthesis phase the groups reflected on their individual and collective experiences and identified a topic of interest to focus on for the remainder of the session. In the Ideation phase the groups were set the aim of 100 ideas in 10 min with the intention that the ideas be ‘fast and loose’ and that they from the range of possibilities the groups would then pick one to explore more deeply through the Prototype phase. The outcomes of the workshop were anticipated to lead towards more refined ideas which could be collated and curated to inform school designers, decision makers, investors and users.

The location of the workshop was a large open room at the West Australian Department of Sport and Recreation. Two of the participants from this organization attended the workshop as professionals engaged with informing and enacting children’s sport and recreation policy. During the course of the afternoon, the layout of the room changed according to the activity. The workshop started with introductory information and the background being delivered in a traditional classroom format. In the immersion phase, the participants were invited to dismantle the traditional classroom set up, to reuse the furniture, the space and the content of a box of craft tools and materials to make a setting in which their group would like to pursue the rest of the challenges. The workshop concluded with participants coming together around these reconstructed spaces for the groups’ final presentations.

Workshop activities were completed individually, in pairs or in groups. The five groups were selectively composed to have a mix of teachers/school managers, government/policy, architects/designers, and academic researchers from various disciplines engaged in research into children’s mobility. At various stages, the participants were asked to complete tasks individually or in their groups. Group tasks varied from constructing the group’s work setting, collectively reframing and refocusing the groups specific
research question, brainstorming and finding 100 ideas in 10 minutes, and collaboratively building a prototype of one of their five best ideas.

Each of the five groups developed responses to separate research questions with distinct outcomes. One group developed a large-scale prototype the ‘Impossible Reading Room’ as a means of bringing physical education to the school library (figure 2). Assembled from furniture, masking tape markings on the floor, caution tape strung between chairs, sports gear and craft materials, the prototype was tested by other participants at the workshop to see whether the group’s prototype did suggest a more physically active encounter with a library setting. Another group asked the question: How can we allow kids to move through a school in a way that provides a diversity of experiences for social, active and educational benefits? By exploring how it would feel to move through various spaces including sensory and social experiences they came to the idea of a ‘landscape code’ to guide the design for primary school landscape. The group presented their ideas through a series of short video studies where some group members performed the part of landscape elements, and others played the part of children playing in and moving through these landscapes (figure 3).

3. Intense Experiences, Capacity to Change, Connection to Everyday

Transformative learning experiences are those that are most likely to prompt a change in worldview and behaviour. They can be catalyst events that are uncommon, unusual or uncomfortable, and prompt a challenging of assumptions and beliefs (Dewey, 1910). Many of the day-to-day activities of participants and facilitators (architecture, design, teaching, management, leadership) are associated with high levels of responsibility, and therefore risk. It is difficult in these high-risk professional environments to make the
space for transformative learning which requires more than the relatively low-risk activities of reviewing and building into currently-held beliefs. The opportunity presented by these workshops for participants to be able to explore new ideas, to try out different ways of doing things, and to give and receive feedback from each other was one not often possible within their high-risk professional lives.

3.1 The role of workshop design and facilitation in supporting transformative learning

While all participants in the two case study workshops had a common interest, their diverse backgrounds, practices and points of view meant that the activities were demanding and at times even uncomfortable for participants. For some groups, pushing through those uncomfortable moments and exploring different ways of thinking was difficult. Feedback received from some participants indicated that these workshops were a reminder of the uncertainty, and even fear, that many learners face: fear of failure, of doing or saying the wrong thing, and of the final outcome not meeting expectations. Yet providing a 'safe' environment in which these challenges could be met meant that risks were more likely to be taken. The familiarity of the facilitators and some of the other participants; the choice of venues as a shared community or institutional space; and a shared interest in school spaces, children’s experiences and teaching and learning (Workshop 1) or physical activity (Workshop 2) contributed to this safe environment and the active engagement of participants.

![Diagram of facilitator role](image)

**Figure 4:** The role of the facilitator in establishing the safe, intense, collaborative and reflective environment to support the opportunity for a transformative learning experience for participants.

This discussion will focus just three aspects of these learning experiences that modified the participants’ ability to engage more or less fully in the workshops as a transformative event (Figure 4). These aspects have emerged from ongoing research in which alternative methods of documenting and analysing existing architectural programs have identified key aspects of transformative learning experiences (Mackintosh, unpublished). Three of these aspects are discussed here: the intensity of the workshop experience for participants as they learnt to interact in unfamiliar context; the agency of participants to find the capacity and ability to change from their typical roles into new behaviours; and the opportunities taken by participants to make connections between the workshop activities and their own everyday professional or personal practices. For each of these aspects we first introduce the concepts
and then draw illustrative examples from the two case studies. This reflective discussion will, as with the paper so far, focus on the experience and event of the workshops, rather than the products.

### 3.1.1 Unfamiliar Contexts as Provocation

The significance of unfamiliar contexts and the intensity of learning experiences, became evident during the mapping of contexts, documentation of interactions, and recording of participant narratives in prior research (Mackintosh, unpublished). Unfamiliarity and intensity can be considered across three contexts of learning experiences: social, physical and educational. The types of participants and their roles, size of the overall group, or number of groups within the system are all factors within the social context. The built context can be experienced as intense when activities take place in new, unfamiliar spaces different from the typical spaces that dominate school campuses or professional workplaces. The educational context—the curricula and content of learning—can be intense when it is narrowly focused and there is little opportunity to diversify content. The intensity of an experience varies between individuals, depending on their prior experiences, ability and worldview.

Workshop 1 worked to produce a new situation for both architects and teachers. For the architects the workshop structure was challenging because rather than starting with a physical brief, the workshop started with the high school curriculum. Participants were first asked to work out what was being taught, how it was being taught and how it was learnt. Only towards the end of the workshop were participants asked to explore what physical space might be needed to home the learning program proposed for that curricula. For many of the architects looking at curriculum and the pedagogic language was new, and this produced a challenging experience. For the teachers in the group, familiarity with the high school curriculum and learning was high, but the idea that a learning experience could be designed to span 20 weeks was unfamiliar. Planning a longitudinal learning experience for students was challenging for those used to working within the bite-size structure of the high school learning environment. Conversely, for the architects, thinking about a learning experience as longitudinal and iterative was familiar from their university experiences, and from the long duration of design projects.

For many non-designers at Workshop 2 the structure (educational context) of the workshop was new. The fast-paced, playful and creative-thinking approach which worked through phases of empathy, problem identification, ideation and prototyping to produce a designed artefact by the end of the session resulted in an intense experience for the non-designers. But, even for many of the designers the workshop was successful in establishing an unfamiliar context, as designers were asked to communicate design ideas in different ways than they would typically. For example they were encouraged not to produce architectural drawings, but to instead seek ways of exploring and communicating ideas that were more inclusive of all members of their group. One group that produced experiential videos only pursued this path when the facilitator overheard a group member propose to communicate their ideas about diversity of school landscapes through architectural drawings. The facilitator pointed out that that mode of communication would exclude all but two members of the group, and suggested that they might find another means to work through their ideas.

Observations made at these workshops indicate that the role of the facilitator is critical in supporting participant engagement and transformation. Facilitators respond to situations as they occur, and adapt the guidance offered to participants accordingly as they navigate through these unfamiliar and intense contexts. In Workshop 1 it was important for the facilitators to remain distant at times, and to allow groups to navigate their own way through the new experiences. This resulted in some participants recognising why the task was challenging, and ways in which they could change their own teaching
practices. In Workshop 2 the facilitators provided reminders that each group included people with different visual communication abilities, different areas of expertise related to the workshop focus, and that there were no pre-existing good answers to the central questions of the workshop. These reminders prompted communication and exploration that were new to all participants in the group.

3.1.2 Agency: Capacity and Ability to Change

Kolb discusses learning as a process of adaptation, and distinguishes this from non-learning, the failure to modify ideas and habits as a result of an experience (Kolb, 1984). Typically models of transformative learning focus on the abilities and skills required to responded and adapt to change, and to transform through communication, collaboration and critical thinking (Taylor, 1997). However transformative learning requires not only the ability to change but the capacity to adapt and change. Earlier research has indicated that the capacity to change, or agency, is influenced by the level of decision making and autonomy of participants: when the role of the participants is well established and interactions are tightly controlled, there may be little opportunity for participants to respond to changes in experience (Mackintosh, unpublished). In some cases, the capacity for change is controlled by certain participants, or limited by the boundaries of contexts. In both workshops some groups and individuals were able to find capacity and ability to change, while others were not.

A key limiting factor in the workshop was how closely individuals held on to their usual roles, or conversely, how easy they found it to let go. For example in Workshop 1, one of the principals was at first unable to let go of his normal role as a director of a group. This stalled the group’s progress as the only ideas getting any breathing space came from just one individual. When this participant was later able to step back and make room for other’s contributions the work of the group accelerated, and he was able to gain personally from the process as a participant within a group, rather than within his usual leadership role. What comes into focus in this example is what is meant by collaboration skills. Collaboration skills are not the same as the ability to direct a group to enact an idea. Feedback from the participants identified that for this workshop context, “the important thing here was listening.” We questioned if participants who were not typically in decision-making roles—such as recently graduated teachers and architects, and high school students—found the process empowering.

In Workshop 2, the ability for some group members to contribute was restricted by the actions of others who held tightly on to a self-selected role within the group as someone who held the answers to the questions, or the ability to communicate them through construction of visual artefacts. For example, some architects, that were used to leading design projects and client briefings, struggled to adopt a facilitation or visual scribe role even when those groups contained other participants with very senior roles who had significant insight to offer on the subject. While in other groups, where more collaborative and co-exploratory approaches were taken, more unexpected outcomes emerged and took form in visual languages inclusive of all the group participants. In these groups, participants reported thinking about the situation in new ways.

Drawing from reflections on these two workshops highlights the challenge of establishing a setting where participants are able to permit themselves and each other to step out of their typical work roles to address an unfamiliar problem. There are challenges for the facilitator in inviting and pairing participants, and in designing activities that work to unsettle assumptions about who is expert and who is learner. An additional challenge is building adjacency between workshop activities and participant’s everyday activities to provide participants the opportunities to build links between these.
3.1.3 Making Connections to the Everyday

There is a temporal component of interaction that is important when examining transformative learning experiences. Often, learning experiences around problems and projects rely on a snapshot of a context—an instant in time—which limits the opportunity for learning to cross over into everyday life. This can be seen in the minimal positive change in ecological crisis despite ongoing development in environmental education over recent decades (Department of Education and Skills, 2006). However, to be able to know and understand complex systems and the interactions that that take place may take time and focus. To that end, the ‘density’ of interactions, the scale of the groups of participants, and the ongoing or repetitive nature of the experience should be considered as part of workshop design and reflection. This relates in part to the theories of fast and slow thinking (Kahneman, 2011) and the differences between cognitive processes, the process of knowing through reasoning, awareness and perception, and meta-cognitive processes, which require an awareness or analysis of one’s own thinking processes. Allowing time for both slow and fast thinking within workshops, and developing mechanisms to capture the thinking that occurs after the event, can support transformation.

Similarly, stories and shared experiences, even when contextualised, are snapshots or moments. In order for a snapshot of experience to provoke transformation connections need to be built by the participant between the experience and their everyday activities. Temporal proximity may facilitate the construction of these connections. In the case of architectural designers participating in the workshops—we might ask, what are the projects that they are currently working on: is there a school project in the office currently? Are they currently working through some related design challenges? Beyond selecting the date and time of the workshop, there is little the workshop facilitator can do to connect temporally to participant’s everyday. However, building space within the workshop event for participants to place snapshots of experience back into your own context can be done.

In Workshop 1, at the conclusion of the event participants were encouraged to consider what they had learnt, to write this on a post-it-note and place this on the wall. A follow up survey was also distributed, inviting participants to say how their experiences at the workshop might inform their continuing professional activities. The final wrap up reflection activity of Workshop 2, after all groups had presented their artefacts, asked participants: ‘thinking about movement and stillness at school, school children in the future will...’ The activity was an opportunity for participants to reflect on potential for change, to think with aspiration about the future and what their role might be in producing those futures from their various roles within schools, design and policy environments.

In both cases, informal discussion after the event, over a snack and drink also enabled a chance to debrief and for participant’s to bring their own reflection into conversation. Simultaneously, an opportunity to find out how others had experienced and understood the workshop offered opportunity to access further insight into their own experiences, and to begin to build connections between this experience and other experiences through comparison.

4. Conclusion

Transformative learning models are useful for examining professional development in architectural design practice as they recognise the complex systems in which learning takes place, and the role of the different participants within these systems. Providing catalyst events can prompt change in participants and facilitators, as worldviews and behavior are challenged. Three aspects of these learning experiences are discussed in relation to participants’ ability to engage more or less fully in the workshops as a
transformative event. We offer these points of discussion for others who seek to guide the pedagogical development needed to transform the architecture profession.

Three key aspects to consider in supporting transformative learning are: unfamiliar contexts as provocation; agency as capacity and ability to change, and; making connections to the everyday. We invite consideration not only of where the learning takes place, and with whom. We note that the newness of the context and participants—and their sameness or diversity—can increase the intensity of the experience. Developing participant’s agency as an ability to change supports their capacity for ongoing learning. Providing the opportunity for participants to connect their learning experiences with their everyday activities strengthens the potential for change. The discussion in this paper is aligned with ongoing research in which case-study analysis of transformative experiences in university-based architectural learning, and alternative methods of documenting existing architectural programs, have identified these characteristics of the transformative learning experiences (Mackintosh, unpublished). This paper explores the continued relevance of transformative learning approaches to professional development within the discipline of architecture. This paper has reflected on two cross-disciplinary professional workshops. The discussions that were held and the process of thinking about school experiences meant that the final outcomes were not only ideas about learning spaces, but the provoking thoughts that may become the catalyst for new and exciting learning environments.

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References

“Back” to the Future

Parametric in an Ancient Treatise on Architecture

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Abstract: Ancient treatises on architecture in India form a knowledge system which is intertwined with historical architecture in a complex manner. The content cloaks issues in architectural issues with philosophy, religion and other contextual references which leads to some practitioners’ contention that the treatise is “religious mumbo-jumbo” while others attempt to employ it as a technical construction manual. This paper submits that the treatise is primarily about architectural theory and practice and its focus is design processes for different building types set out in the form of textual guidelines detailing the stages involved in the generation of the built form. This finds resonance in parametric design viewed as a set of instructions establishing relationship between objects controlled by variables which renders the treatise relevant to contemporary architecture in general and computation design process in particular. The utility of the treatise is enhanced in conservation efforts, especially reconstruction of ruined historical buildings, and post-colonial scholarship in indigenous knowledge systems. Also, by premising correlation with contemporary processes in computation design, this paper informs their historical location and contributes towards their place as integral to design systems. It is premised that by going “back” in history in the form of an ancient treatise, the future, envisioned as parametric design, is informed.

Keywords: Parametric design process, historical treatise on architecture in India, Samranganasutradhara.

1. Introduction

Ancient treatises on architecture in India form a knowledge system which is reflected in historical buildings in a complex manner. Most practitioners refer to treatises in a peripheral and technical manner while acknowledging their latent influence on historical monuments like temples and palaces. This paper suggests that the treatise is in the realm of theory and practice and submits that their relevance to contemporary architecture is significant. A compilation of earlier texts from inter-disciplinary sources, Indian treatises are written in regional languages whose authorship is ambiguous, given the paucity of scholarship on ancient India. From the Mayamatam to the Samranganasutradhara, each treatise builds on the knowledge base of earlier texts and spans across the sub-continent in origin and language including Pali and regional Sanskrit.
Content includes philosophy and science along with theory, practice and construction processes in architecture. As most scholars are from fields outside architecture, the full import of its architectural merit is lost which, when combined with factors including translation and cultural distance, lowers the intelligibility of the text for architects. The tone is conversational as most text is in the form of instructions, stages of architectural process interspersed with philosophical insights. The censorial genre discourages the casual reader and the uninitiated from using the text irresponsibly. Favourable and unfavorable attributes of the built environment associated with implications on the user/client/owner have been analyzed by this study and it is premised that they are based on aesthetical principles of form and space and user experience in the built environment. Fraught with cultural and gender biases, social hierarchy and contextual issues, the study removes this encrustation to arrive at the architectural core of the writing. Sacred associations’ cloaks content rendering it esoteric and obscurantist to the casual reader, therefore, all superfluous implications of religion require strict sieving such that architectural content is not sacrificed at the cost of religious bias. This results in some practitioners’ contentions that the treatise is “religious mumbo-jumbo” while others use it as a technical construction manual and attempt to apply the text literally without conducting an abstraction exercise to arrive at principles which may be relevant to theory/practice/construction.

By conducting a grounded theory research methodology, data from the text has been interpreted architecturally and formulated into a theoretical construct with a particular focus on design process. The treatise selected as the case study in this paper is the Samranganasutradhara, attributed to the polymath King Bhoja - which dilutes its religious intent- around the 10th century, locating it in pre-colonial India. Narrated by the celestial architect Vishwakarma to his children, it raises questions pertaining to all aspects of architecture which are answered in subsequent chapters. The core reading is a Hindi translation of the original treatise in Sanskrit (Jugnu 2011) which minimizes loss of meaning in translation. After interpreting the Hindi and Sanskrit text for architectural implications, an English interpretive translation is rendered comprehensible to the modern scholar by associative correlation with contemporary paradigms. Finally, this study focuses on the design process aspect as this is relevant to theory and practice and forms the majority of the content. During successive readings, it became apparent that the process set out in the text is analogous to generative and computation process. Simultaneously, a critical analysis of generative, computation and parametric design processes is conducted to explore associative layers and discover correlation with the treatise.

द्विशालथैकशालस्यत्रिशालस्यचयोगत: II 25.05 II
पदशालमण्डायतेवेशभेदास्तस्यतुषोड़श।

In this manner, combination of bi-hall, uni-hall and tri-hall dwellings
Hexa-cell dwelling are assembled and these are 16 in number


The focus of this study is the instructions to generate built forms in the treatise – dwellings, palaces and temples- which resemble text algorithms in a generative parametric design system employed as a tool to design with (Leach 2009), which is at variance with its popular connotation as a style and a representation technology. Parametric is referred to as a set of instructions to generate a form utilizing algorithms which are an explicit statement of a sequence of operations needed to perform a task. The logic and structure of the design process is the focus of parametric design and the end product is an
infinite set of solutions which, according to Eisenman, are made finite by the individual intellect of the architect.

Here, the focus is on requirements of the process instead of its product which is generated from the textual instructions is in the form of a three dimensional object – parameters and schema. Parametric design process is an iterative activity which involves continuous generation of a design artefact, evaluation of its ability to satisfy requirements efficiently, which if unacceptable to the architect is followed by a new iteration which involves either a radical reformulation of design concept and/or a modification of design parameters. The linguistic parametric design lists a finite set of instructions, analogous to cooking recipes and furniture assembly instructions, where the individual stage needs to be explicit, detailed and adaptable. “In a field made quadrangular, divide into four parts” (56.45.1) assumes that the architect interprets this as all sides of the quadrangle are divided into four parts based on the premise of three dimensional spatial construct. “The wall should on all sides’ measure one part, and the remainder should be the sanctum” (56.45.2) signifies the demarcation of void by the solid while “With a projection of two parts, a width of three parts, and adorned by pillars” (56.46.2) highlights that the adornment of the pillars is left to the designer. Flexibility and adaptability is built into the system as only ratio and proportion and not absolute numbers are employed in the generation of the form.

The following text from the treatise gives guidelines on the design process to generate the form for a temple.

In a field made quadrangular, divide into four parts
The wall should on all sides’ measure one part, and the remainder should be the sanctum
Moreover, in front of that, one should build a pillared porch
With a projection of two parts, a width of three parts, and adorned by pillars
According to the parts of the height of the base, the wall should be two parts
The antarapatra should be half a part and the varandika should be one part
The height of the shikhara is known to be four parts and a quarter
With a cord of three guna, one should draw the profile as a lotus petal
Across the width of the shoulder, sub-divide into three parts
The neck should be half a part and the finial should be one part.

Based on Adam Hardy (2015)

Figure 3: Stages of generation of the temple from text instructions of 56.45-48 (source: Author, 2017)

3. Stages

In conventional design process, a solution is generated, evaluated against criteria and modified in reaction to the evaluation. On the other hand, in generative design, several options are generated and the designer chooses the most appropriate one.

On inverse juxtaposition the creations may expand or contract
Types of dwelling are infinite in number

Generic stages of a generative design process involve identifying the critical points which impact the product during the process and at the end of it.

3.1. Start

This highlights the importance of marking the beginning – the start conditions- as the foundation on which subsequent stages are built upon and is written as “Acquired area is to be made quadrangular and divided into ten parts.”

Figure 3: Architectural interpretation of text (source: Author, 2017)
3.2. Generate

Generate an object which is the modified by an earlier stage and a receptacle for modification by the next instruction, for instance “In the centre of this, four parts are a platform with four columns. Outside this platform, create one concentric porch with 12 columns.”

![Figure 3: Architectural interpretation of text (source: Author, 2017)](image)

3.3. Output

The final output of an accretive process offers no single best solution but a class of satisfactory solutions.

In this manner, porch, gallery, boundary wall, projections and fenestration and their features and attributes result in numerous creations.

4. Types of parameters

Parameters are correlated with the Vitruvian triad of Firmitas (Solid), Utilitas (Useful), Venustas (Beautiful).

4.1. Venustas

Aesthetic considerations are integrated into the parameter by its formulation based on proportional measurements categorized as formal as set out in the following text:

30.19 Difference in height between plinth and height of storey is half of total height of building. Plinth may be ornamented with whatever is aesthetically pleasing.

4.2. Utilitas

Building is rendered useful by incorporating performative criteria like ergonomics, climate and culture among others.

(बृहस्पतिः – 54.39-41 (as text of Samranganasutradhara is missing) याम्यांशलाभंधान्यफलप्रदम पराम्यांशलाभंधान्यफलप्रदम।
This beneficial and bestower of sons for humans building
Is composed of two halls in south-west location
This is the giver of wealth & prosperity
Building composed with North –west location of halls is called yamsurya
This leads to fear/danger from king and fire and destroys the clan.

Architectural interpretation of the text is based on climatic and cultural considerations of solid and void relationship as the text assumes the generation of the courtyard by enclosing built volume. The importance of the courtyard in the Indian context includes privacy for women and children, protection against enemies and wild animals, warm climate allowing outdoor living, large composite family units requiring open space for social interaction as well as sacred considerations for the centre used for water bodies or specific plants like the tulsi (holy basil). The orientation of the courtyard has implications on its usage as the primary consideration for an open court to increase its usability is comfort of its user which in the Indian climate is reducing the heat factor of solar impact. This performative parameter is integrated in the text algorithm above based on the technical performance of the building as interacting with its user and the designer needs to explicitly describe and resolve both the parametric schema and the performative parameters prior to form exploration. Early performance integration ensures that all subsequent form explorations are viable. Multi-disciplinary thought including ergonomics, aesthetics, climate, philosophy, sustainability, efficiency, religion, spirituality, cultural and social issues infuse parameters as required. An attribute is declared as favourable based primarily on its performative effect as is displayed below.

Table 1: Graphic performative interpretation of text (source: Author, 2017)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>सिद्धार्थ</td>
<td>Favourable: Open court is in the northeast which makes it comfortable.</td>
</tr>
<tr>
<td>यमसूर्य</td>
<td>Unfavourable: Courtyard is in southeast making it uncomfortable.</td>
</tr>
<tr>
<td>दण्ड</td>
<td>Unfavourable: Courtyard is in southwest.</td>
</tr>
<tr>
<td>धन</td>
<td>Favourable: Courtyard is in northwest and building is in south east.</td>
</tr>
</tbody>
</table>
4.3. Firmitas

This is interpreted as referring to the construction parameters to ensure buildability

During masonry, be aware that for the wall, do not use excess mortar
Or break bricks to use in masonry
But if the brick is asymmetric/disproportionate/odd
Then use an axe/scalpel/chisel to make it even in appearance.

5. Components

Parametric design process for architecture requires integration of the following aspects:

5.1. Form

Form is integrated into parametric design in different ways as demonstrated by the shape grammar of Palladio and the catenary arch of Gaudi. The Samranganasutradhara incorporates form depending on the typology of the building – residence, palace or temple. In public housing, a single cell increases in complexity additively and by 90 degree rotation, in palaces by using the grid as an ordering principle while the temple generates form by sculptural addition of three dimensional objects like cuboid, parabolic cuboid, doughnut among others.

5.2. Design variables

By subjecting the form to different schemas, specific options are chosen which may be useful for the design problem or not. Choice of variables by the architect allows individual creativity and choice and the Samranganasutradhara instructs about favourable and unfavourable variables based on performative indices.

21.03,04:
The (trishala) dwelling with no building in the north direction is named hiranyanabha.
Such a building generates wealth for its owner.
The dwelling without building in the south is named chulli
This destroys financial wealth.

Hiranyanabha is favourable as the internal court is in the rear of the building affording privacy - a desired aspect in the cultural context - to its inhabitants and its location on the north side shields it from the strong and perpetual south sun making it comfortable as an outdoor activity space – a cultural and social requirement. The converse disposition of chulli makes it an unfavourable option.

5.3. Data structure

Data may be presented as numbers or text setting out an algorithm. For public dwellings, the text calculates that for an eight-cell enclosure, there are 65536 options based on number, location and orientation of the porch/transition space. To arrive at a particular type, say 15204, a mathematical computation process, the prastara, is employed and the specific configuration of built form and porch is generated.

5.4. Mathematical expressions

Operations involved in executing the instructions instructed by the algorithm include simple calculations like proportional relationships between building elements as well as complex geometric ones like generating the parabolic form of the spire on top of the sanctum.

Multiply the length of the site with its width. Divide this by 8.
The remainder is termed “aaya”. (26.17)

5.5. Logical methods

Systems proposed by the algorithm are required to be based in logic and accessible to the informed practitioner to minimise the contra-indications of insufficient and inaccurate employment by uninformed users.

Table 2: Variable analysis (Source: Author, 2017)

<table>
<thead>
<tr>
<th>No</th>
<th>Variable attribute</th>
<th>Description</th>
<th>Relevance</th>
<th>Architectural Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Spatial unit</td>
<td>एकशाला (Ekshala) द्विशाला (Dvishala) त्रिशाला (Trishala)</td>
<td>Uni-cell, bi-cell, tri-cell unit Built form enclosing space Solid - void</td>
<td>Additive built volume, Inside-outside relationship.</td>
</tr>
<tr>
<td>2</td>
<td>Orientation of spatial unit</td>
<td>सिद्धार्थ (Sidharth) यमसूर्य (Yamsurya)</td>
<td>Based on built volume response to climatology</td>
<td>Comfort of inhabitant in built environment.</td>
</tr>
</tbody>
</table>
### 6. Representation

Representation of algorithmic computations is in the form of graphics categorized as analog and symbolic based on the output. Form based representation like drawing, sketch, model and other medium of representing reality denote the formal output of parametric design process while data based graphics like graph, chart and table, indicating technical performance issues like loading, heat transfer and other such issues, constitute symbolic representation (Ipek Dino, 2012). Symbolic systems inform the analog outputs for evaluation as well as contribute to the knowledge system of performance criteria for built environments.

![Figure 6: Graphic generation of a palace from text instructions (source: Author, 2017)](image)
6. Conclusion

Textual instructions in the design process increases productivity by rejecting unviable options, extends functionality, enhances precision levels, evaluates conditions and reacts efficiently within constraints like budget and context (Dino 2012). Therefore, it is viable to explore the treatise as a traditional knowledge system interpreted for relevance to architecture. Parametric design methods are evolving from a representational tool to a thinking aid which lends credibility to the treatise, by association, as based in theory and practice of architecture instead of an obscurantist manuscript.

It is inferred that on one hand, computation based design process has historical lineage and simultaneously, historical design process, as evidenced in a treatise, is relevant to contemporary explorations in alternative paradigms. Therefore, this paper submits that going back in history provides links to the future.

References

Gateway Pavilion

Returning to Conventional Practice

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Abstract: The design and production of architecture is being heavily influenced by software, both positively and negatively. On the one side, it can be seen to provide new design opportunities while on the other it can create unexpected constraints. It is attractive and easy to generate complex digital forms however to realise it may seem overwhelming. This is reflected in architects constantly developing complex digital forms but they are seldom translated into production. Articles suggest students can work with digital software without much consideration of tolerance for manufacturing, however project and material realities say otherwise. When an appropriate workflow is applied, the making process is not as complicated as many are led to believe. The Gateway Pavilion on Waiheke Island reveals pedagogical requirements to teach students essential skills to produce complex designs with a practical build process. This paper is a case study reviewing the alternate route taken when digital fabrication is no longer an option.

Keywords: Prototyping; design-build; pedagogy.

1. Introduction: the Waiheke Pavilion

The Waiheke Gateway Pavilion was originally conceived in 2009 by an award-winning Architecture practice, Stevens Lawson Architects for the Venice Architecture Biennale. The concept for the pavilion was to be something akin to a dissolving wharenui, a traditional Maori building form that morphs from building to landscape as one moves around the structure. This concept was developed through the implementation of digital tools in design, analysis, and fabrication.

Unitec Institute of technology was tasked to realise the concept design for the Waiheke Headland Sculpture on the Gulf Festival in January 2017. The team consisted of architecture and construction students drawn from first, second, third and fourth year streams. The handful of academic staff and professional consultants to support them were required to negotiate with a large discrepancy in skill between all the students.

It is attractive and easy to generate complex digital or sculptural forms however to realise this, it may seem overwhelming (Sass, 2007). This is reflected in architects constantly developing complex digital
shapes but they are seldom translated into production. Articles suggest students can work with digital software without much consideration of tolerance for manufacturing, however project and material realities say otherwise (Parsons, 2014). The Gateway Pavilion, was a twisting, morphing, spiralling, portal frame-like structure. The intention for both the Biennale and Sculpture trail was to physically realise the scheme through a CNC production methodology, as there were over 300 individual components and over 500 associated unique joints. The structure was built using glulam beams, while the floorboards were specified as treated radiata pine. Each component varied in length from 1100mm to 8000mm that presented a unique engineering and construction challenge to students due to the numerous irregular geometrical connections. The brief for the architecture students was to finalise and detail the design from the provided massing virtual Sketch-Up model, to be subsequently assembled by construction students. The architects, Nicholas Stevens and Gary Lawson, along with the engineering firm Holmes Consulting, encouraged students to collaborate with them as much as possible to work through the developed design process. The timeframe provided was limited, with initial developments taking place from late October 2016 to a complete product in late January 2017. The project was originally designed with low tolerance and high precision making, but a malfunctioning CNC router midway through the project led to a more traditional construction approach to be observed.

The following paper will be divided into four sections. To begin, parameters towards materiality, tolerance, technology, engineering and construction will be discussed in relation to methodology. To follow, a section documents the knowledge gained by producing scaled prototypes to overcome those issues presented in the previous section. To conclude, the pedagogical learning outcomes and project analysis will be discussed.

2. Parameters of Fabricating Objects

This section will investigate the issues that confronted the team of architecture and construction students when developing a construction workflow to create the complex form. The problems that needed to be overcome were:

1. Materiality and Tolerance
2. Technology and software
3. Connections and Joints
4. Analogue Construction Techniques

By investigating these problems, the students devised a method for manufacturing and assembling the Sculpture. However, design and engineering factors were not considered from the Unitec position.

2.1. Materiality and tolerance

With advances in digital fabrication, many believe tolerance can be reduced to zero. Pinpoint precision may be attainable for particular production circumstances, but a thought must be spared to material physics and environmental conditions (Male-Alemony & Portell, 2014) when constructing architecture.

The emblematic work of Walter Gropius and Konrad Wachsmann at the Bauhaus in pre-war Germany prototyped with panelised systems. Their research eventually led to huge benefactors in 1943 at government and at a corporate level to produce large scale factory-based production (Anderson and Anderson, 2007). A four-way connector development was central to the construction system (Smith, 2010), as the panel system alone was not enough to warrant a patent. Gropius and Wachsmann, made
great progress with large amounts of prototyping – the result creating panels that can act as walls, ceilings and floors. In 1947 a factory line was set up to manufacture houses, but failures with production equipment manufacturing suitable tolerances affected output and led the enterprise to bankruptcy (Bergdoll, 2008).

Tolerance needs to be integrated into the design process to realise a successful project (Parsons, 2014). This requires three dimensional virtual models to be prototyped or vetted in order to be constantly updated with construction tolerances and reality’s imperfections become fine-tuned (Willis and Woodward, 2010).

2.2. Technology and software

Modelling conceptual ideas in 3D digital space provides an environment for information to be readily available at the discretion of designers and fabricators fingertips. A great benefit of architectural software, is its ability to create successive design iterations efficiently (Sheil, 2005) Embedded data can be utilized to generate; scaled prototyping, visualisations and quantity surveying information (Iwamoto, 2009). The obvious advantages of working within a digital environment over an analogue hand process is with how information can be manipulated, transferred and replicated with ease (Dunn, 2012). For example, if an architect needed to change a hand drawn design, a workflow to amend it would entail a laborious process to redraw it. Again, if conceptual model was required for spatial validation, a designer cannot simply extract data from a virtual model and print it via a laser cutter. They must be physically measured, drawn, hand cut and checked before any final assembly can be pursued.

Negative impacts of utilising technology can led to a large quantity of students not being exposed to vital training that is simply eliminated by automation. Questions remain, to what extent can design and construction be democratised (McMeel & Walker, 2015). As the uptake of digital technologies become more prominent with its ease of use, individual skill and expertise of the producer will diminish or be reduced (Parson, 2014). How will future generations of architects cope when the machine fails or simply does not produce what is required without a complete understanding or expertise?

The gap between physical and digital are continuing to converge, it will require the architect or designer to increasingly collaborate or acquire skill, imagination and the expertise of a crafts person. It is likely that prototyping equipment and CNC produced mock-up will become a regular exercise to produce important details as architects become more accustomed to working with Computer Aided Design and Computer Aided manufacture (CAD/CAM) or file to factory workflows (Willis and Woodward, 2010). This process is forcing architects, engineers and builders to need to “throw away the rule book”, and rethink how they approach workflow, the presentation of data and the sharing of ideas (Chaszer and Glymph, 2010).

2.3. Connections and joints

Many prefab innovators try to draw parallels to flat pack furniture or Lego, Meccano, and other children’s assembly toys. Connector joints are key for a successful product. Sass notes that snap-fit mechanical joints - dovetails, slots, and tabs - are common and are the most appropriate method for aligning and assembling building components. One must recognise that assembly and attachment control is part of the design process. A designer must judge factors of functionality, component shape, locking, assembly motion, tolerance, and strength prior to manufacturing (Sass, 2007). Therefore, it can be safe to say the design process must include prototyping and testing to some extent.
2.4. Analogue construction

There is a need for contractors to not only be familiar with CAD/CAM capability, but also be well equipped with conventional construction knowledge and skill to cope with challenges that cannot be anticipated in a computer-generated model. Designers need to be well versed in fabrication logic to not only be able to produce tangible digital production files, but also a range of well-produced 2D drawings to service large portion of contractors who are not well versed in the 3D realm. The fact remains that even when armed with digital technologies, complex design requires large amounts of skill and expertise (Chaszer and Gymph, 2010).

It is a known fact that analogue construction methods cannot produce the same levels of accuracy as if it was produced digitally. However, when an appropriate workflow is applied, the making process is not as complicated as many are led to believe (Krygiel, 2010).

Responsibility with analogue fabrication of components rests with a larger sum of people, when compared with automated fabrication. The draftsperson needs to draw information that can be easily comprehended and the fabricator needs to measure. A digital workflow by comparison only requires an optimal team to produce digital file for fabrication. The requirement for organisation is much less and simpler with files only needing to be decided by software, therefore the requirement creating time-consuming elements such as a well-documented set of shop drawings is negated (Sass, 2007).

2.5. Methodology

Complex digital forms can be easily produced in a digital environment, however to realize them in a physical world, it may seem overwhelming when the incorrect approach informs production (Sass, 2007). The creation of the gateway pavilion needed to have a flexible, but rigorous approach to cope with the limited timeframe provided. The design process, a fundamental staple within an architectural practice is not so dissimilar to the iterative process within a science experiment to resolve problems (Lucas, 2016). There is a need for architects to work with, engineers and other construction consultants to break down design ideas into manageable portions. This produces numerous scenarios to be tested allowing for fewer uncertainties to arise (Anderson and Anderson, 2006). If you can test the design before committing it to the contractual process, you can afford to be more ambitious. Although, it must be recognized that there is rarely enough time for major changes to be implemented into an idea (Thorton, 2005). An iterative prototyping programme therefore was selected to develop the design into a credible construction system by observing and researching how others have integrated different scales of prototyping into the production programme (Stacey, 2008).

3. Prototyping Process

The prototyping process was an essential stage of the project to make the construction process proceed smoothly. The practise of prototyping allowed the students to formulate solutions and an understanding of materials and unfamiliar construction methods. Every decision from scale, shape and placement on site, through to construction details were decided through the creation of prototypes.

The following section will firstly explain why the learning from prototyping through digital methods did not go to waste once the CNC machine became inoperable. Secondly, a justification on why it was required to test an alternative method of fabrication before continuing to site will be discusses. To conclude, an analysis will describe the knowledge gained from testing with prototypes.
3.1. Digital prototyping

The original workflow developed for this project worked between creating digital virtual models and producing scaled mockup models. The first mockup model was created at 1:10 for several reasons. The first was to assess the scale and size, the second, to provide visual representation to all the shareholders in the project, and lastly to refine elements of the sculptural form that looked out of place. The design team, which consisted of engineers, architects, students and academic staff, referenced this model throughout the design and fabrication stages. It was much easier to negotiate discourse around a large comprehensive model to resolve issues. For example, the problem involving the alignment of how each component would meet was noticed at this point and allowed the design team to re-evaluate the digital model. An even more trivial problem of understanding that the structure was not simply a series of portals, but rather a spiralling reciprocal structure was only noticed by many through viewing the physical model.

Throughout the project the conflict between architecture and engineering was discovered and resolved by the production of this model. Specifically, it was to the placement of the bracing elements, metal rods that worked in both compression and tension to stiffen the overall structure and equally space the spiral components apart. Compromise had to be made between architect and engineer, with the architect pushing for a seamless line of frame spacing, while the engineer must ensure the effectiveness of the spacing.

Digital analysis was utilized by the engineer to check spacer connections between each of the portal sections. This structural analysis was done through using a Grasshopper script, a Rhinoceros 3D plugin, which identified the number of spacers that are incorrectly placed. The script began by 3D model inputs being assigned to various groups based on which spacer rule is associated with it. A rule is then applied with intersecting and non-intersecting results appearing as true or false. The data trees were consequently split in relation to these results and therefore identified correct and incorrect spacers. This structural analysis meant that issues could be fixed on the 3D model and be adjusted in the shop drawings while also reducing the amount of back and forth consulting between the engineer and architect.

![Figure 1: Grasshopper script used to check connections.](image)

The next prototype to be developed as the digitally produced 1:1 detailed section that investigated the specification of products other than the glulam and the connection details. Time constraints did not allow for procurement of glulam beams for testing purposes, consequently forcing the team to select Laminated Veneer Lumber (LVL) as suitable replacements.

Firstly, the digital model that was created for this prototype allowed for the quantity surveying to take place. Secondly, the prototype also enabled the students to understand how thick pieces of timber can be cut without straining machinery and consequently damaging the material. Lastly the finer details with
connections was resolved at this point. It was found that the threaded rod had to be cut professionally offsite with the correct machinery and the stainless-steel tube was insufficiently specified leading to further changes being made. Even though the digital model accounted for some tolerance, the students concluded that it needed to increase, leading to larger holes to be bored and the requirement for the bolts to be longer.

![Image of prototype](image)

**Figure 2 (Left):** 1:10 Prototype showing overall form and assembly method; **Figure 3 (Right):** 1:1 Portal section prototype testing manufacturing and connection

### 3.2. Analogue prototyping of six spiralling portal frames

When the malfunction in the CNC was discovered, production of the components was already in motion. Due to the change in circumstances, another full-scale prototype was implemented to test assembly of the first six spiralling portal frames and how the project could be produced without automation.

Previously to this phase, the majority of developments undertaken was by the architecture students and respective design consultants. The manufacture and testing of the final prototype, along with eventual production of components, signalled a shift in workflow as construction students were introduced to the project to provide much needed support. Construction students and some building consultants were initially hesitant to interact with a new form of communication beyond the traditional drawing and to accept digital processes in conjuction with prototyping. Experience on their part dictated their opinion, which by all means is valid as local building practice does not generally get the opportunity to prototype or build complex architectural forms (Krygiel, 2012). As the design programme progressed, acceptance and an understanding towards the need for such an approach developed.

It was important that the drawings were accurate, as it played a crucial part in the manufacturing process. The need for diagrams to aid in the visualisation for projects and their realisation is key to disseminate information for fabrication (Allen, 2009). This concept is highlighted within the prototyping phases, as the original shop drawings needed to be heavily augmented to ensure the communication with entry level labour was understood. The fastest form of prototyping is not by creating mock up or digital simulations, but by augmenting, developing and drawing over by hand and pencil (Gage, 2012). Once drawings were completed the responsibility was handed over to the team members who are responsible for marking out cut lines and cutting the material. In the marking-out process, repetition of similar tasks
meant a lapse in concentration and human error was more likely to occur than if an automated process was used. A solution came from constant reference to the computer model, coordinating one another into manageable organisational teams and the importance of documentation tracking systems to ensure mistakes would not occur.

This prototyping stage was by far the most important as it highlighted problems in material lengths, the documentation and the assembly process. The architectural students formulated a solution to repurpose and expand on the vector CAD/CAM files to produce highly detailed shop drawings. The drawing requirements increased in this prototyping stage to over 600 pages more than double the original amount. When the CAD/CAM files were produced it did not need measurements to be represented for CNC production. Print paper documentation, however needed to be legible by the human eye. The first iteration of the shop drawings were only printed on a single sheet of paper and described components with a confusing amount of information. To overcome this, it was found that each two or more schematic drawings to represent each individual component. Other changes in the documentation can be partly due to how the original components were designed with small tolerance and automated production in mind. As a result, the new prototype showed that this allowance would not work due to unexpected movement in the frame and poorly aligned cuts in the handmade fabricated process. Fortunately the assembly of the structure had already been predetermined to be completed by hand, this allowed for much of the assembly documentation to remain the same.

The constant change of hands associated with analogue construction meant that a strong method of communication was needed. At first, the group of students found it difficult, but over time common ground was found through the prototyping process. To achieve this, it led to the architecture students acquiring an understanding of fabrication and assembly techniques in order to negotiate material and detailing. The construction students on the other hand, decided to contribute to the design process through accepting that planning, documentation and iterative prototyping can lead to a well resolved product, and assisting in the repetitive tasks required to realise the final structure.

Figures 4 and 5: Prototyping of 6 spiralling portal frames
4. Conclusion

Though the Waiheke Gateway Pavilion is of a calibre targeted towards automated and expert joiners with expensive production operations, students were able to effectively engage in the development and realization of the project through following systematic processes. The students’, determination to implement what they learnt throughout the prototyping stages assisted them to take part effectively with the project. While for the organisers, developing strategies to best inform, instruct and distribute labour led to the success of the final outcome for the project on Waiheke Island.

4.1. Pedagogical learning

The need to create the appropriate workspace for students is essential for a good workflow, as it enhances the student’s enthusiasm for making and allows them to connect their own digital models to small scale prototypes (Burgess, 2015). The environment allowed essential skills and values of craft to be incorporate into the design process. The project was very temperamental, with frequently changing deadlines making outcomes unpredictable and adding pressure to the students. To overcome this, students were encouraged to be involved in all the possible tasks from programming timelines to ordering material and in turn allowed for confidence in individual ability to grow. Throughout the project select students were kept up to date with the key deadlines and changes.

The notion of designers as builders (Kieran and Timberlake, 2004) is demonstrated in this project by the architecture students contributing to aspects such as quality assurance, quantity surveying, fabrication, and assembly phases of the project. This was necessary in order to overcome problems that arose due to workflow changes. Few designers utilise craft themselves to create things. Perhaps they do not have the opportunity, or lack of skill. Perhaps there is a cultural stigma where making things in the broadest sense is not valued, and physical craft less so. If designers had to physically work onsite they would appreciate the difficulty of some the tasks they expect others to do (Thornton, 2005).

4.2. Analysis

When combining the available digital tools for communication and design development with an analogue fabrication technique, the Waiheke Gateway Pavilion developed an integrated design and build strategy. This blend of two traditionally opposing methods made for the success of the complex spiralling structure. This project highlights the value of employing iterative processes and how having an integrated workflow can achieve a successful outcome. Iterative investigation was first required to investigate the most efficient approach to develop an alternative fabrication process. Prototyping throughout this project allowed for further understanding of how corner joints and detailed information was to be assembled at full scale.

It became evident that for this project to be successful a greater understanding of other available construction processes needed to be explored comprehensively through prototyping at different scales. Throughout the prototyping process constant design analysis was required by all members of the design and build teams. Students found the process of prototyping to be beneficial to break down and comprehend the project into manageable sections. The practise of prototyping allowed the students to formulate solutions to problems. The assumption that students brought with them various skills sets allowed for a workflow to be tailored and organised not only for efficient outputs, but to ensure the students gained understanding, experience and knowledge for future projects. The architecture students gained an understanding of how materials can contribute to design outputs, and in turn provided them
with different outlook in how to approach digitally designed outcomes. This combination of perspectives from different disciplines allowed for experimentation to develop and to test new strategies.

Important learning experiences came with re-evaluating the project due to the need for analogue organisation; new skills and knowledge to be understood, acquired, and to be worked back into the design to fabrication process. Aspects on how best to integrate students from collaborating industries that tend to have conflicting purposes between the importance of design and the practicable needed to be negotiated. Overall this project was a learning experience not only for the architectural students that were involved from the designing and documentation stages, but also for the construction students that only joined in fabrication stages of the project. New skill levels have been achieved for the architecture students as they can now not only produce encoded data for digital production and a highly-defined computer generated model, but can also create shop drawings that convey accurate information for the construction trades. In addition, the project has highlighted the value of bringing closer the disciplines of design and construction to encourage more collaborative working arrangements greatly benefiting the final result.

Figure 6: Interior shot of final construction on opening day of Headland Sculpture on the Gulf festival.

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Improvisations in Polyrhythmic Spatiality

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Abstract: This paper outlines creative practice ‘research through design’ project work wherein musical improvisation on the digital drum kit forms the methodological basis for an examination of the “Y-Condition” between music and architecture as applied to design process. Through the mass generation of drum data and the translation into the spatial domain using parametric digital design tools, spatialization of a corpus of polyrhythmic drumming in a solo context is enabled. This process enables novel models of musical analysis and representation, and also provides opportunities for a post-Xenakian integrated ‘musico-spatial design’ creative practice to emerge.

Keywords: Music and Architecture, Design Research, improvisation, parametric digital design, design process

1. Musical Improvisation as Design Research

This paper outlines elements of an integrated music-architecture research project that aims to explore the intersections between domains of creative practice. Broadly, the research aims to explore the following:

- The complexities of polyrhythmic drumming in terms of both performance practice and the musical outcomes;
- Improvisation as a generative methodology;
- Methods of using the tools, media and methods of architectural design to spatialize elements of drum based polyrhythms;
- The merging of the practices of music and spatial design, towards a novel integrated ‘musico-spatial design’ creative practice.

From these broad aims, this paper will address the principal research question addressing how polyrhythmic drumming can be brought into the spatial domain using parametric digital design tools as a means of notation and representation for the purposes of furthering understandings of the creative process. The research methodology is founded on the principles of design research as ‘research through design’ (Downton, 2003) wherein ‘designing is also a way of conducting research of the kind that design undertakes and, by this means, of producing knowledge for use in designing’. I propose that the act of making music through the interface of a musical instrument is a design activity that shares parallels with
the act of designing architecture through the interface of the pen, ruler and computer. This designerly engagement in the instrument or interface is a means of creative expression, problem solving, communicating and collaborating. Whilst there are great differences between the act of composing or improvising a piece of music and designing a building or spatial element, there are also similarities that are worthy of study.

Donald Schön (1983) has provided the basis for an understanding of how designers think, act and reflect on their work in a cycle of ‘reflection-in-action’ as ‘reflective practitioners’. Drawing upon years of lived and designed experience, the mature designer embodies a body of knowledge and skills that inform design activity as ‘tacit knowing-in-action’. Thus, designers design without necessarily knowing how they design. Musicians are ‘designers’ who ‘design’ in real time in a solo or group capacity. The design activity embodied in the creation of music in one of its many forms involves the processing of real-time decisions, reactions and responses that is informed by a body of knowledge and practice. Music-making as a form of design activity occurs in real-time, with split-second “live” delineation between ideation and output. Great live bands work together with great energy to create complex and creative music, alive with energy. The source of this energy is the musicianship built up over years of practice enhanced by the synergies of performer interactions and the unexpected outcomes that arise from improvised music.

I propose a process of musical improvisation as a methodological basis to explore the outcome of musical ‘design decisions’ and to provide the data for translations into the spatial realm. Improvisation is a complex creative activity that is the subject of much research. Improvisation involves the contemporaneous activities of composition and playing with a set of control parameters that include ‘form, timbre, texture, articulation, gesture, activity level, pitch relationships, motoric ‘feel’, expressive design, emotion, note placement and dynamics. Improvisation occurs with millisecond response times, with neuronal transmission from auditory stimuli being activated 8-9 milliseconds after stimulation, playing within a ‘closed’ or ‘open’ context (with or without external stimuli) (Pressing, 1987). The practice of improvisation occurs within an evolving complex system referred to as the ‘Field of Musical Improvisation (FMI)’ that explores the relationship between the actual improvisation (aesthetic choices, technical abilities, formalistic features, inter-musical knowledge), environment (technology, acoustics) and the social (artistic, ethical) behavior of the musicians mutually as well as of performers and listeners (Cobussen et al., 2010). Improvisation may occur across a wide range of musical scenarios ranging from small variations on an existing format to so-called ‘free jazz’ wherein musicians improvise in a continually evolving flow (Benson, 2003).

Spatial designers also engage with a large number of design parameters that are determined by the brief and site, and evolve over the course of ill-defined and ‘wicked (Rittel and Webber, 1973)’ problem solving and making. Whereas the physical parameters that comprise a building may include form, mass, void, fenestration, material, structure and services, the means through which architects consider, design and arrange them to form a building is long and slow, and often is reliant on the input from specialist consultants. Perhaps the most appropriate way to consider the commonalities in music and architectural design activity is to relate the improvisation to the sketch. Both of these design activities involve initial creative responses to a set condition or problem, are low risk and are generally spontaneous.

2. Drumming as Creative Practice

The creative practice at the heart of this paper is the merging together of the author’s dual practices of architecture and digital drumming and furthers previous research relating to music and parametric spatial design improvisation and 3D Spatial Drum Notation (Ham, 2016; Ham et al., 2016; Ham, 2017; Ham et al.,
2017). Whereas drummers are often societally defined by one or more negative ideological tropes that are founded on aesthetic/mind versus hedonistic/body, racism, the downplay of intellect and prejudice against unpitched instruments (Bruford, 2015), drumming is actually a complex activity that requires highly evolved spatio-temporal awareness, hand-eye co-ordination across all four limbs, musicality and physical fitness (Unknown, 2008) and intelligence (Cleland, 2008; Jones, 2017).

Drummers ‘play’ with the musical parameters available to them during performance to construct beats, fills and in the generation of drum solo work. King Crimson drummer, Bruford recently completed a PhD on the creative practice of the western kit drummer. He defines a ‘Functional- Compositional Continuum (FCC)’ wherein drummers’ ‘functional practice seeks to establish stylistic competence, (whilst) compositional practice seeks to establish stylistic individuation, commonly manifested in choices surrounding the embodied constructs of ‘touch’ and ‘feel’ (Bruford, 2015). Bruford defines the four ‘levers of control’ as the temporal, the metrical, the dynamical and the timbral as forming the foundation for drumming performance. Creative engagement in exercising these levers of control over a performance career helps define a set of ‘referent’ patterns and phrases that define the performers’ musical style (Pressing, 1987). Thus, creative drummers operating on the compositional end of the FCC possess a refined capacity to produce complex polyrhythmic drum patterns: by the velocity-controlled placement of layers of drum notes, using all limbs, in and around a set temporal structure to deliver a designerly musical intention or response.

Polyrhythmic drumming forms the temporal foundation to complex music such as Latin, Jazz and African music. Polyrhythmic drumming involves the playing of overlays of differing numbers of notes between two or more limbs across a common time signature. As an example, a simple 3:2 polyrhythm may involve repeating three strikes on a snare drum at the same time as repeating two strikes on a bass drum. The production of polyrhythms ‘require(s) the simultaneous production of two conflicting but isochronous motor sequences (Summers and Kennedy, 1992). Jazz music, for example, is defined by a ‘swung’ 3:4 or 3:2 beat, as a series of triplets played on a cymbal over a 4 or 2 count on the bass drum and snare, played at a set tempo.

Music, and cultural associations with music, are directly related to the time signature. As music has evolved through the ages, dominant time signatures have changed from 2/4 for marches, 2/4 time for waltzes, 6/8 for jigs, 12/8 for shuffle blues and doo-wop and 4/4 time for modern day rock music. In the domain of western rock music, performers such as The Mars Volta, King Crimson, Mastodon, SoundGarden, Lamb of God and Frank Zappa utilize the drummer to provide complex polyrhythmic beat structures as the foundation for even more complex overlays of instrumentation. Zappa, in particular, was known for composing extremely complex song structures of high ‘statistical density’ such as ‘The Black Page’. Virtuoso drummers such as Terry Bozzio, Thomas Prigden, Stuart Copeland, Jo Jo Mayer and Brian Dailor provide the model for how highly compositional drummers have complete bodily engagement in the instrument to produce highly complex polyrhythmic patterns and phrases through improvisational processes in real time, in solo and accompanied contexts.

3. Spatializing Polyrhythm

The great Iannis Xenakis provides the model of how practitioners with dual skills can engage creatively in the musical and spatial domains separately and through integration. Much work relating to music and architecture occurs, however, in one domain or the other. Elizabeth Martin proposed the idea of the ‘Y-Condition’ as ‘the middle position of music and architecture when translating one to another (Martin, 1994), however my interest lies in the Y-Condition as applied to the creative process and built or modelled
manifestations of music. Instead of playing on the paradigm of ‘architecture as frozen music (von Goethe, 1832)’, my research is concerned with ‘architecture (or, more appropriately, spatial design) as frozen process’.

Whilst significant work has been done on the computational mapping and translation of ‘music into architecture’ this work has principally involved the translation of extant bodies of music. Christensen and Schnabel (2008) translate a collection of 48 of Bach’s fugues into the spatial dimension as ‘a family of forms, aiding comparison and improving the depth of analysis possible’. Explorations by Ferschin et al. (2001) and the built work of Steven Holl in the Stretto House all provide a spatial foundation founded on the music of deceased composers. Music-architecture practitioner Jan Henrik Hansen activates the process by involving composition and playing for some of his ‘musical sculpture’ works (Hansen, 2015), however the act of making spatial elements is given precedence over the act of making music in many cases. For this research, the musician-architect is at the centre of the research as the agent for the active generation of drum music through live (studio) performance.

The founding principal is that the musical outcome of improvised performance is musical data. These data can form the ‘sole building material’ for a ‘data representation architecture that comes from the combination of architecture (design discipline), data (basic information/raw material), and representation (set of organized signs used to express data) (Levy, 2003). The Musical Instrument Digital Interface (MIDI) format provides the data foundation for the research through the recording of hundreds of improvisations on a Roland TD20 digital drum kit in MIDI format using the Reaper Digital Audio Workstation (DAW). MIDI data is exported and translated into Microsoft Excel (.csv) format for purposes of spatialization.

The principal measurable parameters of a drum performance on the digital drum kit are as follows:

- **Drum notes**: These include digital sensor pads that emulate an acoustic drum kit and sound like a snare drum, hi-hats, bass drum, tom toms and cymbals;
- **Drum events over a timeline**: The selective placement of drum notes over a timeline
- **Drum Tempo**: the temporal foundation of a performance, measured in beats per minute (BPM);
- **Velocity**: the force at which the drum pad is struck;
- **Note Duration**: the duration of the note, measured in seconds.

The complexities of this temporal, metrical, timbral and dynamical improvised play have been spatialized through a series of Rhino3D™ Grasshopper™ definitions that translate MIDI parameters into the spatial dimension as notation (Ham, 2017) and representations in CAAD environments and Virtual Environments (Ham et al., 2017). These translations act to continue the creative process from the domain of music into the spatial domain, thus constitute a series of improvisations and compositional processes in themselves. This continuum of performance to notation to representation provides the foundation of an inter-disciplinary practice that integrates the creative practices of music and architecture. Drum improvisations, performed by the author as a musician in the musical domain, are brought into the spatial domain wherein spatial aesthetic and analytical design decisions are made by the author, as an architect. Parametricism allows complete flexibility in representations, so that lengths, heights, ratios and relationships between elements can be manipulated within GH to produce a wide range of spatial outcomes. Figure 1 illustrates four ways of translating and spatializing drum data as a 3D Delaunay lattice structures (image 1 left), panels (image 2), tunnel (image 3) and column forms (image 4 right).
Improvisations in Polyrhythmic Spatiality

4. Spatial Representation of 100 Drum Solos

The methodology for this project involves the performance of a large number of improvisations on the digital drum kit by the author. In the initial exercise, one hundred 60-second drum improvisations were performed across three categories that are reflective of contemporary performance practice: playing drum beats with improvised ‘fills’ (short breakouts from the beat structure), free form drum solos and drumming along to a three-part piece of guitar music (300 total improvisations). The 100 BPM template is representative of mid-range tempo structure whilst one minute improvisations allow enough time for the drummer to initiate a start and finish section and to evolve a theme or idea. The process of mass improvisation is intended to allow the definition of a personal lexicon of drumming patterns and phrases as a ‘polyrhythmic idiolect (Gander, 2017)’ or lexicon of ‘referents.’ A referent, in the context of drumming, is a pattern, phrase or ‘riffs’ that is drawn upon in improvisational situations (Pressing, 1987) as ‘tacit-knowing-in-action (Schön, 1983)’. In performing this exercise, I am also mindful of the way in which a previous iteration informs the outcome of subsequent iterations. As Fischer (2008) states: ‘Two different designers cannot be expected to design in the same way, nor can one designer be expected to design in the same way repeatedly (the same applies to learners and learning)’. From this, one would expect elements of repetition and development of referent patterns and phrases over the course of the research, and for new learning and evolution of nuances and modifications to patterns and phrases to occur.

Figure 2, below, illustrates the representation of drum data as a ‘tunnel’ form (left) and ‘column’ form (right). In the tunnel form, drums are arranged in order from the bass drum (bottom) tom toms, snare (middle), cymbals and hi-hats (far end). The time duration of the drum solo is represented as a series of arcs rotating clockwise. When drums are played during a solo, data points are created along these arcs, with the ‘bumps’ radiating out from the arcs representing the velocity at which the note is played (i.e. how hard the drum skin is struck). To provide a thickness to the solid, note durations of each note played at certain velocities are represented as extensions of the velocity ‘bump’. The column form translates this definition, with drums arranged vertically. The ‘form’ of the drum solo is provided by placing a lofted surface over the data points in GH.

This representation of digital drumming reflects the ‘liquid architectures’ of Marcos Novak (Novak, 2007) however the intention is to balance a readability and interpretation of the drum solo with the exploration of new ways to generate novel spatial forms that reflect the polyrhythmic complexity of the drum solo itself. The same drum solo is represented as tunnel (left) and column (right) forms in Figure 2, below. The more ‘full’ the form is, the more drums have been played across the timeline, with time in the
tunnel form arcing 180 degrees, and 360 degrees for the column form. Figure 2 illustrates a solo with a dominant usage of the bass drum, minimal tom-tom usage and high velocity hi-hat hits later on in the solo. Tunnel forms reveal a different information set than column forms, and each form can be adjusted parametrically to accentuate different parameters and reveal further insights into the improvisation. Through training, one can intuit elements of this musical structure into the spatial forms and gain understandings of the meaning of the spatialization.

Figure 2: Digital Drum data as Spatial Forms (tunnel form to left and column form to right).

When the complete set of 100 drum solos are brought together as ‘tunnel forms’ (Figure 3) and Delaunay Lattice Forms (Figure 4), the form, shape and patterns of the drummers ‘polyrhythmic idiolect’ emerge in the spatial domain. Lofting provides a draped surface over the data points including velocity and note duration and, when the architect’s imagination is engaged and parameters are adjusted appropriately, graceful 3D objects emerge that are easily imaginable as massing options for a bridge or tunnel structure. As drummer and architect, these forms are not just the outcome of a parametric process, but have a personal meaning as the definition of my drumming style manifested in spatial form. The key here is the engagement in a design process that provides a line of continuity from the musical domain into the spatial domain. This Xenakian approach has much potential for further development, with the potential to continue into digital fabrication and realization at 1:1 scale.

The removal of the 3-dimensional spatialization of velocity and note duration of Delaunay lattices in Figure 1 (left) affords the emergence of a complex set of patterns of the 100 drum solo improvisations. The Delaunay GH script seeks to find the nearest data point to form a triangle. This triangulation particularly highlights areas within the drum solo timeline comprised of clusters of fast repeated notes, open spaces in the solo and deformations of the square lattice outline brought about by decisions not to play certain drums until mid-way through the drum solo. Whilst the lattice structures could be easily imagined as a set of design studies for façade structures, the focus at this stage is to provide a spatial manifestation of a large data set that is otherwise unavailable from recorded sounds or traditional notation and complements current research on Music Information Retrieval and music visualization techniques (Hunt et al., 2017).
Figure 3: Spatialization of 100 drum solos as tunnel forms.

Figure 4: Representation of 100 drum solos as 2D Delaunay Lattices.
The final spatialization reported in this paper is the composite 3D spatial representation of the improvised drum composition ‘Layered Relationships’. This piece was composed by the overlay of six polyrhythmic drum-based improvisations, with each layer purposefully referencing the previous to form a ‘wall of sound’. For this composition, a range of synthesized Virtual Instruments were used as a way of transforming the digital drum kit away from traditional drum sounds to include sampled environmental sounds, keyboards and other experimental sound sources. This sonic exploration by the musician-architect is complimented by explorations in the spatial domain so that the initial improvisations push boundaries in both domains. The result is a highly complex spatial layering that reflects the polyrhythmic complexity of the drum performance. This spatialization of multi-layered polyrhythms illustrates the potential of the parametric spatialization method outlined above and the potential for creative outcomes in both the musical and spatial domains.

Figure 5: Composite spatialization of the ‘Layered Relationships’ drum composition

5. Conclusions and Further Research

This research provides an insight into a larger creative practice PhD that explores the nexus between music and architecture/ spatial design. The key to this research is the active engagement of the practitioner in both the musical and spatial domain, with the process of musical improvisation as providing
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the material. This pathway- from the domain of music into the domain of spatial design affords opportunities for creative representations of music- as data. Whilst the eternal reference that ‘architecture is frozen music’ attributed to von Goethe (1832) casts a shadow over this research, it is contended that architecture is, in fact, architecture- and music is music. But between these domains, lies a pathway of creative practice- a ‘musico-spatial design’ creative practice wherein practitioners skilled in both music and architecture can explore the scope of their own work, taking from each domain as appropriate to provide affordance (Norman, 2002) to their understandings of their own practice.

From this initial stage of reflection and analysis, arises opportunities for a new creative practice that merges and integrates music and architecture and redefines Elizabeth Martin’s “Y-Condition” as the intersection of practice and process, and not the intersection of musico-architectural form or product. Whilst the research presented here is based on drum based improvisation- as music- future research is concentrating on the idea of ‘spatial improvisation’. Spatial improvisation involves the adaptation of digital drum performance to the designerly manipulation of the parametric model for the production of pre-conceived or novel spatial outcomes. These spatial improvisations are being explored in Virtual Reality, with real-time feedback enabled between the musical output and the 3D spatialization. This brings in concepts of ‘re-improvisation’ and feedback loops between improvised drumming, 3D polyrhythmic spatialization in VR and subsequent improvisations in response to spatial output. These explorations are actively seeding a new form of integrated musico-spatial design creative practice that furthers the aspirations of the late, great Iannis Xenakis.

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Settlement

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Abstract: In the early 1970s Michael Payne had a national reputation from housing design experience in Hong Kong and the Osaka Expo 70 project. Payne’s previous work and Quaker background led to appointment as architect for a new Quaker community in Whanganui. His design for an intentional community of friends was informed by international experience in housing design and travel, including to foundational Danish co-housing communities soon after they were established. The Quaker Settlement was built over twenty five years and now consists of 17 houses around a number of unique common facilities. They are consistent in design, yet individual. They are an early example of New Zealand low energy, solar, and environmentally sustainable design. Importantly they have been socially sustainable in operation for over 40 years. The Quaker Settlement is an important built exemplar of Payne’s vision and legacy that remains highly relevant today. Cohousing is once again a focus in New Zealand, however groups and architects are struggling to realise projects, or articulate the integrated architectural and social means necessary to create them. This paper revisits the project to determine contexts of its production, to document key characteristics for future reference, and to distil its enduring relevance.

Keywords: Context; Landscape; Urban design; Heritage.

1. Introduction

In March 1974 Michael Payne was at the height of his architectural career. He was known for international work in Hong Kong; the enormous Kwun Loong Lau Kennedy Town housing project, and for the Geyser Room restaurant interior and furnishing at Expo 70 Osaka Japan. An article featuring his work and sole practice based in Whanganui New Zealand had just been published in the NZIA Journal. His reputation as a leading New Zealand architect was established, although his modus operandi was less well known. He had a very hands-on, primarily design and build practice favouring modern, site sensitive architecture based on a tectonic, modular, and people centred approach.


Payne began his practice in 1956 while mid-way through his studies, designing and building a retirement house for his parents Godfrey and Mary Payne, Great North Road, Whanganui. The house was an efficient, modular, split-level, technically innovative, and uncompromisingly modern house with international
influences; Mies Van der Rohe, Harry Seidler and the houses of Richard Neutra. The house siting carefully integrated an existing drive and the rolling contours of the site. The simply planned design was formally split by an entry between two vertically clad timber pavilions; a mid-level living pavilion, and an upper two level bedroom wing raised over a blockwork garage. It was technically adventurous, with a completely flat 50mm paper-faced compressed straw roof finished with fiberglass and resin, frameless glass sliding door panels directly on ball-bearings in a narrow brass track, and with an early provincial use of concrete blockwork and concrete floor slabs for housing. A simple clean aesthetic was achieved with carefully considered details. These included the super thin completely flat roof plane supported on hardwood beams at 1200 centres, full height glass windows at times glazed directly into the vertical weatherboards, simple shiplap weatherboards both outside and inside as the interior linings, and with built in cabinetry cantilevered off the walls. With help from fellow students Rod Smith and Graham Ecroyd, and subtrade contractors he constructed the house as main contractor over the summer of 1957 and in his University holidays. The house was for its time breath-taking and influential, attracting significant public interest and several new commissions.

The Godfrey and Mary Payne house was on the front of a deep peri-urban family farmlet site. The subdivision and associated landscaping as Turere Place was also designed by Payne with specialist advice from Gerhard Rosenberg. It is notable for its low impact minimal approach to landworks and infrastructure, for the introduction of common space and facilities, the retention of major existing trees, and stormwater management though integrated retention areas. This was at a time when low impact subdivision was uncommon. Key details include a street design following lower contours in an inverted hook shape, the extent of green park areas both at the subdivision entry and within its core, a common tennis court, and the single footpath and kerb road design shedding water to local stormwater retention and dispersal. Turere Place is recognised for its subdivision design, and the modern houses within the precinct as discussed in Gatley (2008).

Michael Payne was actively involved in the construction of both of these early projects as a design-builder in the manner of Group Architects in Auckland. He called his practice Modular Constructions and despite cautions from peers that he would be unable to register as an architect, he formed a partnership with a director of a low cost housing company. Craigwin Payne Ltd aimed to design better quality, forward thinking, low cost housing alongside the standard housing Craigwin were known for. Unlike Group Architects, Payne’s design focus was international and modern. The partnership continued for several years until not long after the end of Payne’s studies in architecture. They built 20 or more bespoke, low cost, experimental, modular homes, many using lightweight pumice concrete prefabricated walls. They eventually found that affordable bespoke Modern housing was not a profitable business.

In 1959, as a new graduate, the first stage of the Michael and Merilyn Payne house at 24 Turere Place was designed and built on a difficult south facing hill that was a defining part of the subdivision design. Payne was determined this would not be flattened by earthworks. A large open planned south facing studio was heeled completely into the existing slope and following the hill contour with a boomerang geometry creating a south facing entry and vehicle court. The studio space was anchored with a substantial river stone fireplace that divided the main studio space in two. A huge horizontal glass skylight between steel beams facing north brought sunshine and solar warmth into the volume, and a second skylight lit the small bathroom. Like his other projects it used concrete floor slabs with blockwork retaining and end walls, this time with a 100mm insitu concrete first floor slab roof supported on steel beams and posts.
3. International Experience

When it was clear the Craigwin alliance would not endure, Payne looked at options for the future including employment in Hong Kong where his sister was living. He was appointed as a maintenance surveyor for the Hong Kong Housing Society mid-1961, and in time this offered the opportunity to design, document and project manage the Kwun Loong Lau Kennedy Town housing project. The building was 2050 apartments that housed around 15 000 people in a major interlinked series of high-rise buildings.

The HKHS work and the Kwun Loong Lau Kennedy Town architecture were important hands-on experience of high density housing, its long-term management, and its social implications. Like the earlier single house projects, the project design worked sensitively with the existing site qualities, and minimised infrastructure and site disturbance on a seriously tricky site. The long building snaked along the site contours with shorter wings added across the steep contours at right angles uphill. It was technically innovative, addressing many of the problematic characteristics Payne had noted in other HKHS buildings he was managing. Improvements included the introduction of PVC drainage systems, accessible centralised services below the buildings along the contours, and centralised lifts and services based on studies of peak demands and use. There were also major innovations related to the social operation of the buildings; the way people moved into and within the buildings, and the opportunities the buildings provided for social connection.

“I looked at how people lived at these astonishingly high densities: what they did in their spare time, and where they related to their neighbours” Payne (2008).

The resulting design was aesthetically simple, clearly structured and influenced by an international modern context including Le Corbusiers Unite de habitation in Marseilles as Payne noted (2017). This influence may be read in the expressed ‘beton brute’ concrete work, internal streets, and the community facilities on the roof. The detail composition of each block was enlivened by use of subtly different coloured stone panels and brightly coloured accent doors to different building sections, ventilation louvres, exposed drainage and deep balcony setbacks. Carefully detailed easy stairs with generous landings, and large centralised double floor height lift lobbies were intended to create opportunities for gathering, resting, conversation, and recreation. These spaces for social exchange extended to community facilities on the roof areas, including ball courts, a community centre, kindergarten, and children’s playground. The roof terraces had carefully detailed perimeters with an expressive concrete canopy for shade and seating for passive recreation and to terminate the verticality of the facades. Payne (2008).

The Expo70 Geyser Room restaurant project Osaka Japan was commissioned in early 1969, not too long after the Payne family returned to New Zealand. Payne’s direct Hong Kong and Japanese experience, and the strength of his vision for the project were key. Faced with a restaurant space already defined and an idea of a model of a geyser within it, Payne proposed the project should instead become a geyser experience. This would occur through a cavern like space with an inhabited geyser at its centre, and with all interior design components in the widest possible sense as an integral part of the designed vision. He was appointed design director responsible for realising his vision, and had the design, negotiation, technical persistence, and project management skills across a range of design and disciplinary realms to achieve the vision to significant acclaim. Designscape 12 (1970)
4. Multiple Housing in New Zealand

On his return to New Zealand in April 1968 Payne spent a year redesigning and constructing the second stage of the Michael Payne House at 24 Turere place. Despite its age, the house is an exemplar of low energy, south facing passive design. Its key tactics are a north facing courtyard, north facing sun space circulation and thermal mass in the intermediate floor, a simple stepped sloping roof section and clearstory windows to bring sun deep into the house, and the large central skylight to pull sun down to the lowest level. The house showed the influence of Payne’s travel with sliding shoji screens, cedar ceilings, and a Japanese bath off the main bedroom. The house was also uncompromisingly modern. A series of small square evenly spaced south facing windows created a linear ‘railway carriage’ effect (Payne 2008). Like his earlier houses, it used vertical shiplap boarding to interior and exterior wall faces. The low scale north courtyard side of the house was so well integrated with the garden and landscaping it was described as ‘a bloody marvelous garden with a nice fence behind it’ (Payne 2008). While the landscaping reflected Merilyn’s landscape design ability, the integration of house and environment was a priority for Payne. He achieved this, like on other projects, through continuous use of a single material on the interior and exterior of a house contrasted with frameless glazing. In this case, he also added expressive timber clad wing walls, cantilevering to the south, and extending as fences to the north, and creating the impression of seamlessly connected interior and exterior space. This idea reoccurs in Payne’s architecture including within the design of the Quaker Settlement. The house was also an early New Zealand use of solar panel water heating, which together with the concrete intermediate floor heat sink radiating heat both down and upwards, and the passive solar characteristics of the house demonstrate a concern for energy economy at a time before the early 70s energy crisis.

Figure 1: Wanganui City Council Urban Renewal Proposal (source: WDC archives)
Payne’s experience of housing and design in Hong Kong fundamentally changed his understanding of housing and the city. He became an advocate for urban renewal and higher density housing.

“I’m much less interested now in doing individual houses. There’s a lot of emotional involvement and work on them doesn’t really speak to the more general problems... Multiple housing is what I’m interested in; better land use ...the problems with the cities especially as the energy crisis strikes us is that the population density is too low, with the result that good public transport and other facilities become too expensive to maintain. Payne (1974).

In 1973 he was commissioned to undertake a major urban redevelopment project in central Whanganui. The project design covered six blocks close to the city and introduced significantly higher densities through a range of higher density building typologies including townhouses, courtyard housing, terrace housing and an apartment block. It encouraged upgrading of selected existing housing through improvement grants, and integrated existing housing with selective infill housing and large new areas of housing. It also removed through traffic to “provide play and recreation areas, a quiet neighbourhood” and “sought to introduce a mix of inhabitants by introducing a variety of kinds of accommodation” Payne (1974). More contentiously it closed a major traffic route between the site and the Whanganui River. It also advocated the introduction of Community facilities, a network of accessible linked walkways and small scale open spaces, worked with existing contours without major earthworks, and maintained and extended existing mature planting.

The full Wanganui urban redevelopment project did not occur however in early 1978 the Wanganui District Council proceeded with an initial stage of the project with Payne as architect. As part of the preparation for the housing project, named Pukenamu, Payne reconnected with Danish architect and urbanist Jan Gehl who he had met during Gehl’s visit to Victoria University of Wellington School of Architecture around that time. Payne had been inspired by Gehl’s studies of public places and how they operate socially, how social connections occurred, and what parts of environments social exchange occurred in and why. A one month study trip to Denmark was organised to study Danish housing communities as a preparation for the Pukenamu project. Gehl arranged introductions to people and places key to their research, and accommodation for the Payne’s in his home. The places visited included Gallenbakken, a large new housing estate for 35,000 people, and Sattledarmmen, a foundational cohousing settlement referenced by McCamant Zoom & Durrett (1994) as the original Danish precedent for the worldwide cohousing movement.

5. The Quaker Settlement Project History

The idea of a residential Settlement for the Society of Friends at 76 Virginia Road across from the Quaker school was first considered in 1921 when Ford and Talboys Architects produced a subdivision design and proposed elevations for common buildings on the site. The site was more or less level towards the adjacent road, and had two major sand ridges parallel to the road deeper into the site. The Ford and Talboys proposal included a common pavilion and tennis court, and three duplex common houses. The idea of a ‘Community of Friends’ residential settlement on the 4.7 Hectare Quaker School farm owned and managed by the national Society of Friends was revisited in 1970. Payne, was approached to produce design proposals for the site at 76 Virginia Road for a small group of Quaker clients from around New Zealand in early 1974 in the same period that the Wanganui City Council Urban Renewal project was being designed. The proposal named “Quaker Acres’ was for a community of residents and central community
buildings and seminar facilities to serve both local and national Quaker interests. Negotiation of the individual house sites and their relations to the overall settlement design was subject to different ideas and much discussion. Payne argued

“If we were serious about making a community, the development would need to be compact, limiting the length of vehicular access and services” Payne (2008).

The design was deliberately compact to facilitate social connection and minimise access and infrastructure costs. Like the Turere Place subdivision, it worked from the formed site access and the site contours to minimise earthworks and infrastructure. The initial development plan produced in February 1974 shows two groups of houses each side of a series of linked community buildings. Five houses are linked as two groups of terrace houses, and three as closely located individual houses. In 1975 the Quakers national yearly meeting agreed to transfer the land for the project to the ‘Wanganui Educational Settlement Trust’ that would manage and license occupation of the land to individual owners for settlement. The initial pioneering residential client group was a small group of older Quakers.

“I still marvel at the courage of those early settlers, committing as they did, to build in an empty field without any guarantees that the whole scheme would come to anything” Payne (2008).

5.1 Implementation

The first move to realise the vision was the construction of a workshop and future art and craft space to operate as a temporary base for construction. The work was jointly funded by the first group of settlers, and soon after five initial houses were constructed in 1976 and 1977. Every house was an individual design for the occupant’s needs and preferences. The houses were not connected as per Payne’s original concept however they are located close to each other with a similar formal manner, and designed to an agreed common simple material palette.

“I worked out with the trust an agreement about the external appearance of the buildings so that we could get away from a whole range of personal preferences and make a “community” of buildings” Payne (2008).

The material palette was concrete floors, modular timber framed construction, charcoal concrete roof tiles, white solid plaster exterior cladding with red spouting and downpipes as an accent colour. Interiors included cork tile floors, white plasterboard walls and Monocoustic prefinished ceilings. The underlying idea for the settlement was for a community of houses surrounding the common buildings in the manner of a village. The centralized common spaces included a workshop, kitchen, dining and lounge areas, library, short stay accommodation, an office, and ablutions.

Payne was more than the architect. In the manner of his earlier house projects, he was a hands on project and construction manager, working with a single builder John Remus, and measuring quantities, organising subtrades, ordering and managing materials, and managing finances. He continued this pattern of extended service working on all the various stages of design and building with the same builder to realise all but one house over time. There were in excess of twenty successive building projects in several major phases over a period of 40 years.
5.2. The Danish Research

After the construction of the first five houses and before the construction of the common facilities at the settlement in 1979, Michael and Merilyn travelled to Denmark to study “how the balance between the individual and community was managed” Payne (2017). Jan Gehl’s brother in law took them to visit the new Danish architect designed co-housing project Saettedammen. The 27 house first stage of Saettedammen was realised in late 1970, McCamant et al. (2011) so it was in operation when Payne visited. It had struggled financially to get off the ground and so the scope of original work had been cut. Common landscaping interface intended between the central public parts of the site and the houses had not occurred so there was a very direct relationship between houses and the commons. The parking was centralised at the entry to the site. Together this created a village square effect the inhabitants enjoyed and believed helped social connections to form. They were a mixed age community with lots of families and children, and some larger mixed extended family houses with groups of adults and families living together. There were lots of community functions, and work activities like mending of bikes. The community had been through a ‘honeymoon syndrome’ where significant enthusiasm was being met by a realisation that community also came with expectations and responsibilities to others. Around half of the original residents were owners, and half rented. Low housing, rental and running costs were traded off by contributions to a pool of community labour that looked after the place. Everyone needed to happily take a share of the cleaning and many other community maintenance tasks like cooking shared meals. Payne noted that Saettedammen did not have a purpose beyond living together as an intentional community, and had been formed as a result of a groundswell of interest that was generated through newspaper articles and advertisements. Payne (2017). It had a preschool for residents and the wider community. The community had a low cost, low energy focus. Payne advised them on the technical set up for a solar panel system they were setting up. When he returned to Saettedammen twenty years later he noted that unfinished parts of the design had never been completed and observed that groups of people can find it difficult to agree to modify an existing occupied environment. Payne (2017)

5.3 Common Areas

Stage 1 of the Quaker Settlement common areas were detailed and constructed in 1979 after the return from Denmark. These facilities included a large dining and common room area, a library and meeting room, a working kitchen, an office and associated toilet areas. The design follows the original development concept plan for siting and planning with the exception of short stay units to the north of the library. These would later be sited east of the Quiet Room. Common carports were also constructed around this time located together to the south of the common buildings forming a service and entry courtyard. The common facilities like all of the houses face north. They are structured to create a major north facing courtyard that the kitchen, dining areas, and library face onto. A separate sleeping and ablutions block was constructed soon after in 1981, completing the major facilities. These were designed to accommodate the common life of the residential community, the wider New Zealand Quaker residential seminar purpose, and the wider needs of other local and communities of interest. The sleeping block is distinctive in design, a cross between Marae style and tramping hut shared sleeping areas, with zones of separation created within the larger space through the use of levels and screens. In time additional, more private accommodation was sought and some separate bedrooms were added, and planning changes introduced within the open accommodation to allow separation of the sleeping facilities by gender when required.
5.4 Demographics

A significant housing shift occurred around this time. A settler with young children and a shared house, was introduced into the community in 1981. The trust was keen to involve younger people, families, and single parents. A large rental house with bedsitting rooms was designed to accommodate the needs of this demographic perhaps influenced by similar children’s houses at Saettedarmmen. For a number of years it worked in the manner of blended families with some moving on and others moving to other housing in the settlement. In later years, this larger house was split into two separate smaller units. The larger houses were a deliberate intent to change the demographic character of the emerging settlement. The incremental housing growth continued through the early 1980’s until there were around 11 houses. In 1989 the Payne’s built a larger more architectural house for themselves. It utilised the agreed material palette and reflected their individuality and preferences. A glass house sunspace moderated by an internal grapevine, and a double height lounge space were a particular focus of the house. A further four houses were built over the 90’s with the last new house built in 2004. It was the largest on the settlement, designed in two linked parts to enable it to be readily split into two units if required in the future, as has now occurred in 2017. After periods away from the settlement travelling, with family, and living in a Caravan in 2016, the Payne’s refurbished and moved into one of the first three houses built, and at 55m2, the smallest house at the settlement.

The last communal stage of the project was the Quiet Room built at the start of 2000. The subject of much discussion as to need and design, it was intended as a place for common meetings and silence. It was controversial, as it is in Quaker terms, a non-traditional meeting space. Quaker meeting spaces are conventionally square or rectangle in shape. The Quiet Room is octagonal, with a large central circular skylight. It is a non-hierarchical contemplative space in its simplicity and evenness. The calmness of the space is partially attributable to its pure geometry, the light qualities, and its quiet acoustics. Like the other main buildings of the settlement the ceilings of the Quiet room are 38mm woodtex (cement bonded wood shavings panels) naturally finished and with high acoustic absorption. The building structure was erected as a communal effort by the wider New Zealand Quaker community over a single day, and the interior was finished by Payne and builder John Remus over the following three months.

6. Analysis and Contemporary Significance

Payne’s overall intent for the settlement like for the Hong Kong project was “to make a place people would want to live in and would give a measure of community life” Payne (2008). As a result, attention is given within the design to potential moments where social contact might occur and how the architecture can facilitate this. These range from the building thresholds, or big issues like the compact shape and centralised form of the overall community. All are highly significant. Other examples are the common carports and letterboxes with an associated notice board. With common tasks, job lists, and weekly meetings and community meals these create ‘sociability’ Payne (2017).

Separating the cars from houses was a significant architectural move. Another distinctive characteristic of the settlement pattern is the lack of formed paths between houses and the common areas, the lack of division of the land, and the lack of division of the sites that settlers occupy into smaller parcels. The subsoil is free draining sandy soil so this can occur and its implications are significant.

“Most people want their car with their house and in the typical suburban situation people drive right into their garages and no one sees them. Walking from common carparks to houses takes more time than it does to walk the distance because you encounter others on
the way” Payne (2017). It creates an aesthetic unity, a peaceful common environment that many visitors comment on. Payne (2017)

It also reflects the early influence of the Danish co-housing precedents, which were an important reference point supporting key ideas for the formation and maintenance of community, such as the grouping of cars together with the common areas.

The aesthetic unity is also significant. Common facilities and individual houses are linked with a common aesthetic expression, with common forms, colours and material palette. This is balanced by a highly individual private realm where every house and building is tailored to meet each individual’s needs. Payne noted “If you want to build a weatherboard house every other site in New Zealand is available” and that to be part of the Quaker community, “you must be prepared to accept the ground work already done by others.” This aesthetic unity was a practical means to retain a connection between separate, individual houses and community buildings designed over an extended period of time. It created a continuity between over 20 building projects constructed over 25 years.

There is a great contrast to the surrounding conventional subdivisions where there are “all kinds of expressions of wealth and superiority.” Payne 2017. The different settlements not only look different, an area analysis of the equivalent site areas for the Quaker Settlement and the adjacent subdivisions is revealing. The retirement village subdivision Kowhainui immediately to the west shows a hard surface coverage including roading, housing, driveways, and paths of 40% of the available land area. The new subdivision Lithgow Drive to the east of the site has road, housing, driveway, and path coverage of 60% of the available land area. The Quaker settlement has a site coverage of less than 20% of the available land area, and includes significant common areas and results in a clearly superior wider built environment quality. This environmental quality calls into question the value of many subdivision rules and standards like the extensive development of paths including the doubling of footpaths each side of roads, wide road widths allowing for two directions of flow and parking on their edges, all for limited cul-de-sac traffic, and at the expense of the natural site landscape and green space.

Figure 2: The Quaker Settlement (central) in context. (source: http://maps.whanganui.govt.nz/IntraMaps80/)
The settlement patterns in the surrounding subdivisions are also less sustainable from an energy perspective. At the settlement every house is able to be oriented directly to the north and take advantage of passive design principles. This is efficient and resourceful. Common houses also share a large north facing solar array contributing to a substantially energy self-sufficiency. The resourcefulness of post war architecture is also still evident here as well. There is a simplicity and modesty to the architecture that reminds us that it is possible to provide comfortable affordable housing and community environment without excess.

The big issue for any intentional community is “how do you manage the balance between individual and community life?” Payne 2017. Community living places demands on individual resources and time required to fund, establish and maintain community shared facilities. This takes a degree of shared responsibility and management. Socially it’s like living in a big extended family or like having lots of uncles and aunts. McCamant and Durrett note that “Cohousing institutionalises community on a long term basis. (2011) The number of houses and people in the community is now 17 houses and around 35 people in the community in a mix of owned and rental units, and this number is also noted to be a practical maximum for self-managed socially sustainable community.

“We wouldn’t mind a higher density, but it would be difficult because of the community management of so many. It is possible with a manager, but that would introduce a hierarchy. Would they be paid? Who do ‘they’ manage? What do they manage? “If we had a Director it may have been easier, but it would have crumbled. Everyone here has a willingness to share”. Payne (2017)

In the Quaker Settlement there is an understanding that consequences of decisions in the community effect other people. This plays out as a philosophy and working method of “Distributed responsibility” Payne (2017) that equally shares leadership and management, and is regarded as the critical factor to the community’s long term social sustainability. The Quaker Settlement careful, socially considered design is an enduring exemplar with significant relevance for emerging contemporary Cohousing projects.

References
Abstract: Given the slow rate of adding new houses to the existing stock in New Zealand and the fact 80% of older households fall into the small categories, it is essential to find effective design solutions for redeveloping existing houses to achieve a better quality of life for the elderly. Two New Zealand housing types were redesigned to New Zealand Lifemark standards. Three design proposals were produced for each type with various degrees of sharing. To discover how potential users felt about degrees of sharing in the proposed designs, these were presented to people aged 55‐85 years using an online questionnaire. Participants were asked to comment on the six schemes and proposals for the redesign of the section and outdoor space. The main focus of the survey was to investigate the features liked by respondents in each scheme. This study shows that conversion of the selected houses to accommodate ageing in place is possible. Findings from this study also show having a spare multi‐purpose room and private deck are the features most favoured by the respondents. Size and sunlight are also important factors in housing design, and smaller, and potentially easier to heat and maintain units, are less liked than larger ones.

Keywords: Ageing in place; refurbishment; lifetime homes; shared spaces.

Introduction

Where to live is a concern for New Zealand’s ageing population. With more emphasis on “ageing in place” perhaps the conversion of existing houses should receive more attention than new buildings because of the much higher proportion of the former in the housing stock. Statistics New Zealand (1998, 2006, 2008, 2013a) show in the relevant censuses that dwellings under construction annually formed 1% or less of the New Zealand housing stock. Davey et al. (2004) suggest that people do not have many choices within their communities if they wish to move locally from a family home that is probably too large to a more suitable house.

In 2013, 74% of New Zealanders owned or partly owned their dwelling (Statistics New Zealand, 2015). Moreover, more than 70% of older New Zealander lived in a dwelling with at least six rooms (equivalent to the standard three bedroom house according to the Statistics New Zealand (2014) room standard (Statistics New Zealand, 2017). As a result there is an interest in studying the conversion of New Zealand residential buildings to make them more suitable for ageing in place. This paper explores the possibilities
for conversion of two common New Zealand housing types. It also reports on the preferences and requirements of potential users to see if these design proposals are appealing and can assist the elderly to age in place.

**Design Criteria**

Based on differing size, the two selected housing types for conversion were early 20th century villas and 1940-60s single storey state houses. Villas are normally larger houses and, as stated by BRANZ (2016), most state houses are, “fairly small, with a roof pitch of about 30˚, and small casement windows”.

Older New Zealanders have shown an interest in communal housing (Statistics New Zealand, 2013b). Co-housing can be attractive because of the support and companionship it provides. Davey (2006) considers houses shared with family members or boarders as types of cohousing. Alternatively, in New Zealand 8-12 unrelated residents in Abbeyfield Houses share a family-style home (Davey et al., 2004).

In order to make the modification proposals more suitable for the elderly, New Zealand Lifemark standards were used in redesigning the case study dwellings. This set of standards provides a star rating and points system within which every ‘lifemark’ (LM) home has to meet the requirements specified in one of three categories. For example, a 3-star lifemark home is fully adaptable in the future at minimal cost and a 5-star lifemark is fully accessible (Lifetime Design Limited, 2012). A number of researchers have highlighted the need for the application of universal and accessible design in housing developments aimed at older people (Baldwin et al., 2012; Sutherland and Tarbatt, 2016).

Using the LM 3-star standard three different designs were produced for a villa and state house with different degrees of shared space. The latter ranged from conversion to two smaller units, to having a shared guest bedroom, to private en-suite bedsitting rooms and all living spaces shared.

**Survey**

A number of international design-based studies have investigated the integration of the elderly into the design process. Methods used include the photovoice method and charrettes (Baldwin et al., 2012), a national questionnaire based survey, in-depth interviews, and policy forums (Judd et al., 2014), group discussion, home visit, interviews and design workshops (Park et al., 2016).

In this study an online survey using Qualtrics (2017) was started on 12th of May 2017 and is ongoing. To test the survey questionnaire and obtain feedback two pilot surveys were carried out, involving not just the client group but also researchers into ageing and design professionals. The main survey is anonymous and a snowballing recruitment method is being used involving a number of national and local authorities and organizations. Targeting people aged 55-85, participants are asked to comment on six schemes and proposals for redesigning the section and outdoor space. This is the age when people consider moving from their family home (Park et al., 2016; Judd et al., 2014). Statistics New Zealand (2015) show in 2013, 64.7% of people aged 65+ lived in households with internet access compared to 85.1% of people aged 15–64. Of those aged 65+ with access 69% and 26% were aged 65-74 and 75-84 respectively. However, past censuses show the proportion of people aged 65+ with internet access has increased from 16.6% in 2001 to 39.5% in 2006 and 64.7% in 2013. This means that the proportion has risen 160% in 7 years, suggesting there is significant pool of potential participants of the right age group for the on-line survey.
The first part of the three part survey asks for background information and the second for the participant’s current housing situation. Part three presents the conversion schemes and asks for participants’ preferences regarding the degree of sharing of spaces. Scheme A involves three different options for converting a section (house plot) and is not considered in this paper. Schemes B and C provide separate units with a shared entrance (Figure 1), while schemes D, E and F have more shared spaces (Figures 2 and 3). For each scheme participants were told they would only be sharing the house with people they want to live with or near.

Preferences and design requirements were investigated as follows:

- Indoor and outdoor aspects of the design options were rated on a scale of 1-5 (1 not liked at all, 5 liked very much)
- Schemes were rated on the extent each met participant’s requirements on a scale of 1-5 (1 not liked at all, 5 liked very much)
- The features favoured or disliked for both shared and private spaces were highlighted by selecting from a prepared list, to which things could be added.
- Design preferences could be discussed further in the “other” option provided in multi-choice questions
- Asking who participants would be prepared to share with, whether people in the same age or other age groups, family or non-family members, and which spaces they would share, and the characteristics of these

Some results have been presented elsewhere (Yavari and Vale, 2017). Only the results from the last three bullet points are discussed in this paper. To date 247 persons have taken part in the survey and 233 have either fully or partially completed it. Of these 78.5% are female and 21.5% male.

**Results**

Simplified plans were used following feedback from both pilot surveys. Detailed plans including annotations and furniture were used in the pilot study but participants felt people without training in design could struggle to understand them, and they needed to be simplified. Since the sun was identified in the pilots as an influential factor in decision making, a winter sun path was included, so participants could see which spaces or facades get the sun. The size of units/bedsitting rooms and other spaces in each scheme were listed inside the images. Different colours were used for private and shared spaces. For each design option, the original house along with its conversion was shown. Respondents could enlarge each image by clicking on it although schemes were presented with a large enough font that people with normal vision could read them easily. In this paper, only the proposed designs with the sun path are illustrated. Pairs of schemes with the same design concepts in terms of shared and private spaces are illustrated and discussed together for easy comparison. This assists in identifying disparities and similar characteristics. Hence schemes B and C, and E and F are shown together. Where a respondent stated they liked a particular unit then they could go on to select which features they liked. This was not an option for those who stated they did not like a unit.

**4.1. Schemes B and C - Separate Units with Shared Hall/Entrance**

In schemes B and C, the original houses were converted into two separate units with a shared hall/entrance. Although both plans follow the same design concept, the responses to them differed significantly. In Scheme B, while unit 1 is larger than unit 2, unit 2 gets all day sun while only certain rooms
do in unit 1. In addition, unit 1 is a two bedroom unit with a deck but unit 2 has one bedroom, a bay window and enclosed verandah. They both have separate living rooms and open plan kitchen and dining areas (Figure 1). Both units in scheme C are small, but the smaller studio unit 2 gets much more sun than the larger unit 1. Another difference is that unit 1 has a double bedroom with study area and storage but unit 2 has a single bedroom without any built-in storage.

Figure 1: Left: Scheme B (villa); Right: scheme C (state house): separate units with shared hall/entrance

<table>
<thead>
<tr>
<th>Features favoured</th>
<th>Scheme B - unit 1 (n=93)</th>
<th>Scheme B - unit 2 (n=73)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of unit 1 (82 square metres)</td>
<td>71</td>
<td>76.3</td>
</tr>
<tr>
<td>Open plan kitchen, dining</td>
<td>55</td>
<td>59.1</td>
</tr>
<tr>
<td>Separate living room</td>
<td>54</td>
<td>58.1</td>
</tr>
<tr>
<td>Private deck</td>
<td>80</td>
<td>86.0</td>
</tr>
<tr>
<td>A spare single bedroom which can be used as guest room, study, or office</td>
<td>89</td>
<td>95.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Features favoured</th>
<th>Scheme C - unit 1 (n=71)</th>
<th>Scheme C - unit 2 (n=37)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of unit 1 (52 square metres)</td>
<td>50</td>
<td>70.4</td>
</tr>
<tr>
<td>Open plan kitchen, dining, living room</td>
<td>41</td>
<td>57.7</td>
</tr>
<tr>
<td>Private deck</td>
<td>53</td>
<td>74.6</td>
</tr>
<tr>
<td>Storage</td>
<td>48</td>
<td>67.6</td>
</tr>
<tr>
<td>Adequate sunlight</td>
<td>45</td>
<td>63.4</td>
</tr>
</tbody>
</table>

The survey found that while almost 80% of the respondents were interested in either of units in scheme B, only 52% found either of units in scheme C acceptable. This suggests the popularity of larger units and the space these offer. In spite of getting plenty of sunlight, unit 2 in scheme C was the least favoured with 17.8% of respondents showing an interest in it followed by 34.1%, 34.6% and 44.1% for unit 1 scheme C, unit 2 scheme B, and unit 1 scheme B respectively, showing that on average, size appears
more important more than sun in the house. This is supported by the fact that overall the villa conversion was more attractive to respondents, and that unit 1 in it was more attractive than unit 2.

Table 1 shows the number and percentage of respondents and the features they selected as reasons for their choice of either unit 1 or 2 in schemes B and C. In scheme B the spare single room which can accommodate various activities such as reading, office work, sleeping guests is the most popular feature with more than 95% of those selecting unit 1 favouring it, following by the private deck. One respondent mentioned the potential of the private deck in unit 1 scheme B for conversion into a conservatory. This highlights the significance of having flexible spaces to accommodate the various needs of occupants at different life stages. In all schemes with private decks around 75% of respondents have singled these out as important features, even though the original house did not have a deck. Size and storage were other features popular with respondents in looking at schemes B and C. In addition, as can be seen in Table 1, 68.5% of respondents liked an open plan kitchen and dining compared to 46.6% who favoured the separate living room in unit 1 scheme B, suggesting open plan arrangements might be better for smaller domestic environments.

Respondents were also asked to indicate any additional features they liked for each unit in the “other” option. Analysing comments from this section for scheme B it seems getting plenty of sunlight was a favourite feature for 18 respondents (out of 27 who selected “other” option). It seems that sunlight indoors as well as size are influential factors when it comes to conversion of existing houses.

4.2. Scheme D – Separate Units with Some Shared Spaces

In this scheme, unit 2 is 25m² larger than unit 1 and gets plenty of sun during the day (Figure 2), while unit 1 only gets sun for part of the day. In addition, while unit 1 has an open plan kitchen, living and dining, unit 2 has a separate living room, kitchen and dining room, as well as a conservatory/sunroom, and both shared and separate entrances. Both units have separate deck, laundry and storage. Shared spaces include a double bedroom, sitting room with study/office area, entrance and deck (Figure 2). The characteristics of unit 2 make it more popular with 66% of respondents favouring it compared to 11.3% who preferred unit 1.

Table 2 confirms the results shown in Table 1. In Table 2, the private conservatory/sun room and private deck were selected by more than 80% of respondents as reasons for selecting unit 2 followed by
its size at just under 80%. In addition, as in schemes B and C, private decks were liked by almost 80% of respondents who had selected unit 1 (Table 2). In the “other” section for unit 2 scheme D, 16 (out of 20) respondents gave sunlight as an influential factor in their decision.

Table 2: Features favoured by those who liked scheme D

<table>
<thead>
<tr>
<th>Features favoured</th>
<th>Frequency</th>
<th>Percent</th>
<th>Features favoured</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheme D - unit 1 (n=23)</td>
<td></td>
<td></td>
<td>Scheme D - unit 2 (n=134)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size of unit 1(70 square metres)</td>
<td>13</td>
<td>56.5</td>
<td>Size of unit 2 (95 square metres)</td>
<td>107</td>
<td>79.9</td>
</tr>
<tr>
<td>Open plan kitchen, dining, living room</td>
<td>17</td>
<td>73.9</td>
<td>Separate living room</td>
<td>68</td>
<td>50.7</td>
</tr>
<tr>
<td>Private deck</td>
<td>18</td>
<td>78.3</td>
<td>Separate dining room</td>
<td>44</td>
<td>32.8</td>
</tr>
<tr>
<td>Storage</td>
<td>12</td>
<td>52.2</td>
<td>Separate kitchen</td>
<td>60</td>
<td>44.8</td>
</tr>
<tr>
<td>Shared entrance</td>
<td>6</td>
<td>26.1</td>
<td>Private conservatory/sun room</td>
<td>110</td>
<td>82.1</td>
</tr>
<tr>
<td>Potential shared guest suite</td>
<td>15</td>
<td>65.2</td>
<td>Private deck</td>
<td>109</td>
<td>81.3</td>
</tr>
<tr>
<td>Potential shared suite for carer</td>
<td>13</td>
<td>56.5</td>
<td>Storage</td>
<td>97</td>
<td>72.4</td>
</tr>
<tr>
<td>Potential unit for renting out</td>
<td>13</td>
<td>56.5</td>
<td>Separate entrance</td>
<td>87</td>
<td>64.9</td>
</tr>
<tr>
<td>Adequate sunlight</td>
<td>14</td>
<td>60.9</td>
<td>Potential shared guest suite</td>
<td>77</td>
<td>57.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Potential shared suite for carer</td>
<td>59</td>
<td>44.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Potential unit for renting out</td>
<td>46</td>
<td>34.3</td>
</tr>
</tbody>
</table>

4.3. Schemes E and F – Private Bed-Sitting Rooms, with Shared Living Spaces, Guest Room/Study

While bed‐sitting room 1 in scheme E is 3m² smaller than bed‐sitting room 2, it has a separate deck facing east. Bed‐sitting room 2 has a bay window facing north‐east which gets the sun for most of the day. A large living room, kitchen, dining, study/office area and deck are shared in this scheme (Figure 3). In scheme F, both bed-sitting rooms are the same size and living room, kitchen, dining area, small

Figure 3: Left: Scheme E (villa); Right: scheme F (state house): private bedsitting room, with shared living spaces
study/office area and deck are shared (Figure 3). More than 60% of respondents liked neither bedsitting room 1 or 2, these being favoured by 19% and 18% of respondents respectively. Other findings suggest those aged 55+ are not willing to share spaces and features within their dwellings. Schemes E and F were least liked by respondents (Yavari and Vale, 2017).

Table 3: Features favoured by those who liked schemes E and F

<table>
<thead>
<tr>
<th>Features favoured</th>
<th>Frequency</th>
<th>Percent</th>
<th>Features favoured</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheme E – bed-sitting room 1 (n=38)</td>
<td></td>
<td></td>
<td>Scheme E – bed-sitting room 2 (n=35)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size of bed-sitting room 1 (25 square metres)</td>
<td>12</td>
<td>31.6</td>
<td>Size of bed-sitting room 2 (28 square metres)</td>
<td>27</td>
<td>77.1</td>
</tr>
<tr>
<td>Private deck</td>
<td>35</td>
<td>92.1</td>
<td>Bay window</td>
<td>26</td>
<td>74.3</td>
</tr>
<tr>
<td>Scheme E-shared spaces (n=167)*</td>
<td></td>
<td></td>
<td>Scheme F-shared spaces (n=171)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open plan kitchen, dining</td>
<td>58</td>
<td>34.7</td>
<td>Open plan kitchen, dining</td>
<td>65</td>
<td>38.0</td>
</tr>
<tr>
<td>Open plan dining, sitting area, study</td>
<td>57</td>
<td>34.1</td>
<td>Separate living room</td>
<td>79</td>
<td>46.2</td>
</tr>
<tr>
<td>Separate living room, with bay window</td>
<td>76</td>
<td>45.5</td>
<td>Single bedroom which can be used as guest room/study/office/sitting room</td>
<td>87</td>
<td>50.9</td>
</tr>
<tr>
<td>Single bedroom which can be used as guest room/study/office</td>
<td>96</td>
<td>57.5</td>
<td>Shared deck</td>
<td>52</td>
<td>30.4</td>
</tr>
<tr>
<td>Shared deck</td>
<td>42</td>
<td>25.1</td>
<td>Shared porch</td>
<td>32</td>
<td>18.7</td>
</tr>
<tr>
<td>Shared verandah</td>
<td>39</td>
<td>23.4</td>
<td>Shared shed/storage accessed from outside.</td>
<td>58</td>
<td>33.9</td>
</tr>
<tr>
<td>Shared porch</td>
<td>26</td>
<td>15.6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*N is indicative of the number of participants who selected at least one feature in the list.

As seen in Table 3, although the low proportion of respondents who favoured bed-sitting room 1 and 2 are the same, a significant percentage (77%) of those selected bed-sitting 2 liked its size. This is followed by the bay window, liked by 74% who liked this room. Table 3 also confirms the evidence from tables 1 and 2 that private decks are liked, as that in bedsitting room 1 was liked by more than 90% of respondents who favoured that room (Table 3). The extra multi-purpose room was the most attractive feature for the shared spaces in both villa-scheme E and state house-scheme F, being liked by more than half of the respondents. In addition, the shared separate living room was also liked more than the shared open plan kitchen, dining area in both schemes.

Sharing with different age groups

Sharing with the same age group

In the survey, participants were asked to rate their preferences for sharing various spaces within their house with the same age group on a scale of 1-5 (1-not at all, 5-very much). Table 4 presents average scores for female and male participants for selected spaces. Using an independent sample t tests showed no relationship between gender and mean scores. Table 4 also shows that the lowest mean score of 1.78 was for sharing a study. An independent sample t test found means for sharing different spaces are not statistically significant by gender.
Table 4: Mean and Standard deviation of participants for sharing various spaces with the same age group

<table>
<thead>
<tr>
<th>Space</th>
<th>55-64</th>
<th></th>
<th>65-74</th>
<th></th>
<th>75-85</th>
<th></th>
<th>Total</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean N</td>
<td>Std. Deviation</td>
<td>Mean N</td>
<td>Std. Deviation</td>
<td>Mean N</td>
<td>Std. Deviation</td>
<td>Mean N</td>
<td>Std. Deviation</td>
</tr>
<tr>
<td>Living/dining areas</td>
<td>2.09</td>
<td>1.097</td>
<td>2.08</td>
<td>1.128</td>
<td>1.90</td>
<td>1.071</td>
<td>2.05</td>
<td>1.105</td>
</tr>
<tr>
<td>Kitchen</td>
<td>2.00</td>
<td>1.074</td>
<td>1.89</td>
<td>1.085</td>
<td>1.62</td>
<td>0.953</td>
<td>1.87</td>
<td>1.061</td>
</tr>
<tr>
<td>Guest bedroom</td>
<td>2.45</td>
<td>1.381</td>
<td>2.49</td>
<td>1.283</td>
<td>2.23</td>
<td>1.143</td>
<td>2.42</td>
<td>1.281</td>
</tr>
<tr>
<td>Hobby room</td>
<td>2.67</td>
<td>1.354</td>
<td>2.67</td>
<td>1.248</td>
<td>2.38</td>
<td>1.206</td>
<td>2.61</td>
<td>1.268</td>
</tr>
<tr>
<td>Study</td>
<td>1.92</td>
<td>1.064</td>
<td>1.80</td>
<td>1.000</td>
<td>1.54</td>
<td>0.854</td>
<td>1.78</td>
<td>0.994</td>
</tr>
<tr>
<td>Laundry</td>
<td>3.09</td>
<td>1.362</td>
<td>3.00</td>
<td>1.349</td>
<td>2.63</td>
<td>1.199</td>
<td>2.95</td>
<td>1.327</td>
</tr>
</tbody>
</table>

5.2. Sharing with other age groups

In the survey, participants were asked to select who they might want to share with. Out of 247 participants, only 187 answered this question. They were allowed to select all that applies to them. Figure 4 illustrates the views of those respondents on sharing various spaces within their home with others who are not family members.

Figure 4: Preferences of people aged 55+ for sharing various domestic spaces with other age groups not in their family

When it came to the study 75.4% of participants were not willing to share this room with any other age group. Sharing of living/dining rooms and kitchens is also unpopular but almost 60% of the respondents were interested in sharing a laundry. The laundry is a common space in many cohousing developments and also in self-service laundromats. This suggests that varying degrees of sharing within a residential development would probably best suit the different preferences of users.
sharing with other age groups the 41-64 group received the highest votes with a significant difference with the next choice of 21-40 for all spaces (Figure 4).

**Design implications**

Having indoor sun is a significant factor when it comes to choice of dwelling. Size is also critical as a considerable number of respondents who did not favour one bedroom units required an extra room for a study and visiting guests and family members. This suggests having a large enough multi-purpose guest room/study/office within conversions of existing houses would be appreciated. This has also been suggested by Judd et al. (2014).

For some people sound insulation is a vital issue when they went through the survey. Since findings from this survey show that smaller units were unpopular, to reflect the preferences of older people and meet their needs, setting a minimum size for the original house to be converted is important, and then detailing the conversion for aural privacy, such as having buffering spaces like storage and bathrooms along party walls is vital.

The survey also reveals decks and verandahs that support outdoor activities such as sitting, BBQ, reading, and light gardening are attractive. The importance of designing outdoor environments that include private outdoor space (such as patios and balconies) have also been highlighted in other studies (Baldwin et al., 2012; Park et al., 2016; Yavari et al., 2016). Park et al. (2016) also found the most successful shared spaces are those outdoor spaces specifically designed to provide opportunities for shared activities such as a barbecue area. Considering the profound influence of integrating nature into built environment on wellbeing and quality of life (Beatley, 2011), outdoor environments need to be designed to enhance the quality of life for the elderly.

Scheme B where a villa was converted into private units and scheme D with private units and some shared spaces were the most popular options, with 79% and 77% of respondents liking either unit 1 or 2 in these schemes. Scheme E with 63% not liking bedsitting rooms 1 and 2 was the least liked scheme.

**Conclusion**

Findings from this survey suggest that people aged 55-85 have very specific housing needs when it comes to ageing in place. Therefore, engaging potential users with the design process at an early stage might be a good idea for making conversion and modification practices more effective. However, other concerns such as financial and environmental issues were not examined in this survey, and these might make a difference to the results.

The study shows it is possible to convert relatively small houses to allow ageing in place but that these might not satisfy the target client group. The conversions of the larger villas appeared to provide much more acceptable housing, even when these included a degree of shared spaces.

This work is still in progress and one intention is to hold focus groups with those aged 55+ to talk through the designs and gain greater understanding of what housing they want and can afford and that will allow them to age in place with a good quality of life.
References


Estimating the Floor Area of a House Knowing its Number of Rooms and how these are named

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Abstract: Globally, statistics are used to investigate the condition of housing as an indicator of quality of life. Among these house size is an important parameter for showing the quality of housing, although measuring the floor area of a house is both time consuming and expensive, and would be very difficult for big census samples. Information about the overall floor area of a house is also used in life cycle analysis and energy and lighting simulation tools. A floor plan study of New Zealand houses was undertaken as part of a larger project. In total, 287 published plans of New Zealand houses of various ages with differing numbers of rooms were selected and analyzed in AutoCAD to find room and whole house areas. Data about the average floor area for each room type for all houses were gathered in an Excel spreadsheet and transferred to SPSS for further analysis. This showed that the size and combination of rooms of NZ houses follow a specific pattern. Using the results, a tool was developed for estimating the floor area of a house based on its number of different types of room. This study showed that with careful analysis of the floor plans of examples from an existing national housing stock, it is possible to find patterns for the size and types of rooms and use such information for predicting the floor area of similar house types.

Keywords: House size; room standard; room type; New Zealand.

1. Introduction

All over the world statistics are used to investigate the condition of housing as an indicator of quality of life (Statistics New Zealand, 2016). House size is regarded as an important parameter for showing the quality of housing and reflecting the wealth and social aspirations of occupants. Measuring the floor area of a house is a time consuming and expensive process, and would be very difficult for big census samples. It also requires a degree of expert knowledge to have confidence in the results. To simplify this process house size is normally estimated from the reported number of rooms and bedrooms in census data. Most crowding indices including the American Crowding Index (ACI), British Bedroom Standard (BBS) and Canadian National Occupancy Standard (CNOS) also use number of rooms and bedrooms for measuring the level of crowding in the house (Goodyear et al., 2011). However, because the size of rooms and
bedrooms can vary significantly between countries, there are serious concerns over being totally dependent on the number of rooms and bedrooms as an indicator of house size. Hence, it seems that the overall floor area of the house could be a better indicator of house size than counting rooms and bedrooms. This raises the question as to whether it is possible to estimate the floor area of a house using just the information about the type and number of its rooms.

This paper tries to address this by analysing floor plans that are representative of the existing New Zealand housing stock and generalizing the findings. The aim is to do the time consuming measuring once and then use census data on the number and type of rooms to estimate all house floor areas in the New Zealand housing stock.

This process or tool for estimating the floor area of New Zealand houses by number and type of rooms, was initially designed for use in life cycle analysis. The application of this tool to the life cycle analysis of New Zealand houses is discussed elsewhere (Khajehzadeh (2017) and Khajehzadeh ad Vale (2015)). However, such tool could also be used by the New Zealand government to monitor the increase or decrease in house size and see how various strategies might affect the average floor area of the house. The other use of this tool is in energy and lighting simulation tools as it gives an accurate estimation of the average floor area of various room types and avoids guess-based data entry in simulations.

Finding the characteristics of a large sample of a particular group of objects and applying such characteristics to other members of that group is a popular method for creating estimating tools. The basis for development of this tool is the study of floor plans of New Zealand houses, finding potential patterns in size, type and number of rooms and then using this data for estimating the floor area of similar sized houses in the same context. For example, by analysing the floor plans of a group of New Zealand six room houses (i.e. typical three bedroom houses), it is possible to find the average floor area of master bedrooms, second and third bedrooms, living room, dining room, and kitchen. This information can then be used to estimate the subtotal floor plan of any other six room house. Where a 6 room house has two bedrooms and a study, a group of such houses can be analysed in a similar way to find the average areas for each room type.

2. Method

As part of a larger study of the resources going into New Zealand houses, 287 published floor plans of New Zealand houses with differing numbers of rooms (from 3 to 9+ rooms) were selected, redrawn and analysed in AutoCAD 2015/2016. The number of rooms follows Statistics New Zealand (2014) room standard definitions. It includes all habitable spaces (with floor area more than 4m²) enclosed by walls, floor and ceiling/roof excluding all service areas (bathroom, laundry etc.). In this definition, service spaces including bathroom, toilet and laundry are not counted as a room even if they meet all other criteria. In addition, the kitchen, living room and dining room are counted separately even where these are combined. For example, a house with a combined living rooms/dining room/kitchen, two bedrooms, a study and two bathroom/toilets will be considered as a six room house.

In total, 287 floor plans were selected from those built in New Zealand or designed for the New Zealand market. This included a minimum of 40 samples for each house size category (e.g. at least 40 4 room houses, 40 5 room houses and so on) because first analysis showed that this sample size gave a relatively constant average for all house sizes. All selected houses were detached or semi-detached one-family houses and representative of various decades of construction in New Zealand.

The floor areas of all rooms and the whole house were calculated for all sample houses. To make the floor area of rooms in all sample houses comparable, rooms were put into 23 categories (master bedroom, other bedroom(s), study (including library/office), games room (including rumpus room/gym), studio (or workshop), separate living room, separate dining room, separate kitchen, combined living room/kitchen, combined living room/dining room, combined dining room/kitchen, combined living room/dining room/kitchen, bathroom with no toilet, toilet, en-suite, combined bathroom/toilet, combined toilet/laundry, combined bathroom/toilet/laundry, laundry, utility room, conservatory, storage (other than a fitted cupboard), and circulation space (corridor, hall, staircase, and landing)). Where more than one room type occurred (except bedrooms) these were numbered in size order with the largest room being 1. For bedrooms, the largest became the master bedroom and other bedrooms were numbered in size order (bedroom 2, bedroom 3 etc.). In measuring the floor area of rooms of the sample houses following rules were followed:

- The floor areas of shared internal walls were equally divided between adjacent rooms.
- As garages are excluded in this analysis, integral garage walls were treated as being external and floor areas of integral garages excluded from the total house floor area.
- Small spaces such as built-in wardrobes or small storage spaces were included in the floor area of the room from which these are accessed.
- Walk-in wardrobes were also included in the floor area of the relevant bedroom.
- A room, including a room with combined functions, is physically separated from adjacent rooms by a door or door-sized opening.
- The room usage and name generally follow the nomenclature of the floor plan although for combined rooms this was only considered valid if the room was big enough to contain all usages or each usage was well defined in the arrangement of the furniture and fittings.
- Pantries, sculleries, and kitchen fittings are included in the floor area of the kitchen and laundries in garages are excluded from this study.
- Where circulation spaces are separated, the floor area is the subtotal of all circulation areas.

A sample floor plan and how various rooms are measured according to above criteria can also be found in Khajehzadeh (2017).

Apart from data on the floor area of rooms from sample houses, analysis of the floor plans also provided information regarding number of rooms of each type in each sample house and the floor area of the circulation spaces as a percentage of the total floor area of the house. This information was analysed in SPSS. Houses were grouped according to the number of rooms and then various features of sample houses including number and size of rooms and the presence of different types of rooms in various sized houses were analysed against house size category (based on number rooms). The full detail of the
study, sample composition, analyses and results are presented elsewhere (Khajehzadeh (2017) and (Khajehzadeh and Vale (2017)).

3. Results Extracted from the Source Study

As noted before, the detailed analysis and results of this study are presented elsewhere (Khajehzadeh (2017) and Khajehzadeh and Vale (2017)). Because some results are directly used in the development of the tool in this paper, key findings of the main study are briefly noted below:

- This study found the overall floor area of various sized house based on number of rooms. This showed that on average, floor areas of New Zealand houses (garages excluded) with 3, 4, 5, 6, 7, 8 and 9-9+ rooms are respectively 51.7, 70.7, 96.2, 120.2, 161.3, 190.0 and 254.9m².
- The average number of different room types were found for the various sized houses. For example, it became evident on average how many bedrooms, bathrooms, living rooms etc. are found in six room NZ houses, 7 room NZ houses etc. This study also showed that the average number of most room types is significantly different by house size. In other words, it became clear that with an increase in house size the number of most rooms also increases.
- The average floor area of the various room types were found for each house size category. For example, the average size of a master bedroom for houses with 4, 5, 6, 7, 8 and 9-9+ rooms was calculated. This study also showed the average size of most room types increases with an increase in house size. For example, the average floor area of the master bedroom in a 4, 5, 6, 7, 8 and 9-9+ room house is respectively 14.9, 16.8, 17.4, 21.2, 23.4 and 27.9m² and the difference between these is statistically significant.
- The probability of finding a particular room type in houses of different sizes was also found as part of this study. For example, a study tends to be part of a 5-5+ room houses while a games room is only found in 8-8+ room houses.

Although sizes of different types of room are highly dependent on the relevant house size, it is possible to generalize this to houses within a similar size category. Accepting this, the findings of this part of the study can be used as the foundation for the development of a tool to estimate floor area of New Zealand houses based on census data of the number and type of rooms.

4. Developing the Tool

From SPSS analyses, it is possible to put all room types into three categories based on their dependency on house size. The following sections describe these categories in more detail.

4.1. Rooms whose floor area is significantly different by house size

Results of SPSS analyses showed that the floor area of some room types is significantly different by house size (Khajehzadeh (2017) and Khajehzadeh and Vale (2017)). Rooms that fall into this category are the master bedroom, second, third, fourth, fifth, and sixth bedroom, kitchen, living room 1, combined living room/kitchen, combined living room/dining room/kitchen, bathroom 1, bathroom/toilet 1, en-suite 1, and toilet 1. For these rooms, each house is first sized according to the number of rooms (e.g. a 5 room house) based on the Statistics New Zealand room standard. Then for each room type, including the service spaces which are omitted from the room standard, where there are sufficient sample numbers (at least 30) the average floor area of that particular room type for 5 room houses in this study is used. Where the
number of samples is less than 30 an equal number of samples from one size more and one size less are used to give a new average floor area for that room type. For instance, if there are only 20 kitchens in 5 room houses, then 5 from both 4 and 6 room houses will also be included in the average for this house size. Table 1 gives the average floor area for these room types based on the findings of this study.

### 4.2. Rooms whose floor area is not significantly different by house size

Results of SPSS analyses showed that the floor area of some room types is not significantly different by house size (Khajehzadeh (2017) and Khajehzadeh and Vale (2017)). Rooms that fall in this category are the study, games room, studio 1 (or workshop), studio 2, living room 2, living room 3, dining room, combined living room/dining room, combined dining room/kitchen, bathroom 2, bathroom/toilet 2, en-suite 2, en-suite 3, toilet 2, toilet/laundry, bathroom/toilet/laundry, laundry, utility room and storage fall into this category. The assumption here is that regardless of house size, all such rooms have a similar floor area. So all samples with these room types are used to create an average floor area for that particular room for all house sizes. Room types with less than 30 samples are also included in this category. As discussed in 4.3, the study, games room and studio do not necessarily fit in this category and are considered in a third category (Exceptions). Table 1 gives the average floor area for these room types based on findings of this study. In very small houses, such as those with four and five rooms, it might seem somewhat unusual to have two bathrooms or two en-suites but these do exist (e.g. a house with a combined living room/dining room/kitchen, two bedrooms and two bathrooms one or both of are en-suite), and consequently the floor areas of these are included in Table 1.

### 4.3. Exceptions

There are exceptions because some room types do not fit in either of first two categories. For instance, the average floor area of a games room (27.97m²) is taken from 8 and 9-9+ room houses as other house sizes do not have this room type. At the same time, people might use the rooms in their house in a different way, and a six room house for a couple might have a games room in bedroom two or three. Allocating 27.97m² to this room is wrong because a 6 room house does not have such large rooms. The same might be true of a study and studio. The assumption is that people would usually allocate the largest spare bedroom to a games room and studio and the smallest spare bedroom to the study. Based on this, for these rooms, the average floor area of the largest bedroom (after the master bedroom) of the same sized house becomes the area of the games room and studio and the average floor area of the smallest bedroom that of the study.

Accepting the rules in 4.1, 4.2 and 4.3, Table 1 summarizes the proposed floor areas for each room type in each houses category. These will become the basis of the floor area calculation tool.

### 4.4. Calculating floor area of circulation spaces

The SPSS analyses also showed that the floor area of circulation spaces (as a percentage of the floor area of all other spaces) is significantly different by house size (Khajehzadeh (2017) and Khajehzadeh and Vale (2017)), so a different strategy is used for these. The floor area of circulation spaces was calculated as a percentage of the overall floor area of all other rooms in each house size. An average of these percentages was then calculated for each house size (Table 2). Using Table 2, it is possible to estimate the floor area of circulation spaces in different sized houses based on the floor area of all other rooms and spaces. For
example, if the subtotal floor area of all rooms and spaces of a six room house is 105m², then the floor area of the circulation space of the house is 15.9m² ((105×15.18)÷100).

<table>
<thead>
<tr>
<th>Room type</th>
<th>4 room</th>
<th>5 room</th>
<th>6 room</th>
<th>7 room</th>
<th>8 room</th>
<th>9-9+ room</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master bedroom</td>
<td>14.85</td>
<td>16.78</td>
<td>17.44</td>
<td>21.19</td>
<td>23.37</td>
<td>27.92</td>
</tr>
<tr>
<td>Second bedroom</td>
<td>11.55</td>
<td>12.81</td>
<td>13.15</td>
<td>14.98</td>
<td>15.60</td>
<td>17.53</td>
</tr>
<tr>
<td>Third bedroom</td>
<td>N/A</td>
<td>10.90</td>
<td>11.11</td>
<td>12.71</td>
<td>13.56</td>
<td>14.83</td>
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<tr>
<td>Fourth bedroom</td>
<td>N/A</td>
<td>N/A</td>
<td>11.98</td>
<td>11.95</td>
<td>12.52</td>
<td>13.80</td>
</tr>
<tr>
<td>Fifth bedroom</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>13.02</td>
<td>13.02</td>
</tr>
<tr>
<td>Sixth bedroom</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>11.39</td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>11.55</td>
<td>10.06</td>
<td>10.06</td>
<td>10.06</td>
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<td>10.56</td>
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<td>11.55</td>
<td>12.81</td>
<td>13.15</td>
<td>14.98</td>
<td>27.97</td>
<td>27.97</td>
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<td>Studio 1</td>
<td>11.55</td>
<td>12.81</td>
<td>13.15</td>
<td>28.09</td>
<td>28.09</td>
<td></td>
</tr>
<tr>
<td>Studio 2</td>
<td>N/A</td>
<td>10.90</td>
<td>11.98</td>
<td>19.65</td>
<td>19.65</td>
<td>19.65</td>
</tr>
<tr>
<td>Kitchen</td>
<td>11.62</td>
<td>12.63</td>
<td>11.50</td>
<td>16.23</td>
<td>18.76</td>
<td>18.76</td>
</tr>
<tr>
<td>Living room 1</td>
<td>21.81</td>
<td>22.17</td>
<td>24.92</td>
<td>29.45</td>
<td>30.78</td>
<td>30.78</td>
</tr>
<tr>
<td>Living room 3</td>
<td>N/A</td>
<td>12.81</td>
<td>13.15</td>
<td>14.98</td>
<td>15.60</td>
<td>21.81</td>
</tr>
<tr>
<td>Dining room</td>
<td>11.55</td>
<td>16.71</td>
<td>16.71</td>
<td>16.71</td>
<td>16.71</td>
<td>16.71</td>
</tr>
<tr>
<td>Combined living/kitchen</td>
<td>29.35</td>
<td>34.59</td>
<td>35.82</td>
<td>35.82</td>
<td>35.82</td>
<td>35.82</td>
</tr>
<tr>
<td>Combined living/dining</td>
<td>35.00</td>
<td>35.00</td>
<td>35.00</td>
<td>35.00</td>
<td>35.00</td>
<td>35.00</td>
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<td>Combined living room/dining room/kitchen</td>
<td>44.34</td>
<td>44.34</td>
<td>49.45</td>
<td>52.86</td>
<td>53.59</td>
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<td>4.82</td>
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<td>6.25</td>
<td>7.17</td>
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<tr>
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<td>2.68</td>
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<td>2.68</td>
</tr>
<tr>
<td>Bathroom/Toilet 1</td>
<td>5.47</td>
<td>5.28</td>
<td>6.53</td>
<td>7.56</td>
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<td>9.39</td>
</tr>
<tr>
<td>Bathroom/Toilet 2</td>
<td>5.24</td>
<td>5.24</td>
<td>5.24</td>
<td>5.24</td>
<td>5.24</td>
<td>5.24</td>
</tr>
<tr>
<td>En-suite 1</td>
<td>4.59</td>
<td>4.59</td>
<td>4.77</td>
<td>5.37</td>
<td>6.32</td>
<td>8.30</td>
</tr>
<tr>
<td>En-suite 2</td>
<td>5.86</td>
<td>5.86</td>
<td>5.86</td>
<td>5.86</td>
<td>5.86</td>
<td>5.86</td>
</tr>
<tr>
<td>En-suite 3</td>
<td>N/A</td>
<td>7.91</td>
<td>7.91</td>
<td>7.91</td>
<td>7.91</td>
<td>7.91</td>
</tr>
<tr>
<td>Toilet 1</td>
<td>1.92</td>
<td>1.96</td>
<td>2.12</td>
<td>2.42</td>
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</tr>
<tr>
<td>Toilet 2</td>
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<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Toilet/Laundry</td>
<td>7.63</td>
<td>7.63</td>
<td>7.63</td>
<td>7.63</td>
<td>7.63</td>
<td>7.63</td>
</tr>
<tr>
<td>Bathroom/Toilet/Laundry</td>
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<td>7.40</td>
<td>7.40</td>
<td>7.40</td>
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</tr>
<tr>
<td>Laundry</td>
<td>5.69</td>
<td>5.69</td>
<td>5.69</td>
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<td>5.69</td>
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<td>11.18</td>
<td>11.18</td>
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<td>11.18</td>
<td>11.18</td>
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<tr>
<td>Storage</td>
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<td>3.51</td>
<td>3.51</td>
<td>3.51</td>
<td>3.51</td>
</tr>
</tbody>
</table>
Figure 1 shows the process of estimating the floor area of a house using this tool. For instance, if we need to estimate the overall floor area of a five room house with a master bedroom, second bedroom, combined living room/dining room/kitchen, bathroom/toilet and a laundry, we need to look at the second column of Tables 1 and 2 (for five room houses). According to Table 1, the floor areas of the master bedroom, second bedroom, combined living room/dining room/kitchen, bathroom/toilet and laundry for a five room house are respectively 16.78m², 12.81m², 44.34m², 5.28m² and 5.69m². The subtotal floor area of all rooms excluding circulation spaces is thus 84.90m². Using Table 2, 12.99% of this will be given over to circulation, making the estimated floor area of circulation spaces in this house 11.03m². Consequently, the total floor area of this five room house is 95.93m².

5. Conclusion

Having precise information about the floor area of a country’s housing stock is both important and useful for activities including life cycle assessment studies, energy and lighting simulation tools and even for governments to have better understanding of changes in house size patterns.

In many fields of science, by analysing the characteristics of sample members of a large group, it is possible to find shared characteristics of the whole group and apply these to all other members of the group. The results of a floor plan study of New Zealand houses showed that the floor area of most room types is significantly different by house size (based on number of rooms). This makes it possible to estimate the average floor area of a particular room type providing we know to which house size category this room belongs. Having such information, this study developed a tool that enables researchers to
I. Khajehzadeh and B. Vale estimate the overall floor area of a house using basic information about the type and number of rooms in the house, usually available from census data.

This study set out to develop a first example of such a tool by analysing the floor area of 287 New Zealand houses of different ages. While the outputs of this tool are applicable to the average New Zealand house in any size category, there are concerns in applying this information to particular house types or houses of various ages. It is also important to analyse houses of the same type, just as this study only looked at detached houses, as room sizes in apartments could be very different. This study has used house plans for all ages of houses found in the New Zealand housing stock, so it is not necessarily appropriate to use the average room size in Table 1 for older New Zealand houses. However, as stated above, this study is a first step in trying to generalise house areas from only knowing the number of rooms a house and how these rooms are named.

6. References


Bedroom and Room Standards and Large Housing in New Zealand

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Abstract: In most developed countries censuses and crowding indices measure house size in terms of number rooms or bedrooms, even though the average house size varies in different countries. According to Statistics New Zealand and studies by BRANZ, recently New Zealand houses have changed both in terms of overall floor area and types of rooms. A floor plan study of 287 New Zealand houses revealed new houses have many specialized rooms and normal room types (sleeping bedrooms, living rooms) are bigger. Though bathrooms/laundries are never counted as habitable rooms, some in new houses are exceed the size of a bedroom in a 3-bedroom New Zealand state house. The study also shows the floor area of a 3 bedroom house in New Zealand varies from 79-225m², thereby questioning whether using number of bedrooms could be underestimating house size in New Zealand and other developed countries. This paper uses evidence to propose that censuses and crowding indices need more complicated tools for predicting house size and discusses the form these might take.

Keywords: Room standard; New Zealand; large housing; crowding index.

1. Introduction

All over the world statistics are used to investigate the condition of housing as an indicator of quality of life (Statistics New Zealand, 2016). Within these statistics house size is seen as an important parameter regarding the quality of housing as well as reflecting the wealth and social aspirations of occupants. Measuring the floor area of a house is a time consuming and expensive process, and would be very difficult for big census samples. It also requires a degree of expert knowledge to have confidence in the results. To simplify this process house size is normally estimated by using the reported number of rooms and bedrooms in census data. Where room sizes are relatively constant this is reasonable as houses with more rooms and/or bedrooms are bigger than those with fewer rooms and/or bedrooms, although as discussed later, this is not the case for all houses.

According to Statistics New Zealand (2014a) “a room is defined as a space in a dwelling which is used, or intended for habitation, and is enclosed by walls reaching from the floor to the ceiling or roof covering.”
For floor area, “habitable rooms should be at least two metres in height and of at least four square metres in area”. Service areas such as pantries, hallways, spa–rooms, walk–in wardrobes, corridors, verandas, garages, laundries, toilets and bathrooms are excluded even if they meet the minimum floor area criteria (Statistics New Zealand, 2014a). If a dwelling has an open-plan, then room equivalents should be counted as if they had walls between them (i.e. a combined living room/dining room/kitchen is counted as 3 rooms). These criteria set the room standard. Statistics New Zealand (2014a) defines a bedroom as “a room in a dwelling which is used, or intended for sleeping in.” It is also classed as a bedroom only if it is furnished as such and includes items such as a bed or mattress, dresser and chest of drawer even if it is not being used for sleeping at the time of the data collection. These criteria set the bedroom standard. This suggests definitions of bedrooms are highly dependent on the way occupants furnish their houses.

The New Zealand housing regulations 1947 (New Zealand Government, 2013) remains the only official document which include sizes for some room types. In this reprint the minimum acceptable floor area for kitchens of houses with two or fewer residents is 3m² and 4m² for all other households. In addition, the minimum floor areas of bedrooms in new and existing houses are respectively 6.0 and 4.5m². There is no standard for the minimum floor area of other rooms although there is a minimum height standard of 2.1m for existing houses and 2.4m for new houses. These minimum dimensions differ from those of Statistics New Zealand above.

Table 3 Average floor area, number of rooms, and room size for New Zealand and 15 European countries (source: Dol and Haffner (2010) and Statistics New Zealand (2014b)).

<table>
<thead>
<tr>
<th>Country</th>
<th>Average floor area</th>
<th>Number of rooms</th>
<th>Average room size</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Zealand</td>
<td>149</td>
<td>6.3</td>
<td>23.7</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>125</td>
<td>5.5</td>
<td>22.7</td>
</tr>
<tr>
<td>Denmark</td>
<td>113</td>
<td>3.8</td>
<td>29.7</td>
</tr>
<tr>
<td>Ireland</td>
<td>104</td>
<td>5.6</td>
<td>18.6</td>
</tr>
<tr>
<td>Netherlands</td>
<td>98</td>
<td>4.2</td>
<td>23.3</td>
</tr>
<tr>
<td>Italy</td>
<td>96</td>
<td>4.2</td>
<td>22.8</td>
</tr>
<tr>
<td>Austria</td>
<td>94</td>
<td>4.1</td>
<td>22.9</td>
</tr>
<tr>
<td>Sweden</td>
<td>91</td>
<td>4.2</td>
<td>21.6</td>
</tr>
<tr>
<td>France</td>
<td>90</td>
<td>4.0</td>
<td>22.5</td>
</tr>
<tr>
<td>Germany</td>
<td>90</td>
<td>4.4</td>
<td>20.5</td>
</tr>
<tr>
<td>Spain</td>
<td>90</td>
<td>5.0</td>
<td>18.0</td>
</tr>
<tr>
<td>UK</td>
<td>87</td>
<td>4.7</td>
<td>18.5</td>
</tr>
<tr>
<td>Portugal</td>
<td>83</td>
<td>4.3</td>
<td>19.3</td>
</tr>
<tr>
<td>Belgium</td>
<td>81</td>
<td>4.7</td>
<td>17.2</td>
</tr>
<tr>
<td>Greece</td>
<td>81</td>
<td>3.8</td>
<td>21.3</td>
</tr>
<tr>
<td>Finland</td>
<td>77</td>
<td>3.6</td>
<td>21.3</td>
</tr>
</tbody>
</table>

According to Statistics New Zealand (2014b) the average floor area of new New Zealand houses has increased from 108.7m² in 1974 to 191.6m² in 2011, a 76% increase in 37 years. A study by BRANZ (Page, 2007) also shows new New Zealand houses are bigger than in the past. At the same time, average household size has decreased from 3.7 in 1951 to 2.6 in 2011 (Statistics New Zealand, 2008) meaning fewer people are living in larger houses (the latter is termed large housing in this study). Large housing seems to be a new phenomenon not only in New Zealand but also in other developed countries such as Australia (Fuller and Crawford, 2011). A comparison of New Zealand houses with 15 European countries
(Dol and Haffner, 2010) indicates the former are larger in terms of average floor area, average number of rooms, and average room size (Table 1). A 2014 survey of 287 owner occupied houses in New Zealand by Khajehzadeh (2017) indicates some features of these large houses are double/triple garage, double/triple living rooms, extra bedrooms with no usual occupant, specialized rooms (i.e. study/office, play room, games room/rumpus room, studio/workshop), and more than one bathroom (including en-suites).

The types of houses are also changing in New Zealand. According to Statistics New Zealand (2002, 2011 and 2014c) numbers of 1, 2 and 3 bedroom houses have respectively decreased by 7, 19 and 14% from 1986 to 2013 (Figure 1). Over the same period, numbers of 4, 5, 6, 7 and 8-8+ bedroom houses have increased by 51, 123, 175 and 100% (Figure 1). A study by the United States Census Bureau by Sarkar (2011) on changes in American houses over recent decades shows the percentage of houses with 4 and more bedrooms increased from 16.8% in the 1960s and earlier to 33.6% in 2005-2009.

![Figure 6 House size as a percentage of total NZ houses 1986-2013 (Source: Statistics New Zealand (2002, 2011 and 2014c))](image)

Houses size as determined from the census is used to estimate the level of overcrowding in different household types in different parts of the country. Statistics New Zealand (2014d) define crowding as “a theoretical concept about the acceptable number of people per household. Crowding in households relates to situations where the number of people residing in a household exceeds the ability of the dwelling to provide adequate shelter and services to its members.” Living in overcrowded houses is proved to lead to problems: mental (Harker (2006) and Robert-Hughes et al. (2011)), physical (Harker (2006) and Robert-Hughes et al. (2011)) and social (Murray (1974), UCL (2010), Reynolds et al. (2004), Reynolds and Robinson (2005) and Friedman (2010)). Studies by Harker (2006) have shown a negative relationship between educational achievements and overcrowding. At the same time, living in houses larger than needed equates to using more natural resources for housing, and often a significant part of such resources remains underused (Khajehzadeh, 2017).
2. Crowding Indices

Crowding indices are tools used to measure the level of crowding in the household. There are six common ones in use in the world: The American crowding index (ACI) or People Per Room (PPR), Equivalised Crowding Index (ECI), Canadian National Occupancy Standard (CNOS), British Bedroom Standard (BBS), Occupancy Rating standard, and People per floor area index (Goodyear et al. 2011). The ACI is the most popular index while a version of CNOS is used by Statistics New Zealand and in Australia and seems to be the best fit for the New Zealand situation (Goodyear et al. 2011). Crowding indices are usually calculated according to the number of residents, number of rooms, type of room, sex of residents, and age of residents (Goodyear et al. 2011).

Different crowding indices consider room or bedroom numbers when measuring house size and also different age/gender conditions for sharing bedrooms. Table 2 compares three popular crowding indices. Table 2 shows the number of rooms/bedrooms is a key parameter in all these crowding indices and an inaccurate figure for the number of rooms/bedrooms could lead to misleading crowding rates. Crowding indices are mainly used for measuring overcrowding although they can also help in measuring under-use of houses, which in turn could be linked to wastage of the resources and energy that go into housing (Khajehzadeh (2017) and Khajehzadeh and Vale (2015a)). However, it seems that while all crowding indices are relatively precise for measuring overcrowded houses, none are good for measuring the level of under-utilization in large houses, as will be discussed below.

Table 4 Comparison of 3 crowding indices and their categorization of being overcrowded (prepared based on data from Goodyear et al. (2011))

<table>
<thead>
<tr>
<th>House size basis</th>
<th>Which pairs should share a bedroom?</th>
<th>Age which needs separate bedroom</th>
<th>Crowding condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACI Rooms NA NA NA NA NA</td>
<td>Couples</td>
<td>Young children of any gender if</td>
<td>Crowded Not crowded</td>
</tr>
<tr>
<td>BBS Bedrooms Yes Age&lt;10 Age&lt;21 Age&gt;21</td>
<td>Extra bedrooms</td>
<td>1 above standard</td>
<td>Overcrowded Equal to standard</td>
</tr>
<tr>
<td>CNOS Bedrooms Yes Age&lt;5 Age&lt;18 Age&gt;18</td>
<td>Extra bedrooms</td>
<td>Under-occupied 2+ extra bedrooms</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ACI Rooms NA NA NA NA NA</th>
<th>Couples</th>
<th>Young children of any gender if</th>
<th>Crowded Not crowded</th>
</tr>
</thead>
<tbody>
<tr>
<td>BBS Bedrooms Yes Age&lt;10 Age&lt;21 Age&gt;21</td>
<td>Extra bedrooms</td>
<td>1 above standard</td>
<td>Overcrowded Equal to standard</td>
</tr>
<tr>
<td>CNOS Bedrooms Yes Age&lt;5 Age&lt;18 Age&gt;18</td>
<td>Extra bedrooms</td>
<td>Under-occupied 2+ extra bedrooms</td>
<td></td>
</tr>
</tbody>
</table>

Crowded

| 1.5<PPR 1<PPR<=1.5 0.5<PPR<=1 PPR<=0.5 |
| 1+ extra bedrooms 0 extra bedrooms 1 extra bedrooms 2+ extra bedrooms |
| 2+ extra bedrooms needed 1 extra bedroom needed 1 bedroom spare 2+ bedrooms spare |
| 0 extra bedrooms 1 extra bedrooms 2+ extra bedrooms |
3. Large Housing and Room/Bedroom Standard

When considering large housing, three concerns emerge regarding the accuracy of room and bedroom standards as tools for measuring house size.

- The first problem is that specialized rooms such as study/office/library, games room/rumpus room/gym, playroom and studio/workshop are considered as a room in the room standard but are not considered as a bedroom(s) in the bedroom standard. For instance a house with 3 bedrooms, 1 study and 1 games room will be counted as a 3 bedroom house while a house with only 3 bedrooms and no specialized rooms will also be counted as a 3 bedroom house although the actual size and floor area of the two houses could be quite different.

- The second problem is the presence of multiple bathrooms (including en-suites) and walk-in wardrobes in new NZ houses. Service areas are not counted either as rooms or bedrooms in room and bedroom standards. Results of a floor plan study of some New Zealand houses show that some new houses have en-suites as large as 14m² (Navigation homes, 2015), walk-in wardrobes as large as 9m² (House plans, 2016) and laundries as large as 17m² (New Zealand Home and Building, 1979), meaning some of these service rooms are bigger than a bedroom, but are never considered in room and bedroom standards.

- The third problem is inconsistency between different countries when discussing house size and crowding. According to the Housing Statistics for European Union 2010 (Dol and Haffner, 2010) the average floor area of UK houses is 82.7m² compared to 196.8m² for New Zealand in 2008 (Statistics New Zealand, 2014b). A comparison of figures for both countries in Table 1 reveals that while the average number of rooms in NZ houses is 34% more than the UK, the average floor area of NZ houses is 71% more than the UK, indicating the number of rooms is perhaps not a good tool for measuring house size when it comes to comparison between countries.

Figure 7 Percentages of crowded and not crowded houses in New Zealand and its major cities based on census 2006 data (prepared from Statistics New Zealand (2014e))
According to Statistics New Zealand (2014e) and based on census 2006 data, while the problem of crowded housing affects 10.4% of NZ households, 64.5% of the NZ population live in what might be called large housing (Figure 2). Figure 2 also shows the central Otago district has the largest and Auckland the smallest houses in New Zealand.

4. Study Design

A PhD study was designed to discover more about different aspects of large housing in New Zealand (Khajehzadeh, 2017). This was further broken down into four sub-studies. The first was a preliminary study of New Zealand houses advertised on TradeMe, currently claimed as “the leading online marketplace and classified advertising platform in New Zealand” (TradeMe, 2014). This study was undertaken to find out more about the types of rooms in New Zealand houses along with overall house size and types of furniture. The written descriptions and random photos of 60 houses (10 each of 1-6 bedrooms) were examined to collect information on which to base the questionnaire for the main survey. The number of bedrooms was used as an indicator of house size.

The second sub-study was a pilot study for the main survey. A questionnaire was prepared based on the findings of the TradeMe study, and was undertaken by 7 households (14 individuals) living in Wellington. Of the seven participating households, 2 were single person (1 living in a small and 1 in a large house), 3 were couples (1 living in a small and 2 in large houses) and 2 were couples with one child (1 living in a small and 1 in a large house). The survey asked about their household composition, house features and furniture. Based on house layout, a time-use diary was prepared for each person to report the time he/she spent in each room as well as “out of home” for 14 consecutive days in winter. A full description of this study and the results are presented elsewhere (Khajehzadeh and Vale, 2015b).

The third and main study was an on-line survey administered in February-April 2015 in New Zealand. The survey was limited to single people, couples and couples with 1 or 2 children living in owner occupied houses. The survey asked about family members, house features (number and names of rooms), furniture (type, number and location) and time-use in different rooms of the house (for each family member for 1 day). Overall 445 households took part in the survey with 285 (64.0%) finishing the house/furniture part and 212 households (538 individuals) the time-use part. Results of this study gave a better understanding of what large housing mean in terms of house features and furniture. In addition, this study showed how long various rooms in New Zealand houses are really used and who uses these (Khajehzadeh and Vale (2016) and Khajehzadeh et al. (2016)).

The fourth and final study was designed to investigate the size of rooms in New Zealand houses. Houses were selected of different sizes and from a variety of periods. Houses were taken from old New Zealand journals and catalogues of new houses constructed in different parts of New Zealand. To standardize the data floor plans of 287 New Zealand houses were drawn using Auto CAD 2015/2016 and the floor area of each room was measured. For each room, the area occupied by internal walls was shared proportionally between appropriate rooms. A spreadsheet was created showing the floor area of each room type for all houses. Full details of this floor plan study and its results are presented elsewhere (Khajehzadeh and Vale, 2017). This paper uses the results of the floor plan study to show how a change in the average floor area of New Zealand houses can influence the accuracy of using room/bedroom standards.
5. Results

The floor plan study of 287 NZ houses showed that rooms in larger houses are bigger than rooms with the same function in small houses. For instance, the average floor area of the master bedroom in a 9-9+ room house is 87% bigger than the master bedroom of a 4 room house. The same pattern can be seen in all room types. Table 3 compares the average floor area of selected room categories, the total floor area of the house (garage excluded) and the floor area per room for different sized NZ houses. According to Table 3, the average floor area per room in 9-9+ room NZ houses is 60% more than that of 4 room houses.

Table 5 Average floor area of selected rooms, total floor area (garage excluded) and floor area per room for different sized houses based on the floor plan study of 287 New Zealand houses

<table>
<thead>
<tr>
<th>Room Type</th>
<th>Master bedroom</th>
<th>Kitchen</th>
<th>Living room</th>
<th>Dining room</th>
<th>Combined L/D/K</th>
<th>Bathroom/Toilet</th>
<th>Total floor area (m²)</th>
<th>Floor area per room (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 room houses</td>
<td>14.9</td>
<td>11.6</td>
<td>21.8</td>
<td>NA</td>
<td>35.3</td>
<td>5.5</td>
<td>70.7</td>
<td>17.7</td>
</tr>
<tr>
<td>5 room houses</td>
<td>16.8</td>
<td>12.6</td>
<td>22.2</td>
<td>14.6</td>
<td>40.9</td>
<td>5.3</td>
<td>96.2</td>
<td>19.2</td>
</tr>
<tr>
<td>6 room houses</td>
<td>17.4</td>
<td>11.5</td>
<td>24.9</td>
<td>16.3</td>
<td>49.5</td>
<td>6.5</td>
<td>120.2</td>
<td>20.0</td>
</tr>
<tr>
<td>7 room houses</td>
<td>21.2</td>
<td>14.8</td>
<td>30.2</td>
<td>17.5</td>
<td>53.8</td>
<td>7.6</td>
<td>161.3</td>
<td>23.0</td>
</tr>
<tr>
<td>8 room houses</td>
<td>23.4</td>
<td>15.3</td>
<td>32.7</td>
<td>16.8</td>
<td>53.6</td>
<td>7.1</td>
<td>190.0</td>
<td>23.8</td>
</tr>
<tr>
<td>9+ room houses</td>
<td>27.9</td>
<td>18.7</td>
<td>29.6</td>
<td>17.5</td>
<td>62.2</td>
<td>9.4</td>
<td>254.9</td>
<td>28.3</td>
</tr>
</tbody>
</table>

The floor plan study also indicates a big difference between the minimum and maximum floor area of houses with the same number of bedrooms (see Table 4). Usually older New Zealand houses have a smaller total floor area compared to a new New Zealand house with the same number of rooms. So date of construction can be important when it comes to estimation of New Zealand house size based on number of rooms.

Table 6 Average, minimum and maximum floor area of different sized New Zealand houses

<table>
<thead>
<tr>
<th>House Size</th>
<th>Average floor area (m²)</th>
<th>Minimum floor area (m²)</th>
<th>Maximum floor area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 bedroom houses</td>
<td>86.2</td>
<td>45.0</td>
<td>157.3</td>
</tr>
<tr>
<td>3 bedroom houses</td>
<td>138.8</td>
<td>78.9</td>
<td>277.1</td>
</tr>
<tr>
<td>4 bedroom houses</td>
<td>197.5</td>
<td>94.9</td>
<td>339.3</td>
</tr>
<tr>
<td>5 bedroom houses</td>
<td>275.9</td>
<td>195.7</td>
<td>367.6</td>
</tr>
</tbody>
</table>

House size also affects the number of rooms of each type. Figure 3 presents the average number of bedrooms, bathrooms, living rooms, dining rooms, kitchens and specialized rooms in different sized houses. Although the number of kitchens stays constant in all house sizes the number of bathrooms, living rooms, dining rooms and specialized rooms increases as houses become larger. The number of living rooms is similar in small houses (4-6 room houses) but increases in houses with 7 and more rooms. According to Figure 3, the average number of specialized rooms and the average number of bathrooms in 9-9+ room houses is 1650% and 67% more respectively than in 6 room houses (the standard 3 bedroom house). This could be important because specialized rooms, extra bathrooms and extra living rooms which are mainly seen in larger houses are not counted in CNOS and BBS.
6. Discussion

The results of this study show that, as in other developed countries, New Zealand houses have increased in size over the last few years. In addition, the occupancy rate has decreased in most of these countries including New Zealand. This shows fewer people are living in larger houses. Having more bedrooms with no usual occupants, multiple living rooms, double/triple garaging, multiple bathrooms (including en-suites) and specialized rooms (i.e. study/office/library, games room/gym/rumpus room, play room, media room and studio/workshop) are features of large housing in New Zealand.

Crowding indices are highly dependent on house size and either use number of rooms or number of bedrooms as indicators of this. Rooms and bedroom standards are widely used by statistics for counting the number of rooms and bedrooms for census reasons. While some features of large houses like extra bedrooms are reflected in all crowding indices others such as extra living rooms and specialized rooms (like a study or play room) are never reflected in CNOS and BBS and can only be seen in ACI. For instance, assume a couple with two children (both boys with age 6 and 19 years old) live in a house with 1 combined living room/dining room/kitchen, 2 bedrooms and 1 study. Their crowding condition as measured by different crowding indices is presented in Table 5. This shows the same house for the same household is crowded in CNOS but not crowded in ACI or BBS. On the other hand, similar houses with different furnishing plans might be categorized differently in CNOS and BBS. Other features such as double/triple garaging and extra bathrooms will not be reflected in any of the crowding indices. This could be important as the time-use part of this study shows that many people use their garages for things other than parking cars (such as a games room or workshop).

Service spaces like bathrooms, en-suites and laundries are not counted as rooms in the room standard or as a bedroom in the bedroom standard. Although the floor plan study of NZ houses indicates that some New Zealand houses have bathrooms, en-suites and laundries as big as a bedroom and even bigger than
a standard double bedroom in UK houses (Vale and Vale, 2009), these spaces are not counted in any crowding index.

Table 7 The crowding condition of a couple with two children (2 boys age 6 and 19) living in a house with 1 combined living room/dining room/kitchen, 2 bedrooms and 1 study in various crowding indices

<table>
<thead>
<tr>
<th></th>
<th>ACI</th>
<th>BBS</th>
<th>CNOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of rooms</td>
<td>6</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Number of bedrooms</td>
<td>NA</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Number of occupants</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Person per room</td>
<td>4 ÷ 6 = 0.67</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Number of needed bedrooms</td>
<td>NA</td>
<td>2 (1 for couple + 1 for both boys)</td>
<td>3 (1 for couple + 1 for each boy)</td>
</tr>
<tr>
<td>Crowding condition</td>
<td>Not crowded (0.67 &lt; 1 PPR)</td>
<td>Not crowded-equal to standard (2 = 2)</td>
<td>Crowded - 1 extra bedroom needed (2&lt;3)</td>
</tr>
</tbody>
</table>

This study also shows that similar types of room have very different floor areas in large and small houses. This means that when a 6 room house is compared with a 4 room house, the difference is greater than just the 2 additional rooms. The problem becomes more significant when comparing houses with similar numbers of rooms in various countries. For instance the floor area of a 5 room house in the UK is much smaller than a 5 room New Zealand house although both are treated the same in most crowding indices. How big rooms are is, as yet, not seen as being important.

7. Conclusion

Recent changes in the size and layout of New Zealand houses (and those of other developed countries) have questioned the validity of room and bedroom standards to the point that these may need revision. Crowding indices are precise in terms of measuring overcrowded houses but less so when it comes to measuring the level of underutilization or number of spare bedrooms. Crowding indices with a room basis (ACI) are perhaps of more use than those that are bedroom based (BBS and CNOS) because regardless of room name and furniture all habitable rooms are captured. A combination of ACI with BBS and CNOS could be more useful for the new housing stock. For instance, the benefits of CNOS and BBS such as age/gender limits for sharing bedrooms can be combined with the total number of rooms in ACI. However, developing these ideas into an alternative method requires further detailed study.

References


Advancing Collaboration between Students of Architecture and Engineering

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Abstract: Following on from the Canterbury Earthquakes Royal Commission recommendations 163 and 185, various methods are underway to start improving dialogue and collaboration between architecture students and engineering students in New Zealand. This includes work at all three architecture schools in New Zealand, the inclusion of an architect in residence at Canterbury University’s School of Engineering, and most importantly, the Arch-Eng-Build workshops held annually by the Cement and Concrete Association, the Building Research Association and others. The Arch-Eng-Build workshops are small scale and focused on a select group of talented students from each discipline and have been expanded to include building management students as well. As admirable as the Arch-Eng-Build workshops are, the aims need to be expanded to a wider audience, i.e. all students of architecture and engineering. This paper explores the way forward for the NZ tertiary education system and makes proposals for further vital collaboration and integration between the professions.

Keywords: Collaboration; education; architecture; engineering.

1. Introduction

Following the Canterbury earthquakes, the Royal Commission made a series of recommendations, mostly about building design. Towards the end of the report however, were recommendation 163 - that “A structural Chartered Professional Engineer should be engaged at the same time as the architect for the design of a complex building” and also recommendation 185 - the very last recommendation - that IPENZ, NZIA and NZRAB, supported by MBIE, “should work together to ensure greater collaboration and information sharing between architects and structural engineers.” Surely it is undeniable that this collaboration needs to start earlier, rather than mid-career.

Official methods move slowly. As an architect and an architectural lecturer, it is not readily apparent that much progress has been made on pursuing and achieving these goals. The Construction Industry Council (CIC) has made some progress on revising the standard forms on who has responsibility for what, at work on building projects, and these revisions have been published and adapted by members.
Architects and engineers always need to work well together and those who start their collaboration early should reap the benefits of early structural integration, yet this is not a common approach. The obvious need for architects and engineers to work closer together in a non-adversarial manner has been laboriously slow on the uptake and the two professions are separate, right from the very beginning of their education. Architects and engineers are, in New Zealand and in most of the world, still taught separately. At the very least this is ineffective, at worst it is counter-intuitive. It seems wrong that we work on the same projects, yet are educated in so entirely different ways. Perhaps this is why it is so difficult to foster understanding and better working methods between the two professions.

2. Arch-Eng-Build Workshops

The biggest step in the long march of progress comes instead primarily from a smaller initiative initially known as the Arch-Eng workshops. Originally set up by Joe Gamman for the Cement and Concrete Association of New Zealand (CCANZ), the original “proof of concept” Arch-Eng workshop in 2011 was a simple collaboration between a group of five Architecture students from Victoria University and a group of five Structural Engineering students from University of Canterbury. The high-performing students were brought together at Victoria University, given a tour of the proposed competition site and some notable buildings, and put in teams of two (one architecture student and one engineering student), for the purpose of a 48-hour design competition, to design a building strongly featuring concrete as a main structural material.

The project was a success for the students involved, as for most that was the first chance they had to work with someone in the other profession. Comments from both sides were broadly similar - that they were generally amazed what the other member of their team knew, that they themselves did not. Architecture students, generally, were impressed at the ability of the engineering students to calculate loads etc. of the structure, while engineering students, generally, were impressed at the ability of the architecture students to draw, design, and render.

The Arch-Eng project has gone on every year since, and grown each time. In 2012 BRANZ (Building Research Association of New Zealand) joined as a sponsor and took over as the lead initiator of the event in 2013. The students were sourced from a wider range with the Schools at the Universities included and in 2013 CPIT (Canterbury Polytech Institute of Technology, now ‘Ara’) was also invited along. The range of materials utilised now includes not just concrete but steel and timber also, with funding from each of those industry bodies also, i.e. NZ Wood and HERA (Heavy Engineering Research Association) as well as CCANZ and BRANZ. In 2015 the workshop was expanded to incorporate building studies students as well, with candidates being drawn from the Construction Management, Quantity Surveying and Building Science fields as well as the Architecture and Engineering students, and the number of institutions now involved widened further still.

The workshop now includes Engineering students from Canterbury, Auckland and Unitec as well as Ara (formerly CPIT); Architecture students from Auckland, Victoria, Unitec, and Ara; and Construction Management students from Victoria, Massey, Weltec and Bay of Plenty Polytechnic. The students now work in teams of three: one each from Architecture, Engineering, and Building/Construction Management. It is now branded as the Arch-Eng-Build workshop and 2017 will be its seventh consecutive year. Due to the wide scope of sponsorship within the industry, the workshops are fully funded for students, and members of the winning team receive $2500 each. The venue for the workshop has moved around over the years, with University of Auckland, Victoria University and CPIT/Ara each hosting it twice. In 2017 the workshop was hosted for the first time at a smaller regional centre, at the Len Lye Centre in
Advancing Collaboration between Students of Architecture and Engineering

New Plymouth, with the building itself being an outstanding example of thoroughly integrated engineering and architecture. The outlook is generally highly positive, with the Institute of Professional Engineers (IPENZ), New Zealand Institute of Architects (NZIA) and New Zealand Institute of Building (NZIOB) all providing support for the concept. The plan is to continue to hold the Arch-Eng-Build workshops around New Zealand and to continue to educate and bring together young architects, builders and engineers. But it needs to go further.

3. How to Widen the Scope?

A program targeting four of the best students from each school each year will, however, not create a sea-change of effect to the rest of the student population. Each year Victoria University of Wellington (VUW) gets at least 100 new students keen to become architects, and so a selection of just four students for Arch-Eng-Build, means that only one in 25 VUW Architecture students is privileged to get this chance to work in collaboration with others. The other schools of Architecture, Engineering and Construction Management around New Zealand will have similar large numbers of students who would benefit from the more integrated experience that the workshops provide. To meet Recommendation 185 more fully, greater collaboration than just a 48-hour competition for a privileged few is needed to build understanding for the future architects and engineers of New Zealand. What is arguably needed is greater integration for all students at all schools, right now, but also greater collaboration between architects and engineers who are already in practice. While the former could be achieved with degree changes, that will not help those people already registered and unlikely to complete any more degree education. Clearly therefore there must be another way.

3.1. Method of education

It can be argued that the current method of education of both architects and engineers is at fault. New Zealand faces a dire shortage of well-experienced Structural Engineers and is looking overseas for experienced practitioners, but the seismic conditions here are not common with many of the countries overseas that we traditionally draw from. New Zealand should be leading world efforts in seismic design and academics such as Stefano Pampanin at UC are certainly leading in this sphere, but the question still is: how can we do better? Why are not all Structural Engineers in New Zealand leading the way in seismic design, at least nationally, if not globally? The question needs to be asked: is part of the problem our methods of teaching?

3.2. Should we teach Engineering to Architects?

The teaching of architecture students is imperfect, with Structures sometimes seen as an unfortunate and obligatory hinderance to a ‘good’ design. Most of the Universities are now trying to teach Structures as part of an integrated design studio, but this is not a 100% success, and primarily occurs at years 3 and 4 only. It requires dedication to integrate structural concepts into every field of architectural design, when other concepts such as Sustainability, Construction Law and Professional Practice are also clamouring for attention alongside Design.

In the School of Architecture at Victoria University, structural engineering concepts are taught to budding young architects by Associate Professor Andrew Charleson, Senior Lecturer Geoff Thomas and Associate Professor Regan Potangaroa: all respected Engineers in their fields. Charleson has written three books on the integration of architecture and structure, which are widely used around the world by
students of architecture. No doubt there are similar teaching stories at Unitec, Auckland University and the Polytechnics as well, but the fact remains that these are small, sporadic teaching efforts on subjects that should arguably be taught much closer together.

The concept is not unheard of. In many places in Europe, engineering concepts are so thoroughly integrated into architectural education that a student may graduate with a Diploma in Architectural Engineering. Not so, yet, in New Zealand. Indeed, at the University of Auckland, the Faculty of Architecture and the Faculty of Engineering are separated so firmly that of the 64 different conjoint degrees offered, despite the possibility of Engineering being studied conjointly with Music, Commerce, Health, Law and Arts, the option is not presented to study Architecture conjointly with Engineering (Conjoints by faculty, 2017). This is symptomatic of a major malfunction in integrated education.

3.3. Should we teach Architecture to Engineers?

The teaching of Engineering to students is starkly different from the teaching of Architecture. At present, all NZ-taught engineers are taught as Civil Engineers for most of their degree, with the option of doing elective papers in Structural Engineering only available in the last two years. Would it not make more sense for students of Engineering to be taught Structural Engineering right from their earliest years? Why is Structural seen as a subset of Civil, when it is arguably a direct equal? Should there not be at least some emphasis on the architectural concepts of space, history, style, design, innovation and aesthetics, rather than concentrating mainly on statics and calculating bending moments? Charleson and Pirie (2009) note the disappointment that architects feel at the lack of engagement and innovation from engineers, as well as the well-known frustration that engineers have over some architect’s lack of structural understanding. What else can be done?

3.4. Architect in Residence

At the University of Canterbury, the School of Engineering has started off by appointing an “Architect in Residence” in the form of Tim Nees, a highly respected ex-Wellingtonian architect. Nees works as an architect in his own practice (now based in Canterbury) but is also teaching a course to the budding Structural Engineers on Architecture - the first time this has been done at Canterbury (Collaboration between engineers and architects, 2015). This development should be celebrated – and perhaps should also be implemented in Auckland’s School of Engineering as well. But why has this course not been in place for the past 50 years? The integration of structure and architecture has been well investigated by Allaf and Charleson (2016), but the emphasis is all too often focused more on the aftermath of the structural integration, rather than adequate and proper investigation before the job has left the drawing board. Victoria University has, in effect, three structural Engineers in Residence, but Schools of Engineering have few staff trained in Architecture (Nees being the only one known). This needs to change.

4. Other Models of Practice

4.1. Traditions in architectural education

Architecture has not always been taught in Universities. Originally architects would have been learning at the side of master builders, and indeed the three professions (architecture, engineering, building) would have been one. While the University of Bologna is the oldest continuously operating educational institution in Europe (founded in 1088), it is unclear whether courses of architecture and engineering were
taught there at the start, with the more established courses being in anatomy and science. Bologna’s current faculty structure includes a School of Architecture and Building Engineering (Laurea Magistrale a ciclo unico, n.d.) but this is more recent than 1088.

In the UK, the customary way of training architects was by articling young students to experienced architects, and this continued until the establishment of the Architecture Association (AA) in 1890. The AA was established in reaction to the problems of incompetence and dishonesty at that stage visible in the ranks of young articled architects (Marriage, 2017). The Beaux-Arts style of architecture and it’s associated methods of teaching (based on copying classical orders of architecture) was widespread across Europe and North America, but this started to decline after the advent of the Bauhaus, established in Weimar in 1919 (Wick, 2000). Since the World Wars and the advent of Modernism, education of architects and engineers in the Western world has been almost exclusively contained within the sphere of university education, with Acts in New Zealand such as the Architects Act (2005) and the Chartered Professional Engineers of New Zealand Act (2002) and their ensuing Regulations effectively mandating a University education.

4.2. Faults with the current system

In New Zealand architectural education, we have been broadly (or blindly) following the lead of the United Kingdom (UK), which also stipulates a university-led education. However, Oliver Wainwright, The Guardian’s architectural correspondent, heavily criticised the architectural education model in 2013, alleging it as having lost its way in the UK:

Bizarrely, architectural education – the discussion of places and spaces, cities and landscapes, a discipline of engaging with the world around us – has been allowed to stagnate in the UK as a hermetic, inward-looking pursuit for more than 50 years. The extended three-part system, which takes a minimum of seven years to complete, is still based on the model that emerged from the RIBA Conference on Architectural Education in 1958 (Wainwright, 2013).

It is notable that New Zealand’s methods of architectural education have faithfully followed the outline set by Sir Leslie Martin at this same RIBA Conference (Martin, 1958). It is also notable that nowhere in Martin’s report is there any discussion of integration with either engineering or with practice, and instead Martin advocates that entry provisions to the various schools of architecture need to be raised to gain a better quality of candidate on their way into the school, not graduating out the other end. Given that the same issues are still being spoken of today in architectural institutions around New Zealand, perhaps it is evidence that the issue is not with the candidates but with the institutions and their ways of teaching.

4.3. London School of Architecture

Recently, there have been moves to shake up that system in the UK, with the establishment in 2013 of a brand-new school: the London School of Architecture (LSA), as an alternative method of education to the established hierarchy of schools. At the LSA there is a concerted effort for the study of architecture to be fully integrated with actively practicing architects, as opposed to a completely university-based degree system followed afterwards with years of practice. The LSA offers a two-year post-graduate programme where in the First Year students are “primarily based with their practices”, while in the Second Year students are based at the LSA studio (LSA.org, n.d). While this approach emphasises a strong interaction
between academia and architectural practice, it does not however offer any closer links with engineering, except as a by-product of working in practice. This encouraging collaboration between schools of architecture and architectural practice is a step along a path towards what has been termed Total Architecture, but could be taken even further by linking in the education of engineers as well.

4.4. Ove Arup and Total Architecture

Ove Arup, the founder and late head of the global leader in Engineering consultancy, spoke of his desire for his firm to be involved in what he termed “Total Design” and its involvement in what he terms “Total Architecture”. Arup notes that this synthesis is achieved by a “tradition embodying human aspirations and experience” and he goes on to note that:

“...it was when this synthesis was lost, when the activity of building was split between a number of separate professions and businesses, when it was not any more a way to satisfy human aspirations for a better life, but a way to make money for various sectarian interests - it was then, and to that extent, that building came to lose its humanity and even to be a menace to man.” (Arup, 1970).

When a figure as important and pivotal to both the architectural and engineering societies as Ove Arup writes that the split between professions and businesses gives rise to buildings that are a “menace to man” then surely this is a statement that should be given more credence than it has been so far. The world of architects is getting further split up by groups advocating BIM, Sustainability, Project Management, and yet the world has not yet seen a rise in quality buildings as a result – indeed, often the reverse is true. The authors of this paper argue that it is only through further (if not total) integration of architecture and engineering that we can work our collective way back to a better-designed world.

4.3. Architectural Engineering

Architectural courses in a combined degree structure exist at some Australasian universities, but only to a limited, desultory extent at most institutions. The University of Adelaide has a School of Architecture and the Built Environment, offering a Bachelor of Engineering (Civil and Architectural) which appears focused on Engineering graduates and does not mention the word ‘architecture’ past its Year One introductory course (Bachelor of Engineering, n.d.). Similarly, University of Canterbury offers a Master of Architectural Engineering but this appears to offer little in the way of real architectural training (Change the World, 2017). Refer to Table 1.

Auckland University has very separate faculties of Architecture and Engineering, as noted previously, despite them being right next to each other and accessible via a (rarely used) set of doors. University of Sydney also has separate faculties for Architecture and Engineering, with little or no apparent cross-over, while Royal Melbourne Institute of Technology (RMIT) offers both Architecture and Engineering, seemingly as completely separate streams. Monash University appears to offer a combined course in both subjects, but it is not fully integrated. Only the University of Melbourne offers what appears to be a rare, fully integrated Master of Architectural Engineering, open to graduates from both schools of Architecture and schools of Engineering (Master of Architectural Engineering, n.d.). Clearly there is room for further collaboration work to be undertaken here, if there is believed to be a need.
Table 8: University collaborations of Architecture and Engineering (Australasia)

<table>
<thead>
<tr>
<th>Tertiary institution</th>
<th>Architecture offered?</th>
<th>Engineering offered?</th>
<th>Collaboration offered?</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Auckland</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Unitec (Auckland)</td>
<td>Yes</td>
<td>Yes (not Structural)</td>
<td>No</td>
</tr>
<tr>
<td>AUT (Auckland)</td>
<td>No</td>
<td>Yes</td>
<td>Limited</td>
</tr>
<tr>
<td>Victoria University of Wellington (VUW)</td>
<td>Yes</td>
<td>Yes (not Structural)</td>
<td>Internal only</td>
</tr>
<tr>
<td>University of Canterbury</td>
<td>No</td>
<td>Yes</td>
<td>Limited</td>
</tr>
<tr>
<td>University of Adelaide</td>
<td>Yes</td>
<td>Yes</td>
<td>Limited</td>
</tr>
<tr>
<td>Bond University</td>
<td>Yes</td>
<td>No</td>
<td>n/a</td>
</tr>
<tr>
<td>Charles Darwin University</td>
<td>Yes</td>
<td>No</td>
<td>n/a</td>
</tr>
<tr>
<td>Curtin University of Technology</td>
<td>Yes</td>
<td>No</td>
<td>n/a</td>
</tr>
<tr>
<td>Deakin University</td>
<td>Yes</td>
<td>Yes</td>
<td>Limited</td>
</tr>
<tr>
<td>Griffith University</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Monash University</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes, Architectural and Engineering Design</td>
</tr>
<tr>
<td>Queensland University of Technology (QUT)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>RMIT (Melbourne)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>University of Melbourne</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes, fully integrated collaboration courses</td>
</tr>
<tr>
<td>University of Sydney</td>
<td>Yes</td>
<td>No</td>
<td>n/a</td>
</tr>
<tr>
<td>University of Western Australia (UWA)</td>
<td>Yes</td>
<td>No</td>
<td>n/a</td>
</tr>
<tr>
<td>University of Canberra</td>
<td>Yes</td>
<td>No</td>
<td>n/a</td>
</tr>
<tr>
<td>University of New South Wales (UNSW)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>University of Newcastle</td>
<td>Yes</td>
<td>No</td>
<td>n/a</td>
</tr>
<tr>
<td>University of South Australia</td>
<td>Yes</td>
<td>No</td>
<td>n/a</td>
</tr>
<tr>
<td>University of Tasmania</td>
<td>Yes</td>
<td>No</td>
<td>n/a</td>
</tr>
<tr>
<td>University of Technology (Sydney)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>University of Queensland</td>
<td>Yes (PG only)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>University of Wollongong</td>
<td>No</td>
<td>Yes</td>
<td>n/a</td>
</tr>
<tr>
<td>University of Southern Queensland (USQ)</td>
<td>No</td>
<td>Yes</td>
<td>n/a</td>
</tr>
</tbody>
</table>

(Source: Australian Education Network)

5. Conclusions

This paper does not – indeed, cannot – come to a definitive conclusion regarding means of improving collaboration at a professional level, but instead simply advocates as a starting point, for the continuing improvement of collaboration between students of architecture and engineering. While collaboration has been started at student level via the Arch-Eng-Build workshops in New Zealand, there is still much work
to be done on integration of education and this paper has shown that there is some movement towards this goal. Some universities in both Australia and New Zealand are forging ahead on a collaborative and integrated teaching path, although it appears that it is precious few at present. To fully achieve the requirements of recommendation 185 of the Canterbury Earthquakes Royal Commission, the current educational integration of architecture and engineering needs to be significantly improved upon. The authors’ hopes are that this attitude towards collaboration will continue to grow, eventually to normalise and overcome the current rift between architects and engineers, permitting greater integration and better education over the forthcoming next 50 years.

Acknowledgements

Grateful acknowledgement is given to the organizers and funders of the annual Arch-Eng workshops, including the Cement and Concrete Association, HERA, NZ Wood, and to BRANZ; as well as the hundreds of students who have taken the Arch-Eng-Build workshops over the past seven years.

References

Biological Systems

Outcomes in Architectural Design Studios

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Abstract: This conference paper is the second of two papers that discuss the outcomes of a long-term pedagogical research project into the integration of interdisciplinary design-research, and making practices into the content of second-year architecture studios. This paper focuses on one studio involved in the design of biological systems. The studio introduced students to the socio-cultural and bioethical dilemmas that arise when using living organisms as a design material. Students were required to create a biological system using traditional design materials and Physarum Polycephalum, a harmless, yellow single-celled organism capable of solving complex mazes and which grows up to 30cm in length. Through the design, prototyping, and testing of these systems students are encouraged to learn through practice, developing their projects iteratively while being critical of the implications of their actions. Through a discussion of the studio aims, structure, project examples, and outcomes, this paper outlines an initial approach to teaching biological design within a studio context. Along with the paper on Responsive Systems these works highlight the importance of critical engagement with materials and processes and of opening up future architectural pedagogy to new fields of exploration.

Keywords: Architectural education; critical design; biological systems; making.

1. Introduction

The architecture that I have studied, that I have practiced with other architects, with my professors... It is over.

Eduardo Souto de Moura (2016)

Architecture consumes earth’s limited resources, it is long lasting and expensive, and it can significantly alter the quality of living of its users. We live in a fully explored, finite, over populated world and so it is imperative that we do not think of and produce architecture in the same ways that we have in the past. It is essential that we understand humans, non-humans, objects, buildings, cities and regions not as isolated entities, but as parts of systems of increasing complexity and uncertainty. As humans, it is
important that we understand our place in these systems, not an overwhelmingly important position but only as part of it. Climate related natural disasters, over population, uncontrolled consumption, disregard for non-humans and non-humans environments, food and water supply constraints, artificial intelligence, massive migrations, cultural tensions, raising inequalities, extremist groups and unannounced acts of random violence are unprecedented challenges that are all connected. It is important to recognize that actions have consequences and that there is no such thing as designing an isolated entity. As a part of this system, architects need to understand the world that they live in, in order to raise awareness about the consequences of their designs.

Starting from these foundations, a long-term pedagogical and research project was implemented at the University of Western Australia under the Integrated Design ethos. During their second year, architecture students are given the opportunity to take a studio called Making. As a part of the school’s design stream, students are invited to develop solutions to design problems that may or may not include architecture. During the semester, students are required to submit both prototypes and finished products at their real scale as opposed to drawings and models. This encourages design development through experimentation, and the production of multiple prototypes that are critically examined and iteratively improved. Through this process, students are expected to develop a better understanding of the difficulties faced in producing built objects, and to consider the relations between projects that only exist in print, on screen, as models and those that exist in the built environment, leading to careful and thoughtful future designs.

The majority of studio coordinators of Making are not architects, and those that are have specific skills that are unusual within architectural practice. Some of the most recent specialized skills ranged from: ceramics, eco-activism, responsive electronic interfaces, biological systems, ecological systems, traditional carpentry, graphic design and conceptual art. By opening the design studios to coordinators with diverse backgrounds, students can focus on different underlying design systems. A different specialist will read and understand a different system. By offering the opportunity for students to work with diverse specialists, we are expanding their fields of action. By opening up the discipline to new fields of action – biological, electronic, multispecies, conceptual arts, we enable students to collaborate in trans-disciplinary approaches and complex environments where outputs are unpredictable, through design. We empower students to become independent thinkers, to have the desire to run their own practices. We accept unexpected ambitious, unfinished projects that can be more interesting than expected finished predictable outcomes. To do that, we ask students to redefine what success means, as its archaic interpretations might not fit anymore. We ask students to pose their own questions instead of reacting to defined problems. It is important to assume that by doing it we are no longer in an expert/apprentice position; we are together with our students in an experimental research journey with unpredictable outcomes. We do not know exactly what students will produce and we do not know how it will be applied in future architecture. It is precisely this, the acceptance of uncertainty, the program’s greatest strength. Together we lay the foundations for a future that we cannot foresee. Our world is quickly changing. Architecture education and practice have to adapt, to open up new fields of exploration and to prepare students for uncertainty.

This conference paper is second in a series of conference papers from our long term pedagogical and research project. The first paper, “Responsive systems and electronic spatial interfaces: outcomes in architectural design studios”, discusses the outcomes from a studio within the same Making unit that specifically focused on the development of responsive systems using electronic media. While the primary design materials differed in each studio, the approach to critical making was the same. Together, these papers contribute to pedagogical research concerned with developing diverse, dynamic studios that
2. Biological Systems using *Physarum Polycephalum*

Designers are increasingly using living organisms as both material and subject matter in order to critically engage in contemporary socio-cultural and bioethical issues (Catts and Zurr, 2002; Catts and Cass, 2008). This practice has loosely coalesced under the title of biodesign, which by necessity is experimental and interdisciplinary, drawing from information from fields such as biological art, critical design, synthetic biology and other life sciences (Antonelli, 2011a; Myers, 2012). Biodesign involves the intervention in an organism’s genetic material, cellular processes or exterior environment. The disruption that may be caused by this intervention is often used to raise questions about the future relations between humans, nonhumans and the environment (Catts and Zurr, 2014).

Inherent within the practice of biodesign is the notion that some living systems are artefacts of human culture. As Eugene Thacker notes, the intervention into living systems necessitates the dynamic exchange between two concepts that often have been considered categorically distinct, that of *bios* (life) and *technê* (art or craft) (Thacker, 2010 pp.117-18). In other words, activities such as biodesign break down the hard-and-fast notion that living organisms are somehow separate from the processes of human cultural production, for better or worse. The lines between nature and culture are blurred, if not altogether obliterated, when designing with/for living systems.

Consequently, biodesign can raise vital questions about what activities are morally acceptable when using living organisms as cultural mediums. Who has the right to design life? How will an altered organism or biological material impact other systems? Will there be any unintended consequences? Is it possible to know these consequences in advance? The host of questions that this field of design opens up necessitates pre-emptive thinking about the potential hazards of meddling with other organisms. As Paola Antonelli explains:

> When the materials of design are not plastics, wood, ceramics or glass, but rather living beings or living tissues, the implications of every project reach far beyond the form/function equation and any idea of comfort, modernity or progress. Design transcends its traditional boundaries and its implications aim straight at the heart of the moral sphere, toying with our deepest-seated beliefs (2011b).

At the heart of these ethical questions is a concern about the impact a new design may have on other systems, a question that is common to architectural discourses. Thus, this studio was conceived as a means of asking familiar design questions with a new medium in order to prepare students to deal with uncertainty.

To design with a living organism in an architectural studio provides many ethical complications. In order to mitigate some of the potential issues, *Physarum polycephalum* was selected as the primary design material. *P. polycephalum* is a harmless, yellow, single-celled amoeba capable solving complex three-dimensional mazes and grows up to 30cm in length. This organism was chosen as an introductory biodesign organism due to the fact that:

- There exists an adequate depth of popular do-it-yourself literature that is readily accessible and allows students to grow *P. polycephalum* outside of a laboratory (Barnett, 2009).
P. polycephalum can be cultured using relatively cheap materials that can be purchased from a local grocery store. The required materials are namely Tupperware, rolled-oats, water, spray bottles and tweezers (Culturing slime mould, 2012).

P. Polycephalum grows fast enough to allow for students to develop multiple prototypes during each assignment.

P. polycephalum is neither animal, nor plant and, therefore, does not have ethical restrictions at the University of Western Australia (Australia, 2013).

By developing designs using P. polycephalum, students became familiar with the organism’s agency, time-cycles and growth requirements, which often conflicted with their own daily schedules. Over the course of the semester, students learned to adapt to an organism’s needs and behaviors when using it as a design medium.

3. Method: the studio format

This studio acted as an introduction to biodesign. The initial aim of the studio was to familiarise students with important themes from the field and provide techniques necessary to successfully culture P. Polycephalum. The initial prompt for students was “how can living organisms be ethically used to design systems that either grow or decay?” The studio format combined discussions and workshops to balance information acquisition with hands-on making. Students were presented with readings on: biodesign and biosystems (Antonelli, 2011a; Antonelli, 2001b; Eck and Lamers, 2013); bioethics (Devall and Sessions, 2001; Singer 2011); and P. polycephalum and its living conditions (Barnett, 2009).

These readings provided students with established pedagogies to develop their own ethical positions throughout the design process. During studio discussions, students voiced various concerns about the use of living organisms for design. Some were focused on the use of P. polycephalum, while others related to broader bioethical issues (e.g. the use of animals for food, the impact of new development on local habitats, industrial farming, ecological rights and industrial global warming). These discussions offered fertile ground for students to translate ethical questions, in which they were personally invested, into concepts and ultimately designs.

In tandem with discussion-based learning, students got their hands wet, so-to-speak, by growing numerous cultures of P. Polycephalum. The amoeba grows in warm, dark, humid environments, which contrasted with the dry, brightly light studios. Through multiple tests, students refined studio methods for culturing P. polycephalum in preparation for creating their biological systems (Figure 1).
After students became comfortable with the growth cycles of *P. polycephalum* and were successfully able to culture the amoeba over multiple surfaces, they were tasked with designing a final prototype for their biological system. The system needed to ethically incorporate *P. polycephalum* as the primary material and to respond to the theme of either growth or decay.

**Figure 1:** Growth rate of *P. Polycephalum*, Matthias Widjaja

Figure 2: *Physarum Polyoculus*, Simon Bow. Designed as a paradoxical system, this project examines the tension between the desire to observe another organism’s growth and the contrasting conditions required for its growth. By integrating *P. polycephalum* with Arduino-based electronics the systems responded to visitors. The project was devised to be installed in a dark room and when viewers walk in front of the sensor (on the right) a light turns on to reveal *P. polycephalum*; however, since the amoeba does not grow in light, this action inhibits the growth of the amoeba.

**4. Results**

Due to the studio’s open-ended and interdisciplinary focus, the students’ responses were experimental and varied. Many projects acted as conceptual vignettes that examined the impact design may have on other organisms. The common theme across the studio was that each project was critically engaged with
the use of *P. polycephalum* as a design material. Projects have been separated into the following typologies:

### 4.1. Biological systems to promote ethical considerations

These projects functioned as vehicles for thought to provoke questions about ethical dilemmas.

- *Physarum Eatery*, a food system using *P. Polycephalum* as the main ingredient
- *Physarum Polyoculus Hybrid*, a sensor based system that halts amoeba growth in the presence of visitors (Figure 2).
- *Cultured Communication*, translates electrical activity of amoeba into sound.
- *Physical Pressure on Nature*, installation that halts growth when visitors stepped on system.
- *Physarum Sound*, amplifies the presence of the amoeba through sound (Figure 3).
- *Physarum Racing*, ironically questions the use of other organisms for entertainment by developing a system that allows participants to bet on races between multiple amoeba cultures.

![Figure 3: Physarum Sound - detail, Lucinda Trevaskis. The system aimed to amplify the presence of the amoeba through sound. Through the use of an Arduino, a Macbook Pro and computer speakers, this project translated the electrical activity from the slime mould into sound.](image)

### 4.2. Biological systems as building materials

*P. polycephalum* was grown on various substrates to act as a binding agent or alter qualities of light.

- *Canopy*, system that uses amoeba growth on Perspex to create shade canopy.
- *Physugi Cup*, taking precedents from wabi-sabi and kintsugi, the amoeba is used to mend broken ceramics (Figure 4).
- *Self-healing*, amoeba is used to repair cracks in wooden structures.
- *Degeneration*, amoeba is grown on fabric to acts as shade cloth.
- *Light Maze*, amoeba is grown over fabric to create a patterned lamp shade.
- *Physarum Homeware*, amoeba grown on Perspex to act as domestic pet.
Figure 4: Physugi Cup, Inspired by kintsugi, the art of mending broken pottery, this project used *P. polycephalum* as system for symbolically mending and venerating imperfections in broken tea ceramics.

### 4.3. Biological mapping systems

The growth of *P. polycephalum* was used as a mapping system.

- **City Walk**, Jhan Fung Siah, amoeba growth on map is used to plot paths in city.
- **Globalization Networking**, amoeba growth on global map to represent resource distribution.
- **Slime Mould Cartography**, mapping amoeba growth across multiple substrates.
- **Trail Making**, using changing lighting conditions, controls amoeba growth across substrate.

### 4.4. Systems that care for *P. Polycephalum*

Systems were designed to protect and/or cares for *P. Polycephalum* in changing environments

- **Transitional Habitat**, system that maintains correct lighting conditions for amoeba growth. It opens at night and closes during the day (Figure 5).
- **Slime Mould Habitat**, participatory system that allows visitors to interact with slime mould by delivering it various types of food, which may limit or enhance its growth.
- **A story of life and death**, hard-shelled spherical habitat that allows amoeba to grow in multiple environments.
After students developed their final prototypes, they voted on a single project to pursue as a group for their final assignment. They chose to develop Physarum Eatery by Hae Yun Jung due to the potential for designing a rich multisensory experience, since a food system would provide a way to experience *P. polycephalum* through taste, touch, sight and smell. Consequently, the second half of the studio semester was dedicated to creating a performative installation in the form of a restaurant, the *Physarum Eatery*. To supplement their research and provide context for developing a food-based performance, students were presented with precedents from relational art (Bourriaud, 1998) that utilise food as a vehicle for thought. This included Rirkrit Tiravanija’s *Untitled (Free)* (1992) and The Tissue Culture and Art Project’s *Disembodied Cuisine* (2003). After a robust research and design process, the final project entailed the creation of: three separate dishes using *P. polycephalum* as the main ingredient; a menu that could be printed and displayed on an iPad; a serving table; a system to display cultures of *P. polycephalum*; a short video showing the amoeba’s growth; and a basic ‘script’ for the servers to explain the concept of the project to visitors. In order to complete these tasks, students were separated into five teams: design + visuals; construction; growth; budget + materials; and research + text.

The final system focused on biophilia, a term made popular by E. O. Wilson which describes an affinity between humans and other organisms. Students described their project as a performance that used food to promote a ‘biophilic consciousness’ and an appreciation of the symbiotic relationship between humans and other microorganisms including *P. polycephalum*. The *Physarum Eatery* debuted during a school-wide exhibition and two student-performers served dishes containing *P. polycephalum* to over fifty individuals.
5. Discussion

While biodesign is a nascent field, studios that teach this field have a rich potential to engage students in contemporary ethics, particularly regarding their current and future relationships with other organisms. Through studio-based learning (and growing), students can see, first-hand, the importance of pre-emptively considering the ethical implications of their designs and how they will impact other systems. This approach exposes architecture students to fields they may otherwise not come into contact with and allows them to become more comfortable with experimentation and interdisciplinary research.

This open-ended studio introduced architecture students to design as a field with concerns beyond utilitarian objects, form and function. Instead, it focused on the creation of thought-provoking, ethically-minded systems that look beyond a human-centred focus. Studios such as this have the potential teach students to actively think through the implications of different types of design to create desirable futures. In this way, this studio is similar to other design studios that foster critical and pre-emptive thinking. However, the use of living materials may elicit a more immediate concern for other living organisms since students see the impact of their design in a matter of hours.

This paper provides an introductory framework for teaching biodesign to architecture students. By providing the reading lists and methodologies, it lays the groundwork for future research into the further pedagogical methods for presenting biodesign in a studio. While this studio focused on growing *P. polycephalum* using DIY methods, this environment also presented significantly limitations to culturing the organism with precise techniques. Providing a laboratory or hybrid environment for this type of studio may allow for more precise culturing and more nuanced design investigations.

Considering the recent growth in techniques for do-it-yourself biology, the intervention into living systems is likely to become more common. This increasing interest in designing life calls for further discussions about how to teach biodesign at a tertiary education level. Currently, there are a limited number of institutions that offer courses that touch on biodesign. These institutions include Central Saint Martin’s Material Futures Masters course, Design Academy Eindhoven’s Food Non Food undergraduate program, the Royal College of Art’s former masters program Interaction Design, The University of Pennsylvania’s Biodesign class and SymbioticA’s Master of Biological Arts at The University of Western
Australia. An increase in biodesign discourse concerning teaching materials, methods and ethical frameworks can only make this field more robust and biodiverse, literally and figuratively.

References

Explore a Combination of Materials in Building Sustainable Construction Practices

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Abstract: The construction sector is associated with significant environmental impacts, being a major consumer of raw materials and energy, and generating a lot of pollution. Therefore, it is essential for the industry to move towards more sustainable construction practices. The selection of building materials is a relevant factor in sustainability, nevertheless, it seems that the industry is more focused on other aspects, such as speed of construction and cost reduction, rather than careful choice of materials. Research through the life cycle assessment methodology has identified that all stages of construction introduce environmental, social and economic impacts. Within the theme of sustainability, there are some important concepts that can also be applied to construction, such as recycling, which is converting waste materials into raw materials to produce new products, and reusing, which uses materials or products again without going through industrial processes and transformations. Sustainable materials must have all the benefits of a conventional product and still have a sustainable performance. Two of these natural materials, bamboo and cork, are alternative construction materials, and when used together, produce new elements for building construction that can be used on sustainable constructive systems. This research proposal introduces the concept of using those materials during the construction phase.

Keywords: Bamboo, cork, construction, modular, sustainability.

1. Introduction

The theme of this article focuses on sustainability, specifically, focusing on natural materials which may be recycled and reused. Given that the construction sector is one that consumes natural resources and is also a major generator of solid waste, this issue becomes crucial for the future of humanity. The concept of “sustainable construction” (Peris-Mora, 2007; Ding, 2008; Li and Du, 2015) is now accepted globally and represents the main issue in sustainability.

In recent years, there has been an increasingly concerning risk regarding the depletion of natural resources, with a growing need to identify new materials and construction techniques (Hebel et al., 2014). This industry, despite its contribution to improving the quality of life, has a great share of responsibility
for polluting the planet. Thus, we seek to build with more responsibility, thinking ahead or, in other words, seeking sustainable construction. Some new methodologies for refurbishment and renovation have been developed for a Life Cycle Assessment (LCA) (Vilches et al., 2017) of the construction industry to avoid this situation continuing without control.

The construction industry has been one of the main industries responsible for environmental degradation, from which derive other problems that harm humans and their surroundings. These problems are not only environmental pollution through the emission of carbon dioxide (CO2) into the atmosphere (Heinonen et al., 2016), but also waste production associated with the construction and demolition of buildings (water and soil pollution), and the excessive and reckless consumption of natural resources (dos Reis Pereira and Ferreira Barata, 2014; Alwan et al., 2017).

From this perspective, there is a growing need to develop processes, methodologies and construction operations in order to significantly reduce these environmental and energy issues associated with the construction industry. The concept of Green Building (GB) has taken a leading position with practitioners and researchers (Darko and Chan, 2016) as well as lean and more sustainable construction practices.

2. Options for Building Materials

Given that construction is a high-waste industry, the choice of sustainable building materials has become and essential one. The concerns in the complete whole life cycle of raw material extraction, production, installation and dismantling need to be carefully understood to reduce negative impact on sustainability.

In fact, in the construction field lies a significant opportunity for a building material choice that considers sustainability. Even though there is no universally accepted definition of what sustainable building materials are, the ones with the following characteristics should be privileged: non-toxic, provided from renewable sources, promote a close-loop cycle and life cycle thinking, and associated with low embodied energy.

2.1. Life Cycle Impact

To establish the environmental impact of a building, focusing on minimising impact, it is critical to analyse all aspects of the materials, elements and processes involved, based on an integrated life cycle thinking (Figure 1).

The life cycle is a term used to refer to all stages and processes of a system to generate products or services. Specifically, in the case of a building, the phases are design, construction, operation and demolition. Increasing the lifespan ensures the reduction of material consumption and the reduction of environmental impacts and several measures in all stages of the cycle should be taken to ensure this increase. Therefore, designers must implement a durability project and prescribe the maximum number of sustainable materials.

Within the building sector tools exist for assessing the environmental impacts of a given material or product. The standardised and most internationally recognised tool is the Life Cycle Analysis (LCA), also known as Life Cycle Assessment and cradle-to-grave analysis. It consists of a technique to assess environmental impacts associated with all the stages of a material’s life. The LCA looks at material supply chains to reveal the energy-related and ecological effect of materials, creating the basis for selecting building materials more responsibly, avoiding the overlook of the environmental priorities. However, there still are flaws and limits to this complex and time-consuming evaluation process. One of these limits
is that the method relies heavily on the available data on building materials and processes, and such data are not always complete or reliable.

Figure 1: Integrated and sustainable approach to the phases of a building life cycle (Source: Bragança 2006).

3. Materials for Sustainable Construction

Nowadays, basic construction materials are still composed of wood, stone, steel, concrete, glass and bricks, which has been the case since the industrial age. However, the processes to producing and transformation of some of these materials cause harmful emissions, making them non-environmentally friendly. Moreover, the abuse of certain materials has significant impacts on our planet, impossible to continue to ignore. Being aware of this, the choice of alternative construction materials should consider the availability of the material, and its application in specific contextual settings. In addition, the concept of materials for sustainable construction must be present throughout the life cycle of the building: concept, design, construction, operation/maintenance and demolition/dismantle (Figure 1). This paper presents a case study using cork and bamboo.

3.1. Cork as a Material of Construction

Cork is a 100% vegetable tissue from the bark of the cork oak trees (named Quercus suber). This tree grows in Mediterranean regions, such as Portugal, Spain, Italy, France, Morocco, and Algeria (Figure 2).

Cork oak trees are endowed with a great longevity and capacity of regeneration, live on average 150 to 200 years, and can be discarded every nine years without being cut. Cork has been known since antiquity as a floating and sealing device, and its market increased from the beginning of the 20th century when it began to be used in the creation of various agglomerates.
Currently, cork is used in exterior and interior coatings, thermal and acoustic insulation and several other applications in different industries. It consists of alveolar-like cell layers, which are filled with an air-like gas and mostly coated by suberin and lignin that give it special characteristics for different uses.

Cork as a material part of construction elements, makes a great contribution to the sustainable construction during the building life cycle. Chiebao (2011) identified a number of key sustainability attributes for cork (see Table 1).

Table 9: Key sustainability attributes of cork construction (Source: Chiebao, 2011).

<table>
<thead>
<tr>
<th>Building life cycle attribute</th>
<th>Environmental advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design</strong></td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td>Since the selection of materials is a critical factor in designing a sustainable building, raw cork, as a building material, has undeniable environmental advantages and can contribute significantly to increase sustainability in construction</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Construction</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Material efficiency</td>
<td>Cork is an environmentally-friendly material because it does not use scarce resources, it is not a pollutant, and it does not require transformation processes of the raw material which make use of expensive energy resources.</td>
</tr>
<tr>
<td>Energy efficiency and emissions</td>
<td>The use of cork products is ecologically very important because a renewable product is used in long life products, promoting the sequestration of CO2. According to Amorim’s sustainable report of 2008 (Corticeira Amorim, 2008), 0.379 kg of CO2/kg of cork is emitted by each kg of final product is responsible for fixing 1.833 kg of CO2.</td>
</tr>
<tr>
<td>Waste</td>
<td>Cork elements produce virtually no waste, except for those that result from the combination with other materials to produce construction elements. At the building dismantle phase, the cork should not cause environmental problems, and reusing/recycling should be possible (Gil, 2011).</td>
</tr>
<tr>
<td>Operation</td>
<td>Cork elements use a natural material which are non-toxic, so it is not generally associated with the harmful effects of indoor air pollution with Volatile Organic Compounds (VOCs), presenting no pernicious effect on the health of building occupants.</td>
</tr>
</tbody>
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Explore a Combination of Materials in Building Sustainable Construction Practices

<table>
<thead>
<tr>
<th>Building life cycle</th>
<th>Environmental advantage</th>
</tr>
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<tbody>
<tr>
<td>Health</td>
<td>Insulation corkboard agglomerates have three principal applications: thermal insulation, acoustical absorption and vibration damping (Silva et al., 2005) Cork agglomerates are suitable for diverse construction applications, interior or exterior walls, buildings and ceilings, to provide thermal and acoustic insulation and sub-paving insulation to minimise transmission of repercussion noises. This allows significant energy savings during the operation phase as earth buildings use less energy for heating and cooling.</td>
</tr>
<tr>
<td>Thermal comfort</td>
<td>Under fire conditions, cork does not release toxic substances as may occur with alternative materials, such as polyurethane foams or extruded and expanded polystyrene</td>
</tr>
<tr>
<td>Acoustic insulation</td>
<td>Cork flooring is naturally resistant to damage from scratching and denting due to impact and friction. A very dense material, it has an excellent recovering ability from high shoe-heel damage, heavyweight objects, and abrasion. Also, its elastic nature helps it maintain its stability during times of expansion and contraction due to climate conditions.</td>
</tr>
<tr>
<td>Fire resistance</td>
<td>Usually, the expanded corkboard pieces are removed entirely, and their insulation properties are unchanged. If necessary, its grinding is promoted, obtaining a re-granulated material destined to be used as an inert material or for thermal insulation applications (Gil, 2011).</td>
</tr>
</tbody>
</table>

With this we can say that cork is a 100% natural and ecological material due to its low embodied energy, that is, the energy spent during the extraction, production and transport is reduced in relation to other insulating materials.

3.2. Bamboo for an Innovative Building Technology

Bamboo belongs to the botanical family of grasses, like rice, corn and sugar cane. Bamboos, in their wild form, grow on all continents except Europe, especially common within the equator belt areas around the globe (Figure 3). Some of the largest species can grow up to 30 meters high with a culm (botanical term for the stem of grass) diameter of up to 15 centimetres (Minke, 2012). Bamboo is one of nature’s most versatile products, and there are great benefits that results from using it as a construction material.

Bamboo is a material extremely resistant to tensile stress, adapting to natural forces, such as the wind. It is also a plant that assimilates CO2 for photosynthesis, storing it during its growth time. Because of its rapid growth, bamboo can take in more CO2 than a typical tree. As a self-regenerating plant, with adequate management and harvest, bamboo can permanently absorb CO2, unlike any other species.

Although it has many advantages as a building material, it also has some weaknesses that prevented it being used as a durable construction element. Water absorption, swelling and shrinking behaviour, limited durability and vulnerability to fungal attacks and insect infestations have limited most of the bamboo applications in the past.
3.2.1. Bamboo in Construction – the present

Bamboo has been used as a construction material around the globe for centuries. However, untreated bamboo has its limitations. In recent years, through the development of new treating, bonding and laminating techniques, bamboo has even migrated to European countries, where there is no tradition of using bamboo for the construction of buildings. The construction of the bamboo pavilions for the 2010 Shanghai World Exposition and the Nomadic Museum in Mexico City, came to demonstrate that bamboo is now recognised around the world as a high-performance building material.

Another reference for bamboo applied as a structural system is the recently-developed project designed by Penda for the Beijing Design Week (BJDW) 2015, called “Rising Canes”. Here the potential of bamboo as a modular construction system, made entirely of bamboo canes and joints tied with rope, was demonstrated. There exist different solutions to fix the joints: Traditionally one uses “lianas” or binding of natural fibres, another option is hard wooden or palm tree (or metal screws) or even bamboo pins, and finally the structural connections are today often reinforced by steel joints (Minke, 2012). From small structures to skyscrapers or even entire modular cities – developed proposals made from this ancient material are being released and built with ever more frequency. Nowadays, bamboo is seen as a sustainable and eco-friendly building material but is still not as widely recognised as perhaps it should be as an exceptional construction material (Minke, 2012).

3.2.2. Bamboo in Construction – the future

International researchers have spent decades investigating ways to profit on bamboo’s tensile strength and material properties, and the possibility of extracting bamboo fibre from the natural raw material, transforming into a manageable industrial product and a viable building material that could be an alternative to steel or timber (Javadian et al., 2015).

The idea of bamboo as a reinforcing component in established building materials such as concrete is not entirely new. However, early attempts to use it as an untreated, non-composite reinforcement material in concrete were not successful. Researchers are working with the newly-developed technologies to explore new types of composite bamboo material. The principle is based on the extraction of the fibre from the natural bamboo, transforming it into a manageable industrial product, and introducing it as a viable building material, an alternative to steel and timber (Fairs, 2015).

Preliminary results of research conducted by Javadian et al. (2015) demonstrate that the bamboo composite can exceeded steel, in tensile capacity and weight.
4. Case Study of Sustainable Unit

A case study project was prepared based on the latest research for sustainable urban units, and the design of the units needs to incorporate the basic human needs and functionality but also needs to be designed with solutions to preserve the longevity of material and low maintenance costs. Therefore, the designed layout needs to be simple and efficient. This aim of this research is also to join the design proposed by Rodrigues and Henriques (2016) with the technical solutions proposed by Xiao and Paudel (2008) (Figure 4).

![Single Module]

Figure 4: Single module proposed by Rodrigues and Henriques (2016) and design solutions proposed by Xiao and Paudel (2008).

The central core can be either built from bamboo poles, or thick laminated panels, to form the necessary thickness, load-bearing and structural properties. All materials applied as 50mm thick wall panels are self-supporting and rigid enough, damage-resistant and easily replaceable/available. The floor can be made of either laminated bamboo panels or simple cut bamboo canes, properly arranged (Figure 5). E.g. Some examples of bamboo structures used for different purposes include temporary scaffolding (Yu and Chan, 2005), small bridges (Laroque, 2007), and internal walls (Varela et al., 2013). Recently recycled bamboo was used to build a temporary theatre for cultural activities such as the Cantonese opera pop up in Hong Kong (http://www.bbc.com/travel/story/20130129-cantonese-opera-pop-up-whets-hong-kongs-appetite-for-art).

![Example of flooring and a wall structure using cut bamboo poles]

Figure 5: Example of flooring and a wall structure using cut bamboo poles (Sources: H&P Architects and Minke, 2012).

The use of non-renewable materials was minimised as much as possible, with only the use of polycarbonate panels for the windows/openings. The materials used are from an available natural source, contributing for low embodied energy materials.
4.1. Building Solutions

One of the main concerns when using some raw materials is the stability of their characteristics over time, that is, how they perform when exposed to natural conditions such as, rain, wind or quick change of temperatures. Using the materials focus in this project and applying some of the knowledge collected by experience of the authors and latest literature review it was possible to propose a new situation and possible future application for the envelope, roof and walls.

The proposed solution (Figure 6) was built from the following materials: (1) structure and flooring: bamboo (2) exterior layers and insulation consisting of expanded cork agglomerate - ICB (Insulation Cork Board), already tested, and laminated plasterboard; (3) waterproofing and roofing: Ceramic roof tiles and underlayment sub-tile and ICB.

The solution for construction sites will use modern prefabrication and modular panels techniques, to facilitate transportation and assembly at the location of the construction site. This part of the research proposal will be based on the modular experience for timber and steel modular structures for containers and temporary facilities (Smith, 2010). The first modular prototype will be prepared with six panels: a floor panel, the four walls and a roof panel. The dimensions of the prototype will be for a typical office container for a construction site. To reduce the labour on site and transportation costs, the roof tiles will be replaced by bamboo tiles (Figure 7). The prototype will be developed in Portugal and Australia and tested at two construction sites in both countries.

5. Conclusions

The aim of this research proposal emphasises the need for thinking globally in building sustainable construction practices. The future project is to develop new agile constructive methodologies to achieve an increased commitment to wellbeing for the future of humanity in how to build. This will be achieved
using and combining different materials that exist in abundance in certain regions of the planet, such as South America, Africa and Asia, and are environmentally friendly. The combination of more sustainable materials and the responsibility of thinking in the whole life cycle of building materials are revealed as a matter of priority. Although new materials are being used in some construction sectors, due to digitalisation and automation practices, there is now, more than ever, a need to rethink the management of the natural resources of our planet properly. The lessons learned from the past can be used in non-developing countries helping to increase use of natural resources more efficiently.

Although some of the concepts are not completely new, and bamboo as a structural element for temporary buildings and facilities has been used for centuries, this research proposal focuses on adapting some of those techniques in a more efficient way. Cork has been underestimated and its characteristics misunderstood. As one of the most important materials for sustainability cork was wrongly be accused to kill trees, however, it does exactly the opposite. Recently, a comparison between shearing a sheep and removing the bark of the cork oak tree made the situation clearer. Trees are not cut down to harvest cork (bark), and the bark grows back again and is harvested by hand every nine years, much like a sheep’s wool with more time between each harvest.

The research proposes a project to develop the use of bamboo and cork with the current requirements in safety, habitability, and sustainability, but also as a business with flexible modular construction process and to help prefabrication and easy assembly methodologies. The present research project is also a solution for testing in a prototype to address rapid needs in urbanisation in developing countries using their natural and local resources. The project will primarily take into consideration the utilisation of such combination of materials for temporary works in construction sites, offices, warehouses, sheds and other short-term facilities and structures. The prototype will be developed using modular approaches, solutions based on panels for pre-fabrication and easy transportation and assembly. This will help developing countries with new business opportunities, reduce poverty and give them a role in the global sustainability of the world. Future research proposals will consist of a combination of other local materials, such as wool, coconut fibre, straw, corn silk and other local raw materials.

References


Stripping Back Kitchen Joinery

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Abstract: At the beginning of the 21st Century, new kitchen joinery was typically constructed of panels. The panels were fabricated of medium density fibreboard, using waste from the timber industry, and finished in melamine. The panel product does not patina well, has a short life and requires disposal in land-fill because of its toxicity, but a large industry promotes and supports these ‘box’ system kitchens. As the world comes to terms with excessive consumption, unsustainable production systems and pollution, this kitchen joinery industry is an anomaly. The joinery design is ‘unacceptable’ for a sustainable world. In the context of the evolution of kitchen joinery in New Zealand and internationally, this paper proposes a new kitchen joinery system. Named Good Bones, the design does not have a ‘box’ carcase. It uses just drawers for storage, minimal robust materials and environmentally friendly finishes which can be user applied. The flexible assembly allows for design adaption to suit houses of different eras, personalization by consecutive owners, adaption to suit new appliances and possible relocation. Two prototype installations in Wellington, New Zealand are presented and reviewed. Users and joiners provide feedback, both on the design and possible implications for the current kitchen joinery industry.

Keywords: Kitchen joinery; sustainable design; design innovation.

1. Introduction

In 2010, the author reviewed the state of the New Zealand kitchen design industry and found problems with current joinery practice (Mackay, 2010). The sleek, shiny minimalist style may have been fashionable but it seemed unacceptable to continue to use melamine coated medium density fibreboard (mdf) to make ‘box’ carcasses. The product had a short lifecycle, contained toxins and was unable to meet ‘cradle-to-cradle’ best practice. With depleting global resources, it seemed unacceptable to waste material and energy in frequent kitchen re-modelling. It seemed unacceptable for consumers to spend precious savings on overelaborate, over-complex and expensive designs. During 2010, the author was involved in discussions and debates on kitchen design in New Zealand national media (Mackay, 2010). The question that was commonly asked by commentators and the general public was ‘what is the alternative to melamine board kitchen cabinetry?’ There was no easy answer.

The author acknowledged this challenge by experimenting with alternative joinery concepts. This paper presents the design process and rationale in the context of the evolution of 20th Century kitchen joinery. It presents prototypes for a new kitchen joinery system, named Good Bones. Prototype one bench
unit was designed and partially fabricated by the author for her own home. A second prototype was designed for colleagues, but fabricated by a joiner. Interviews with the users and the joiner provided feedback on the joinery system.

2. Design Objectives

The objective of the design was to create an alternative approach to the current kitchen joinery panel system. To promote long term use, materials used were to be environmentally friendly, non-toxic and durable. Selected materials should be able to patina gracefully but also be routinely cleaned and occasionally buffed up, re-surfaced or repaired by the user. The system was to be economical in the use of material and be inherently flexible to allow alteration to suit new appliances or circumstances. The design was to recognize the strengths of traditional materials and fabrication but also make use of key 20th and 21st Century technological advances. Finally, the design system should be able to be customized to complement the design style of houses of different eras and to allow a degree of personalization by consecutive owners. The design process started with consideration of the sink bench and the cabinet underneath.

3. Changing Storage Patterns

Typically, early 20th Century sink benches made use of the space underneath to form a cupboard with double doors in the centre. (Figure 1).

Figure 9: This built-in sink bench was match-lined with the wooden top. (Source: Burt, ca 1932)

The unit often had a single shelf with more storage room underneath on the exposed floor; an area difficult to clean. The bulk of kitchen items were stored elsewhere. Crockery and cutlery were kept in a kitchen dresser and food and larger items in a safe; a large cupboard vented to the outside (Bell and Graham, 1905). Mid-20th Century fitted kitchens integrated storage into a fitted kitchen, using cupboards
above the bench and a mixture of cupboards and drawers underneath. (Figure 2). In a wooden carcass, the wooden drawers were supported on waxed wooden drawer runners. To stop the drawers from falling out, the drawers could be only partially extended out of the cabinet. Over time runners wore down (particularly with heavy loads) and drawers jammed.

Figure 2: A design for wooden kitchen joinery promoted to carpentry apprentices in New Zealand from 1958 to 1975. (source: New Zealand Technical Correspondence Institute, 1958)

By 1977, factory applied polyester coated timber fibreboard panel systems became common and to improve sliding drawers were fitted on ‘easy-rolling’ drawer slides (Conran, 1977). By the early 21st Century, European manufacturers Blum, Hafele and Hettich promoted highly machined double extension mild steel drawer slides which enabled drawers to be deep and wide, carry heavy loads, fully extend out the cabinet and to close softly. In 2005, Austrian kitchen designers, Blum, recognized the fundamental improvement in functionality offered by these drawer slides. They recommended that kitchen designs ‘avoid doors in lower cupboards (drawers and pull-outs obviate unnecessary stooping and clearing)’ and ‘include fully extendable pull-outs (these provide unrestricted overview and access)’ (Kesselring, 2006). Drawer slides continued to be secured to the side panels of a ‘box’ joinery system. However, these new runners also had structural integrity. They were not light profiles that required frequent fixings to a supporting rail or panel. The runners were capable of acting as a structural component between just two supports. Pairs of legs could support the drawer runners, as well as the bench top and any shelves required for supporting equipment (e.g. ovens or microwaves). In this case, the ‘box carcass’ made up of panels could be effectively redundant.

The storage concept of using only drawers supported on legs is the central idea of the proposed Good Bones joinery system and it has other implications for a kitchen bench design. The use of double extension runners allowed drawers to become wider and deeper. The storage efficiency of larger drawers is greater than for smaller drawers. Less space is taken up with drawer sides and runners and less material and components are required. Drawers of 600mm deep provide efficient storage for two rows of common
kitchen items. Frequently used items can be located in the front half of the drawers and less used items stored in the rear. Allowing for a 50mm bench-top overhang, a 15mm drawer front and tolerances, a 700mm deep bench top would result.

4. Bench-top Considerations

Over the 20th Century, the depth of kitchen bench tops gradually increased. A 1905 sink bench was 450mm deep (Bell and Graham, 1905). In this kitchen, a central kitchen table was the main work surface so the sink bench was mainly used for rinsing and washing. Fifty years later, a 500mm bench was standard (NZTCI, 1958). The recommended depth then increased to 600mm to line through with standardized appliances (NKBA, 1996). In 2006, the space-saving benefits of even deeper benches (725 to 800mm) were discussed. The extra width allowed work to be shifted to the back (Kesselring, 2006).

The Good Bones design proposal of a 700mm deep kitchen bench top has many advantages. There is space behind the working surface for the storage of commonly used utensils or appliances. A wall-hung draining and storage rack for crockery can be positioned behind the sink. The drips can be collected within a swage and directed towards the sink. Typically a gas hob requires special non-combustible lining behind the unit if the elements are closer than 200mm to the wall. A 700 wide bench can provide a distance greater than 200mm allowing the wall lining of the room to remain unobstructed. The increased depth also questions the need for a sink-bench up-stand or splash-back. If excessive heat or water do not reach the wall then the bench-top to wall junction can be reconsidered.

An early 20th Century sink bench top was typically wooden (Burt, ca 1932). New Zealand heart kauri could be scrubbed to a ‘velvet’ finish. Fixed plumbing pipework dictated the sink bench top should be built-in so a timber bead was scribed to the wall. The terrazzo and stainless bench tops that followed were manufactured with an integrated up-stand against the wall. This feature continued throughout the 20th Century in a wide variety of materials; plastic laminates, ceramic tiles, laminated timber and stone (Grey, 2004). More recently, the practice has been to laminate a sheet material to the wall and seal the gap to the bench top with silicon sealant. The New Zealand Building Code clause E3.3.6 requires the sealing of such joints stating ‘Surfaces of building elements likely to be splashed must be constructed in a way that prevents water splash from penetrating behind linings or into concealed spaces’. A ‘concealed space’ is defined as ‘any part of the space within a building that cannot be seen from an occupied space’ (MBIE, 2017).

Unlike a ‘box’ system, the ‘Good Bones’ kitchen bench has no concealed space behind or underneath it. Therefore, the sealing of the bench-top to the wall is not required. However, a butt junction could gather dust or detritus and be difficult to clean. A straight bench-top edge may not fit to an undulating wall surface in an older house. The simple solution is to separate the bench-top from the wall with a 10mm gap. Such a gap provides a useful space to lodge the cords of kitchen appliances. It is wide enough to clean. On a rare occasion, an item dropped through the gap, it could easily be retrieved by removing a bottom drawer to gain access. A gap at each end of a wall bound bench top also allows useful installation tolerance.

While the gap to the wall is a significant feature, the Good Bones bench requires to be connected to the wall (and the floor) for its bracing. Bracing requirements have had a significant role in the evolution of kitchen joinery.
5. Changing Structural Systems

A built-in 1906 sink bench unit inherently used the timber wall cladding and the floorboards for its bracing. Later, dowelled joints in timber framed cabinets ensured a rigid structure (NZTCI, 1974). ‘Frameless’, (or panel) systems rely on a sheet brace back panel. It also serves as a back to shelving. It allows for units to be fully assembled in the factory and be transported to the site as structurally independent ‘box’ units (Saxton, 2013).

The Good Bones system supports the bench-top on ‘L’ brackets attached to the wall and legs which are precisely located (and secured) on the floor on adjustable feet. The pairs of legs are also stiffened through the multiple connections with the drawer slides and angle shelf supports.

In prototypes 1 and 2 stainless steel rectangular tube was selected for the legs. The legs could have been timber or mild steel, but stainless steel has the advantages of being durable, not requiring a coating, and stainless steel coordinated well functionally and visually with stainless steel adjustable feet. Holes were simply drilled through the tube section legs to take stainless steel machine screws and barrel nuts which supported the drawer slides or stainless steel ‘L’ angles holding shelves for the microwave and oven.

In prototypes 1 and 2, the layout of drawers fell into a natural pattern. Horizontal breaks were made at the base of the oven front and the microwave shelf. This allowed for three upper shallow drawers (for cutlery, utensils and cups) as well as a tall lower drawer (to take rubbish and recycling bins). The drawer under the sinks has an extended drawer front to conceal the sink bowls. The arrangement differs from current ‘box’ system in two ways. Firstly, all drawer sides and backs were just 90mm high. The drawers are effectively sliding trays. The feature uses minimal material, and provides a little extra space for bins or bowls to extend over the top of the sides or at the rear. Items are prevented from moving around by the use of non-slip matting together with the soft-close function of the drawer slide mechanisms. Should items ever become jammed behind a leg-frame, the location can be easily accessed, unlike in ‘box’ joinery, via the adjacent drawer. The openness created by the minimal leg-frames and low drawer sides is appealing. Nothing is hidden or closed off. The second unusual feature of the drawer layout is the absence of a recessed ‘toe space’.

Figure 3: Good Bones prototype 1. Following the removal of drawers and shelves, the legs (with drawer slides attached) and services are exposed. (source: Mackay, 2013)
Figure 4: The *good bones* prototype 1 complete with a shelf for a microwave and timber drawers.
(Source: Mackay, 2013)

The toe space was not a feature of 1900 kitchen bench joinery. The vertical match-lining on the built-in frame extended to the floor. Early experimental fitted kitchens of the 1920’s did not have a defined ‘toe space’ (Kinchin and O’Connor, 2011). In 1975, Terence Conran instructed that ‘base cupboards must have a continuous toe space along the bottom so that you can stand comfortably at the work area’ and defined the minimum size as ‘75mm high and 100mm deep’. More recently, ergonomics texts on kitchen joinery design, assumed the requirement for a recessed toe-space without demonstrating the ergonomic need for the feature. Kitchen design guides continued to specify toe-spaces (Baden-Powell, 2005). In 2017, Austrian kitchen designers Bulthaup have created their b1 series with little or no toespace to cabinetry (Bulthaup, 2017).

The simple exercise of observing the position of one’s feet when standing in front of a bench suggests the ergonomic rationale is flawed. The space may look like a recess for toes but it existence is likely to be more to do with the relationship of the bottom shelf of a box unit and the floor. The *Good Bones* kitchen bench does not need a toe space. The top over-hangs the drawer fronts by 50mm, allowing for the wiping of crumbs into an open hand. The drawers are positioned at a minimum of 25mm from the floor. The gap can increase if floors are not level. Its height is sufficient for the nose of a vacuum cleaner or broom for regular cleaning. Bottom drawers can be easily removed to enable cleaning right under the unit for an occasional ‘special’ clean.

6. Materials and Finishes

A wooden drawer system was selected for the prototypes. Drawer hardware manufacturers specify the design parameters as part of their drawer slide systems. Prefabricated steel drawer systems could work equally well on leg-frames, but wood has advantages and appeal. Before the 1980’s, wooden kitchen joinery was prevalent in New Zealand houses and therefore its use is sympathetic to 21st Century renovations. As Terence Conran observed in 1977, wood is able to be re-furbished by the home-owner (Conran, 1977). It is also a sustainable choice. For economy (and in reference to the Edwardian tradition of using lower status materials in service and concealed spaces), prototype 1 used plantation grown
radiata pine for drawer sides and tempered hardboard for the drawer bases. While the prototype used solid timber drawer fronts, various different materials could be used. The drawer fronts are simply screw fixed from behind (or could possibly be held in place using the drawer handle fixings). This method allows easy personalization by owners.

Timber finishes changed over the 20th Century. Early cupboard interiors were left bare. Mid-century cupboards were painted in enamel paint. Timber veneers of the 1970’s and 1980’s were sealed in polyurethane and factory applied lacquers. Recent advances in timber finishing provide new possibilities. Waterproof hardwax oil can be easily and safely applied and reapplied as necessary by the homeowner.

7. Services

In ‘box’ joinery, a duct to take pipe-work can be formed between the wall-lining and the joinery back panel. Penetrations in the panel must be made for waste-pipes and sealed with a flange to prevent access by vermin. In the installation of the first prototype (as shown in Figure 3), the waste-pipe is fully exposed but the ‘S’ trap runs parallel to the wall to achieve more space for drawers under the sink. Typically, under-bench power socket outlets are installed on the joinery back panel in a second fix. The Good Bones design allows good access to outlets fixed directly on the wall behind.

8. Prototype 1

The site of the first prototype was in the author’s own kitchen in a 1906 timber villa. The south-west facing room (3m by 3.6m) had remained an eat-in kitchen over its history.

Figure 5: The setting of prototype 1 kitchen joinery. (source: Mackay, 2013)

The 2011 renovation repaired or restored the tongue and groove wall linings and reinstated the flooring using recycled matai floorboards. In the position of an original double-hung window, new double doors, designed in the proportions of the original verandah windows, were inserted. The doors open to a courtyard and the evening summer sun. In keeping with the original 1906 kitchen layout, a central table
was positioned for family meals and their preparation. The entry wall (to the right of Figure 5), accommodates a fridge/freezer and pantry shelving. The prototype bench opposite is 3m long by 700mm wide and has a stainless steel top.

Kauri drawer fronts were chosen to match other internal joinery in the villa. Drawer components were machined and given two coats of hardwax oil by the owner in a workshop. The components were assembled ‘on the kitchen table’ using a box template and clamps. With stainless steel countersunk screws, the elements were screwed together using a cordless variable speed drill. Wooden drawer pulls were designed to reference the simplicity of the original kitchen design and earlier New Zealand kitchen joinery (NZTCI, 1958).

![Image of the drawer assembly process on the kitchen table. (source: Mackay, 2013)](image)

The manufacturing and installation was not straightforward. The stainless steel fabricator incorrectly mounted the stainless steel top in particle board instead of plywood. The strength of plywood is necessary to span between leg-frames. The machined position of the some holes on the leg frames was slightly inaccurate. The ‘meccano’ type assembly requires a high level of accuracy. The drawer fronts were designed to have 2mm separation. While the drawer slider system allowed some height adjustment, the drawer fronts were not in exact alignment. Refinement of the installation system could achieve more accuracy. Using the right tools, the drawer assembly went smoothly. The hardwax oil finish, was stained by drips of concentrated detergent but it was easily sanded off and refinished.

After 4 years of use, the owners continue to enjoy their ‘good bones’ joinery. The efficient storage system has allowed a relatively small kitchen to become a much used living space.

9. Prototype 2

A second prototype was installed in a renovated cottage in Breaker Bay on the Wellington’s south coast. The layout allowed views from the galley style kitchen across the dining and living spaces to the seashore. The benches, 2400 and 3000 in length, provided 22 drawers in addition to an adjacent built-in pantry cupboard. The island bench presented a challenge for bracing the Good Bones system. This was solved by butting and securing the bench to a 1050mm high timber console. The console was designed to take a tensioned woven flax panel to partially conceal the view of the back of drawers.
The owners chose a stainless steel bench top and locally grown macrocarpa timber for the console, drawers and drawer fronts. The timber was sustainability grown and used in joinery elsewhere in the house. The owners were invited to choose the drawer handles.

The selected joiner welcomed the opportunity to work with wood and not use melamine board. Although specified as low sided, the heights of the drawer sides were fabricated to match the drawer fronts. The joiner considered this as best practice. He was unaware of the considerable practical and cost benefits of using low sided drawers. The owners’ selection of a cook-top and oven caused problems. The depth of the cook-top interfered with a standard leg-frame, which then required adjustment. The manufacturers of the oven, so accustomed to ‘box’ joinery, designed the cooling system to require enclosure. Ironically a plywood ‘box’ was required to be built to house the oven.

The assembly on site was new experience for the joiner. He felt uncomfortable about not pre-assembling the units in the factory; the current practice with ‘box’ joinery (Saxton, 2013). In theory, accurately machined components should assemble without problems, but the set-up and levelling of the leg-frames must be accurate. Templates could be developed to aid in this procedure and shorten the installation time. The joiner advised that construction programmes would need to allow additional time for site-assembled joinery installation, which is often the last task completed.

During the installation of prototype 2, the designed gap between the bench top and the wall caused consternation on site. The builder was sure it was illegal and that it would compromise the building consent compliance certificate. He was so accustomed to installing cupboard units with backs (forming concealed spaces) that he did not realise that because of the open frame, the gap was legal. The Good Bones system would require a change in thinking by many parties.

10. Conclusion

Over the 20th Century, the ‘box’ joinery system became the standard in the kitchen industry globally. Melamine board became the default material of choice. The sink bench evolved from a simple built-in cupboard to pre-assembled ‘box’ carcasses which require, in their installation, plinths and toe-spaces, up-stands and splash-backs. Benches deepened and cupboards underneath became difficult to access. The invention of double extension drawer slides solved this problem by facilitating deep and accessible
drawers. The kitchen industry of panel manufacturers, joinery factories, kitchen designers and retailers continue to promote ‘box’ kitchen joinery; a product which supports the practice of the industry, but not the needs of consumer or the planet. The expense, the material, the toxicity and the waste are not necessary. The ‘box’ carcase is not necessary. Simple legs can support the drawer slides.

Two prototypes tested the application of this idea. The chosen materials of stainless steel and wood are non-toxic, durable, recyclable or biodegradable. These materials patina gracefully and can be cleaned, resurfaced or repaired on site by the user. The design uses material economically with simple leg-frames, low-sided drawers, bracing to existing structure and without the need of plinths and splash-backs. To adapt to change, the position of the legs can be easily altered and the width of drawers be trimmed and reassembled by re-fixing screws. The bench can be relocated. The design uses the technical innovations of stainless steel, highly machined drawer slides and hardwax oil wood finish as well as the enduring qualities of natural timber. The design allows for customization. The material and finish of drawer fronts and the design of handles can be changed to suit tradition or personal taste.

The two Good Bones prototypes were appreciated by their owners, both for the functional and aesthetic design and their sustainable characteristics. The on-site ‘Meccano’ like assembly offered challenges to current installation practice and the development of strategies are required. More significantly, the Good Bones design concept uses minimal material and no plastic laminate board. It has the potential to challenge and disrupt current kitchen joinery industry practice.

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Design that Builds Industry Skill and Capacity

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Abstract: This paper explores the potential for innovative architectural design to build industry skill and capacity, and support resilient regional economies. It is a result from a final-year student Advanced Design Research (ADR) project at the University of Tasmania’s (UTas) School of Architecture and Design that focussed on the University’s $300m Northern Transformation program (NTP). The students followed a mixed methods approach to seek to understand the potential for collaborative building design processes to develop Tasmanian industry, and through their findings, support those active in overseeing the building program maintain the conditions for this to occur. By the process’s end, the team was able to generate and present a cohesive document, outlining aspects of innovation and capacity building through design as well as providing 15 guidelines for the potential implementation of innovation. This paper sets out the team’s methodology and the five major themes and fifteen guidelines for improving the likelihood of successful design and construction innovation are presented and discussed.

Keywords: Design; innovation; research; industry.

1. Introduction

This paper explores the process undertaken by final-year Masters of Architecture students who explored the potential advancement of innovative architectural design through their involvement in a structured research process and distribution of results to the project’s clients, potential design and construction professionals, as well as other members of the wider community. Innovation is the process by which organisations 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). However, innovation is not a simple linear process. Building design innovation is particularly messy, uncontrollable, unpredictable, and difficult to define (Loosemore 2014). For innovation to be achieved, it needs to be thought of as much more than an outcome. The complexity of the innovative process needs to be understood and the likely consequences of innovation need to be recognised and addressed from the start of the project. Successful innovation cannot be an afterthought. It has to be intertwined and realised during the building’s procurement process.

As part of the government-funded $300m Northern Transformation Program (NTP), the University of Tasmania (UTas) is developing new or largely enhanced campuses at Burnie and Inveresk in Tasmania’s north. One of UTas’s aspirations for the included building projects is to increase the productive capacity
of Tasmanian industry and local communities where possible, and its design brief for the first project encouraged tendering design teams to adopt ‘innovative construction methodologies… supporting the development of Tasmanian industry...” (Castles, 2017). In response to this call, an Advanced Design Research (ADR) selective titled “Design that builds industry skills and capacity” was proposed for final-year Architecture students from UTas. An ADR selective is unit structured to allow students and supervisors to work together to undertake research projects that engage with both empirical and applied processes, as well as speculative and theoretical investigations (Norrie and Owen 2013). Eight students joined the ADR team and expanded the selective’s title to a key question of: how can architectural teams use their skill in innovative public building design to collaboratively develop regional industry skill and capacity, and community resilience? The team’s research sought to understand the potential for these processes and, through their findings, support those active in the NTP to maintain the conditions necessary for innovation and regional capacity building. As the ADR was held before any of the project consultants were appointed, the team’s activity focused on the initial process stages where client and user groups, building design and construction professionals, and community members, were coming to grips with the opportunities and challenges that a large and potentially transformative building construction program presents.

2. Methodology

The ADR team used a mixed-methods research process to explore these questions, and followed a common process for a project of this type. This contained a review of literature and current practice, interaction with an active project to test the themes uncovered in the review, synthesis of the findings and observations into a report, and refinement of these findings and observation after external review into a document suite for distribution. This process aligned with the unit’s assessment tasks which required a research proposal and literature review initially followed by a research report.

The first project stage was the literature review and this occurred concurrently with the first round of project interaction. Without experience in innovative design or industry development, the ADR team began by developing its expertise through a broad literature review and repeated discussions of the uncovered findings and themes. To effectively manage this process, the literature reviews initially focused on documents covering four areas: the UTas building program; the profile of Tasmania’s productive building-focused industries; the broad process of innovation; and case studies of innovation in building design and construction. As the literature review progressed and findings were discussed, the team uncovered several consistent shortcomings in the available documents. Firstly, while the literature showed that universities and similar organisations regularly stated the desire to encourage innovation and develop local capacity through their building processes, papers and case studies avoided discussing how this was or could be achieved. Available documents were regularly simple statements of design achievement or declarations of capability. Critical assessment or reflections on the process were lacking. Second, little documentation was available on the UTas building program or on the profile of industries who may benefit from interaction with it. The group realised that understandings about these areas would have to be developed through research-in-action interviews.

The second project stage was project interaction. This was a vital part of the research and involved the collection and assessment of first-generation information through interview, site inspections, and other observation. The University client group, key government and community participants, members of industry and the design professions, and interested stakeholders were interviewed. While instigated by the ADR team, interviews were largely two-way affairs. Those being interviewed wanted to learn about
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the NTP as much as the ADR team wanted to learn about their views and activity. While not an intended outcome, the ADR team effectively encouraged those interviewed to consider how they could shape or benefit from the program. The interviews and site visits also allowed the team to begin to develop and test an understanding of local industries or industry sectors available and open to development, and the form this development might take. The interactions with local professionals helped them realise the type of experiences that they may encounter post-graduation. They found that a common misconception with those interviewed was that innovation only relates to a product. Although innovation can involve products such as building materials, mechanical components, or services, the literature showed that innovation includes improved methods of construction, documentation precision or approaches by the designers, organisational methods of communication and skills, and risk management procedures.

The project interaction stage revealed other factors important in shaping the form of the final project report. Firstly, many people involved in the process had very little understanding of the building design and procurement process. Secondly, very few people had a broad understanding of the Tasmanian industry and its capabilities. Most industry members could speak confidently of their own sector but had very limited knowledge of other closely aligned industry sectors. Next, there was considerable uncertainty in how the building procurement process should be structured to enable the client group, the designers and industry to work together to achieve innovative outcomes that also built industry capacity. Lastly, the potential beneficiaries of innovation and capacity building were poorly recognised. As such, this group could not be mobilised to support the process. Recognising these factors, the group identified that their final report could be a valuable tool on overcoming these constraints on innovative processes. This was where the document could be most useful.

The final stage of the project was a synthesis of the findings and observations into a report. This began with the discussions held during the literature review and project interaction stages, and continued through to the report’s final review and dissemination to stakeholders. The ADR team originally planned a report based on thematic briefing papers and case studies. However, after viewing an initial case study paper, members of the University client and stakeholder group encouraged the team to make a bold pitch of ideas on how the concepts of innovation and capacity development could be advanced during the design process. In effect, they wanted a series of propositions to which they could respond and distribute to others for their response. In its final form, the document contains a suite of fifteen guidelines included in Part 4, five thematic briefing papers described in Part 3, four building case studies linked to the briefing papers’ themes and an appendix of addition case study summaries and interview notes.

In response to the potential constraints identified during the project interaction stage, the ADR team prepared a flexibly formatted document. Written for a general audience and designed as stand-alone documents, the briefing papers and case studies sought to encourage a greater understanding of the potential for innovation and capacity building while providing examples of it in action. Simple illustrations were used to communicate each of the guidelines. These guidelines were a crucial part of the document as they summarised the ADR research findings into a digestible format for easy communication with all parties involved with the project. After reviewing the papers, a member of the University client group stated that all the briefing papers would provide them with a solid starting point for their own thinking about the possibilities of the NTP, and in addition, gave new ideas about different types of approaches to “building as research”; “research by design”; and “innovation” (Kirsten Orr, pers. comms, 14 June 2017).
3. Thematic Briefing Papers

The final ADR report included five thematic briefing papers covering: sustainable development in buildings; the participants in the building procurement process; risk handling and procurement; and two aspects of innovation in construction. Unlike the case studies which simply reported key aspects of other building projects, these briefing papers were a direct result of local industry feedback, observation of participant capacity and the academic reviews of literature directly relevant to the implementation of innovation. Though the students had limited knowledge on each of the themes prior to engaging with local industries, they developed each of the papers for a general audience. The double A4 format of the briefing papers aimed to both inform and prepare the multiple participants in the involved industries, and aid the relevant professionals to understand the complexity and sensitivity needed in the design process if the full advantages of innovation in the NTP are to be developed.

3.1. Briefing Paper 1: Sustainability

This briefing paper attempted to outline the benefits of sustainable design considerations for the NTP. The term ‘sustainability’ is often talked about with little understanding of its meaning in the built environment. The briefing paper identified five areas of environmental considerations that can reduce the reliance on energy, benefiting the environment, and reducing the running costs. The paper summarised sustainable approaches that could be introduced into the NTP design to develop a healthy working and learning environment, and decrease cost of construction and cost of operations. The outcome of this briefing paper was consolidated into a series of guidelines aimed at achieving carbon neutrality during the building’s construction and operation, and developing a driver for the use of local materials and systems to help improve industry skill and regional economic growth.

3.2 Briefing Paper 2: Participants in the building procurement process

This paper examined the participants of the building procurement process and discussed their potential relevance to work planned under UTas’s NTP. The briefing paper outlined the role of each participant and their actions in different phases of the building procurement process. Every building procurement process includes many participants acting together through a series of seven distinct phases, ranging from the brief formulation to construction. When innovation is a desired outcome during this process, collaboration between building professionals and other participants is critical for its successful implementation. The general nature of the research was established to help communicate where innovative ideas and strategies could flourish within a real-world scenario, dividing the construction and documentation process into the different parties involved in the various stages and identifying which party has influence at each specific stage.

3.3 Briefing Paper 3: Managing the risk of innovation

This paper attempted to identify common risks that arise during innovative procurement processes, as well as how these risks could be managed to reduce setbacks and cost implications. To fully understand how innovation can be developed during the procurement process, an outline of common risk management techniques was investigated and framed in ways relevant to potential innovation in the UTas NTP’s design. The work identified three areas of critical risk during the procurement stage that can be managed through an analysis of their potential to arise and the severity of their effect. Through identifying, quantifying, and finally controlling risk, innovative techniques could be included in the NTP’s
design without the potential for them to be heavily revised or eliminated, in favour of more conservative options due to risk. This briefing paper helped in establishing the guidelines on risk vs reward, as well as encouraging innovation through managing risks, and establishing a framework for assessing risk.

3.4 Briefing Paper 4: Innovation in design

This paper attempted to define innovation and the connections it could have to the procurement process. It discussed the relevance of innovation for universities, outcomes to relevant industries, quality of practice, innovation’s messy tendencies, and the collaboration between participants in innovative design compared to traditional methods. Within this paper, innovation is described as a multi-stage process through which design can be modified into three aspects; new/improved products, services or processes, to distinguish, improve or to be competitive within the industry. The paper also examined innovation within the industry through incremental improvements from poor, standard, best, and innovative practices. The paper resulted in the guidelines for: demonstrating UTas’s research capability in the building, enabling further education for the broader community, encouraging innovation and manage the risks, and enabling effective collaboration between industry and design teams.

3.5 Briefing Paper 5: Capacity of innovation

This paper identified different practice methodologies to understand where innovation could be developed during the projects’ construction and procurement phases. In response to UTas’s brief, as well as the ADR team’s research question, the issue of quantifying the capacity of local industries become apparent. While the construction industry is a key player in this process, the review focused on the capacity and capability on broader local industry development, and discussed how various players can collaborate to drive improvements in productivity through new innovative technologies. The paper indicated that the NTP could act as a catalyst to Tasmania’s economic growth, while also building up community resilience by adoption of innovative construction methodologies. Through the examination of cross industry participation in improving the efficacy of innovation, the NTP could adopt these strategies by enabling cross disciplinary consultation through various inputs by surrounding local industries. This is included in many of the guidelines that focus on collaboration and organisational improvements to benefit the implementation of innovation.

4. Guidelines

In addition to above briefing papers on key themes uncovered in the literature review and project interaction stages, the ADR final report included fifteen guidelines grouped under their focus on innovation and capacity development during the building, engagement, and procurement phases. The guidelines proposed strategies and opportunities for potential professionals and building client groups to adopt to encourage innovative practices during the NTP.

4.1 Building 1: Demonstrate UTas’s research capacity in the building

The NTP buildings can demonstrate UTas’s capacity in research and development to provide a test platform for material and physical sciences, health, education, and other research areas. One way to achieve this is to allow research or experiments based on altering, adapting, or assessing various parts or components of the building. The briefing paper of innovation
stated that universities can create platforms for researcher to build and test the outcome of innovation. Researched case studies illustrate the building as a test bed to improve research findings through continuous development and expansion of the building (Johnson, 2016).

4.2. Building 2: Use local material and systems to develop industry skill

The buildings’ design, construction techniques, and component configuration could be based on the innovative use of local materials and fabrication skills. This can increase economic growth in communities and build regional capacity and capability. The briefing paper of capacity suggested ways to improve industry capacity through innovation. These include supply chain integration, technology refinement, and skill development (Loosemore, 2015). The case study of Bioscience Nottingham University shows the use of local materials in order to reduce the transportation cost and time. This building acted as a constructed example for local industry (Welch, 2010).

4.3. Building 3: Achieve carbon neutrality during the building’s construction and operation

Aspiring to achieve carbon neutrality in the buildings’ construction and operation can demonstrate a commitment to a low carbon future. Preisig et al. (2001) suggested that environmental damage can be controlled and reduced if the designs corresponds to no more than the need required for space, comfort and technology. The case study on the UTas School of Architecture demonstrates various way in achieving sustainability through construction and operation with a high-technological approach, and retaining original building structures (Owen, 2007).

4.4. Building 4: Incorporate data and sensor connectivity

Local industries and practitioners have suggested that technological capacity could drive change in the further development of a building’s design. Such cumulative data recorded could be analysed by researchers, with adjustments made to the corresponding areas of the building’s fabric (Williams, 2017). Participating in data and sensor-based research and developing uses for the information is a world-wide trend and one from which the University and the State could benefit.

4.5. Building 5: Enable varied teaching and learning methods

Modes of teaching are varying with the increased potential of digital communication and the needs for students to learn additional skills. Alternative teaching methods need varied teaching spaces that stimulate teacher and student activity, and increase the value of their interactions.
4.6. Building 6: Employ a modern, prefabrication construction process

Site based construction is subject to unexpected delays due to its exposure to the elements, and its reliance on a site-based tool kit. Precise and more efficient construction is possible through advanced prefabrication and assembly techniques. Experience with prefabrication can build industry's capacity to deliver improvements on these and other projects. The process of prefabrication allows one to conduct material testing and enable the production to work with the supply chain capacity more easily. Case studies (NRAS Inveresk, TRUTEC, etc.) demonstrated that this process can avoid unexpected on-site conditions.

4.7. Engagement 1: Recognise the profile and capacity of local industry

Tasmanian industry is capable of manufacturing building materials, assembling them into components and sub-assemblies, and combining these efficiently into buildings of different scale. Recognition of industry’s current capability and capacity can allow designers to work to industry’s strengths, and develop an understanding of what the community can achieve. Design teams can selectively cooperate with local businesses based on their potential development (Leibinger, 2006).

4.8. Engagement 2: Enable further education for the broader community

Considerable potential exists to increase the community’s educational aspirations and remove barrier to its achievement. Innovation within the building can be explicit and draw the community’s interest. Thus, the design of the educational precinct and its buildings can contribute to broader acceptance of the University and the benefits of ongoing education. The Dr. Chau Chak Wing building was used as a test bed for research and widely published to the public. (Calzini, 2015).

4.9. Engagement 3: Use the buildings for industry-connected research

Effective research collaboration between industry and universities is important to regional development and economic well-being. Innovation within universities can take the form of a continuous exchange of ideas and experiences. When these are shared through collaboration between academic and industry players, significantly higher success rate for research implementation can result. Meaningful collaboration of this type requires spaces where industry feels comfortable and welcome, and equipment that either complements industry’s suite or demonstrates additional capacity. This collaboration is illustrated in the University of Wollongong’s Sustainable Buildings Research Centre (Huntsdale, 2014).
4.10. Engagement 4: Consider the impact on local housing provision and commercial services

The developments at Inveresk and Burnie will generate demand for housing and increased commercial activity near the campuses. While provision of these services is private enterprise’s responsibility, the University and local councils have a role in encouraging orderly and balanced provision, and safeguarding student well-being and community benefit. For example, UTas’s’ Markers’ Workshop in West Park Precinct is a major investment by the Burnie City Council to link and enhance the scale of self-manufacturing industries and delivery port services (Maker’s Workshop, Burnie, Tasmania., 2017).

4.11. Procurement 1: Structure project scope for local participation

Completing the NTP’s building projects in the expected delivery time may stretch the capacity of Tasmanian design, construction and building component manufacturing sectors. Based on practice experience, local industry practitioners suggested that attention is required in project scope and structure method by considering the local economic scale and means of operation (Higgs, 2017). Grouping projects into one package may effectively exclude local participants. Separating projects into discrete packages can improve local participation and generate diversity in the solutions.

4.12. Procurement 2: Encourage innovation and manage the risks

Innovation can deliver rewards through construction saving, quality improvement, or efficient building operation. However, innovation generates risks for the participants as new processes may not deliver expected outcomes. Recognising and managing these risks is part of any successful innovation process. The briefing paper -Managing the Risk of Innovation examines literatures and outlines several types of risk and methods of management. These concepts are commonly practiced in the industry and are evident across different successful case studies such as the Dr Chau Chak Building, and the Visual Art Building, University of Iowa.

4.13. Procurement 3: Enable cross-disciplinary innovation

It is pointed out that an integrated cross disciplinary cooperation is essential for successful procurement of innovation (Loosemore, 2014; Nolan et al., 2016). Academic researchers, industry and building design professionals can each gain from contributing to innovation in the buildings’ design, construction and operation. Mechanisms should be in place to facilitate their participation. Case studies (NRAS Inveresk, RMIT, etc.) demonstrated different ways of engagement and some of the methods that can be potentially adopted into the NTP. Researchers acts as catalysts in the process and can assist participants to understand innovation and its risks.
4.14. Procurement 4: Enable effective collaboration between industry and design teams

Collaboration is an essential ingredient for successful innovation, yet effective collaboration requires time for relationships to develop and for options to be explored. Tight project schedules and complex tendering requirements can restrict open collaboration and limit the potential for participant benefit. It is important to organise and engage major participants in the early stage of the process where solutions can be jointly developed (Loosemore, 2014). However, the industry participants pointed out that procurement can be messy and unpredictable (Higgs, 2017). Case studies such as the Dr Chau Chak Building, and the Visual Art Building, University of Iowa show that active engagement and collaboration across participants are essential for successful innovation procurement.

4.15. Procurement 5: Share the risk and reward of innovation along the supply chain

Collaboration minimises the risks that innovation generates. However, this demands each collaborator invest time and resources on the hope of future benefit. Loosemore (2014) raised the point of sharing risk and reward along the supply chain, where the processes should insure that those exposed to risk and who invest in collaboration share in innovation’s rewards. This creates a motivational environment across all participants for active collaboration and innovation procurement.

5. Conclusion

This paper explored the potential for final-year architecture students to act as catalysts for innovative architectural design practice through their involvement in a structured research process and active dissemination of results to the building clients, potential building design professionals, and members of the wider community. The use of a mixed-methods research process to explore the team’s research question through multiple reviews of literature and current practice and interaction in an active project to test the themes uncovered in the review, enabled them to synthesis the findings and observations into a report, and refine that output through external review. The ADR report discussed five thematic briefing papers covering sustainable development in buildings, the participants in the building procurement process, risk handling and procurement, and two aspects of innovation in construction. These briefing papers were a direct result of local industry feedback, observation of participant capacity, and the academic reviews of literature directly relevant to the implementation of innovation. The final stage of the ADR report included fifteen guidelines grouped under those that focused on innovation and capacity development through the building, engagement, and procurement processes. These proposed strategies and opportunities for potential professionals and building client groups to adopt innovative practices during the procurement, community engagement, and building construction processes of the NTP.

Through this continual process driven research, the team were able to effectively prepare a document that could be disseminated to multiple professionals with the aspiration to inform them, as well as the local community, on the importance of innovation and local participation.
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Enabling Automated Compliance Audit of Architectural Designs

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Abstract: A rapid uptake of Building Information Modelling (BIM) by architects in recent years has enabled improved collaboration and better information sharing among project stakeholders. BIM will continue to have a positive impact on the quality improvement of the built environments and the overall productivity boost in the industry. One activity that has not fully benefited from this collaborative approach is the compliant design process whereby certain design aspects must be audited for compliance with some normative standards or requirement specifications. A challenge to automate this laborious and error-prone conventional manual process has been attributed to the inability of machines to readily process legal knowledge that is conveyed in natural language texts. There have been a number of approaches suggested by researchers towards enabling an automated compliant design process, each has its advantages and also drawbacks. This paper introduces emerging open standards LegalDocML and LegalRuleML for exchanging legal knowledge and describes an automated compliance audit framework that treats both the building design data and the normative information as independent input components to be processed. The framework incorporates a human guidance element to facilitate the audit process. Lastly, a case study highlighting common compliant architectural design problems is used to illustrate the approach.

Keywords: Building information modelling; compliance audit; legal knowledge; process modelling

1. Introduction

1.1. Background

Since the turn of the century, Building Information Modelling (BIM) and associated open standards have progressively enabled better collaboration and information sharing among project stakeholders in the Architectural, Engineering, Construction, and Facilities Management (AEC/FM) domain. A rapid uptake of BIM among architects in recent years has also promoted the Integrated Design and Delivery Solutions (IDDS) approach in building design and construction projects (Owen et al., 2013). One important activity that has not fully benefited from this collaborative approach is the compliant design process whereby certain design aspects, particularly those related to safety, are audited as part of the design process for
compliance with some legal norms such as the provisions in a building code, normative standards (e.g. NZS3604) and requirement specifications such as the design or project brief. Compliance auditing is an integral part of the architectural design process that is often laborious and error-prone. It is an iterative process that conventionally involves manually checking various design options against requirements and constraints stipulated in voluminous paper-based normative documents.

There has been considerable research effort to automate this process over the last few decades. Sharing building information for machine processing was the initial challenge, but this has been addressed by BIM since the turn of the century. Another challenge has been attributed to the inability of machines to process normative information that is conveyed in the natural language. For example, numerical limits are often stated in text rather than other means such as tabulated values. One common attempt to address this is to replicate a set of legal norms and represent them as computable rules that can then be incorporated into the automated compliance audit system. This approach creates a static representation of legal norms that are not responsive to changes in the source document. It also creates a “black-box” in the system that lacks transparency and that is difficult to validate for accuracy and costly to maintain. Furthermore, capturing human expert knowledge adequately for machine processing also represents a practical challenge. Human experts have intuition and tacit knowledge, which is difficult to transfer to machines, for making decisions quickly under exceptional circumstances.

1.2. BIM-based Compliant Design

BIM-based compliance audit in the context of this paper is the process of auditing a given architectural design represented by BIM for conformance with a set of legal norms, normative standards, or requirement specifications such as a client’s brief, represented by a Legal Knowledge Model (LKM). An architectural design that has been subject to compliance auditing is therefore referred to as the “compliant design”. This process mainly occurs during the design phases of a building but may extend throughout the entire life-cycle of the building. The term “compliance audit” refers to the objective of the audit process, which is to achieve compliance, rather than the mode or method of auditing. Therefore, in this context, the term “compliance audit” is equivalent to “compliance checking” or “code checking”, but not “model checking” or “rule checking”. In particular, “model checking” pertains to the quality control process of a BIM-based model given a pre-determined set of rules. A typical example of model checking applications is to detect clashes of architectural and structural elements, which is intended to address potential coordination issues on site. Some commercial model checking tools, such as Solibri Model Checker (Solibri Inc., 2017), offer extended functionality beyond clash detection by allowing rule-checking of certain design features for conformance with pre-defined criteria using a built-in library of proprietary rule-sets, usually with little room for customisations.

There has been an increasing research interest in the area of BIM-based automated compliance audit in the last decade and a variety of approaches have been suggested (Dimyadi and Amor, 2013). The rule-based approach seems to be the most popular (Eastman et al., 2009) and is well suited to prescriptive legal norms. However, there is a need for a practical method of automating the compliant design process that supports performance-based design (PBD) approach, which is gaining popularity internationally. Unlike the prescriptive design approach that is subject to a large rule-set intended for a generic group of buildings, the PBD approach allows specific designs that recognize the individuality and uniqueness of each building, which also promotes innovation. However, the compliance of a PBD usually needs to be verified by means of simulations or computations and ultimately for conformance with a few high-level rules that represent the normative PBD criteria.
1.3. Addressing Challenges with Current Approaches

There are several limitations and also challenges associated with the conventional rule-based approach, as follows:

- The approach assumes that all the information to be checked is available, which is not always the case as it depends on the Level of Details (LoD) specified for a particular stage in the project.
- A general assumption that every situation can be represented as rules, which is not the case as there are implicit types of knowledge inherent in legal norms that require specific human interpretations and cannot be pre-defined. For example, PBD criteria often need to be evaluated by specific calculation methods, which may be dependent on dynamic environmental conditions that cannot easily be pre-determined and represented as rules.
- It does not address the importance of having an official link between the rule-base used by the compliance audit system and the source legal norms they represent. Maintaining an unofficial set of legal norms as rules independently of the source is far from ideal and certainly would not be sustainable in the long run.
- Satisfying a set of rules does not necessarily guarantee compliance. For example, a client may reject a design on subjective grounds although every rule in the design brief has been complied with. This is particularly true when the rules are not adequately defined.

One practical solution for automating the compliant design process is to follow the conventional procedure, but by replacing the manual tasks of accessing and processing information with that of machine automation. Machines can execute procedures efficiently, but rely on human experts to specify and create these procedures. In this approach, the role of human experts is essential and particularly relevant where information is missing from the source and human input is therefore required.

2. Ingredients of an Automated Compliant Design Framework

Two main sources of information are needed in an automated compliant design process, namely BIM-based building design information, which is to be audited against a set of normative information represented in a Legal Knowledge Model (LKM). A practical automated compliance audit framework (Figure 1) has recently been suggested (Dimyadi et al., 2016a) where an audit engine would treat BIM and LKM as independent input components. The third essential input component is the human-guided process model referred to as the Compliant Design Process (CDP). An architect can describe an auditing procedure using a flowchart-like process diagram that specifies exactly which information to extract from where and how they should be processed for execution by the audit engine. Once formally documented, the procedure represented by the CDP can be re-executed for similar compliant design aspects in another project.
The framework allows supplementary human input as well as interfacing with external simulations or computational processes, which is vital for the performance-based design process of engineering disciplines such as building fire safety or emergency evacuation.

2.1. Building Information Modelling (BIM)

BIM allows architectural design information to be captured in a single standard data-rich model for collaboration purposes. The open standard for exchanging BIM data is IFC (Industry Foundation Classes) (ISO 16739, 2013), which is now supported by more than 150 different software applications in the domain. BIM is a multi-faceted concept to design and collaboration. A project may adopt one or more BIM use cases, such as the coordination of architectural and engineering services. BIM handbooks have been published internationally to explain the technology and to assist project stakeholders with standard processes that would enable better workflows. The New Zealand BIM Handbook was published in 2014 and followed by the 2nd edition in 2016 (BIM Acceleration Committee, 2016).

BIM is a semantically-rich database capable of storing information from every discipline involved in the project throughout the life-cycle of the project. Having a single database allows information to be managed more efficiently. An exemplar tool that can be used to manage such information is the open source BIMserver (Beetz et al., 2010) that works specifically with IFC. The tool is intended to be a BIM-based development platform that allows software plugins to be written for undertaking specific tasks such as extracting certain information from the building model for further processing. For example, to extract a subset of the building model containing specific information needed for auditing the provisions of accessible routes. IFC is a large and complex data model and necessarily so to represent such a complex object as a building. For this reason, using a subset of a building model for specific applications is considered practical as processing the entire model would not be inefficient and unnecessarily complex. Furthermore, it is rare that all information within a building model needs to be processed at the same time for one application. For example, detailed structural design information is not essential when auditing a building design for compliance with the provision of sanitary facilities. The open standard method that can be used to define exchange requirements for a model subset or MVD (Model View Definition) is known as IDM (Information Delivery Manual) (ISO 29481-1, 2010). Having a subset of the building model also allows targeted information to be added as required by the application or any missing information supplied. Supplementing BIM with secondary or targeted data has been promoted in recent work as a semantic enrichment strategy (Belsky et al., 2015).
BIM can facilitate early collaborations with engineers and other consultants, which can contribute towards a better coordinated architectural and engineering design that satisfies all the objectives.

2.2. Legal Knowledge Model (LKM)

The term Legal Knowledge Model (LKM) is used in this paper to refer to a computable representation of a set of legal norms or normative standards against which a building design can be audited. LKM should be treated as an input component of an automated compliance audit framework that can be maintained independently alongside the official paper-based source documents. Ultimately, there should be an equivalent set of computerised version of all legal documents and normative standards used in the AEC/FM domain that is both human-readable as well as machine-processable. For example, an LKM for the New Zealand Building Code and all subsequent amendments should be published alongside the paper-based version. Given that human input is essential in an automated compliance audit process, it is therefore pertinent that LKM should maintain the look and feel of the source document as it would allow the user to navigate the content of the document in the same way as one would with the paper-based version, especially when designing an audit procedure for automation.

The current research also investigates the suitability of two emerging open legal knowledge interchange standards, LegalDocML and LegalRuleML (Palmirani et al., 2011; OASIS, 2016) to represent the literal and logical content of legal documents coherently. The isomorphism feature supported by these standards allow a rule represented in LegalRuleML to be associated with its source text in LegalDocML, which is important to ensure any amendment in the text can trigger a change in its formalised rule.

2.2.1 LegalDocML

LegalDocML is a standardization of Akoma Ntoso (Architecture for Knowledge Oriented Management of African Normative Texts using Open Standards and Ontology), a standard developed by UN/DESA (United Nations Department of Economic and Social Affairs) in 2004 for e-Parliament services in a Pan-African context (Vitali et al., 2007).

LegalDocML is exchanged using the open standard XML (eXtensible Markup Language) that is both human and machine readable and is intended to represent the literal content of any paper-based document. It has the ability to capture the entire life-cycle of a document. The latest standardised version of the schema is AKN 3.0.

2.2.2 LegalRuleML

LegalRuleML extends the open standard rule markup language, RuleML (Boley, 2001), with a number of specific statements as well as “deontic” operators (i.e. obligation, permission, prohibition, and rights) to support legal norms modelling. LegalRuleML is naturally exchanged in XML and intended to represent the logical content of a document. A rule in LegalRuleML consists of IF <conditions> and THEN <normative effects>, where conditions pertains to the applicability of the rule and normative effects pertains to deontic specification, which is a Boolean statement in the scope of deontic operators (Dimyadi et al., 2017b). For example, a legal norm that stipulates that “a door must swing in the direction of escape if used by more than 50 persons” can be represented as a rule in LegalRuleML as shown in Figure 2, where <conditions> specifies “occupantLoad is greater than 50” and <normative effects> specifies an obligation that the “doorOpeningDirection shall be OUTWARDS".
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Figure 2: A rule representation excerpt in LegalRuleML (adapted from Dimyadi and Amor, 2017a)

The link between the formalised rule in LegalRuleML and its text provision in LegalDocML (isomorphism feature) is achieved by a pair of elements known as “LegalSource” and “Association” (Dimyadi et al., 2017b). A change in the “LegalSource” is then used to trigger an alert when the associated rule is executed.

2.3. Compliant Design Process (CDP)

Conventionally, a designer would follow a set of procedures when undertaking a compliant design. These procedures are typically based on industry’s best practices that have been adopted as standards, which can formally be described in process diagrams. An executable process diagram that describes a compliant design procedure is referred to as CDP (Compliant Design Process), which is the human-guided auditing procedure and an input component of the automated compliance audit framework introduced earlier in this paper. Formally documenting a manual process in the CDP effectively removes the error-prone human element in the process, and allows the process to be executed reliably by machines. A subset of the open standard Business Process Model and Notation (BPMN) (Object Management Group, 2011) specification has been used to model the CDP (Figure 3), which also supports data exchange in XML. A certain type of activity known as scriptTask in the CDP can embed computer instructions to perform calculations, extract information from specified sources, interact with the user, and make decisions.
Figure 3: BPMN-compliant executable CDP

The ScriptTask element supports computer instructions that are written in any scripting language that has the capabilities to query domain-specific data sources such as BIM or LKM. For example, domain-specific query languages such as BIMRL (BIM Rule Language) (Solihin et al., 2017) can be used to query and extract information from an IFC-based building model. Domain-specific query languages such as RQKL (Dimyadi et al., 2016b) has been suggested for querying normative information from a LKM as well performing general calculations.

3. Examples

Common architectural design problems include complying with normative requirements about access routes and accessibility, building heights in relation to legal boundaries, fire safety and means of escape provisions, and the design coordination with other disciplines. A couple of practical examples have been chosen to illustrate the automated compliant design approach described in this paper.

3.1. Door opening direction

Considerations on the door opening direction within a building is usually influenced by the desired occupant movement and flow during normal use, but also dictated by the flow of people towards final exits in the event of an emergency evacuation. The latter is based on the requirements of the building code and typically depends on the maximum number of people likely to use the door.

3.1.1. Input Parameters

The expected occupant load in a space is seldom specified in the building model, but the information can be derived from the type of activity intended for the space and the prescribed occupant load density associated with that activity given in the LKM.

For example, the New Zealand building code prescribes a list of occupant load densities (in persons per m²) for different space activities and occupancy types. For a space intended to be an office, the prescribed occupant load density is 10 m² per person. Depending on the LoD of the building model provided at the time, the space activity information may also be missing. In this case, the CDP would request the required information by way of a manual input before the process can proceed. Alternatively, this can be provided to the system by way of a supplementary input data source, such as a room schedule with additional properties.

3.1.2. Auditing Procedure

Knowing the occupant load in a space and the prescribed occupant load threshold, it is then possible to determine the compliant opening direction of the door. If the occupant load is below the threshold, then either direction is acceptable. The auditing procedure described above can be formally documented in a BPMN-compliant CDP process diagram (Figure 4) for machine execution.

The CDP would audit every space in the model. Each scriptTask has embedded instructions to access information or perform calculations (Figure 5). For example, the scriptTask “get floor area” has specific instructions on how to get the floor area of each space from the building model. Similarly, the scriptTask “get space activity” would attempt to obtain the type of activity for each space from the building model. Then, the scriptTask “get occupant density” would query the LKM and obtain the prescribed occupant
density associated with the space activity type. The instructions may include exceptions where information cannot be found from the specified sources and an alternative method of obtaining the required information, such as pausing the process and instigating a manual input from the user.

Figure 4: CDP to check if the opening direction of doors are compliant

```xml
<scriptTask id="PO_p1037">
  <incoming>PO_p1036</incoming>
  <outgoing>PO_p1043</outgoing>
  <script>SET OL = (floorArea/occupantDensity)</script>
</scriptTask>
```

Figure 5: Exemplar embedded script in a scriptTask (Dimyadi and Amor, 2017a)

The XML excerpt of the CDP shown in Figure 5 relates to the scriptTask “calc OL”, which is to calculate the occupant load (OL) given the floorArea and occupantDensity.

3.1.3. Compliance Audit Outcome

An outcome of the compliance audit process for this example could be a report in the form of a list of spaces that have non-compliant doors.

3.2. Check for certain design features in the building model

The approach can also be used to check if the building model complies with a design requirement specification. The process involves checking if certain design features, such as fire safety features, have been incorporated in the building model. For example, a fire separation dividing two spaces into separate fire compartments or “firecells” horizontally on a floor should have fire rating information incorporated into the wall object. Additionally, any door on that wall is expected to have the same fire rating. Any structural penetration on the wall is also expected to have a fire seal with the same fire rating as the wall. In this example, we assume that any floor between different levels has been checked to be fire-rated.

3.2.1. Input Parameters

In this case, walls to be checked for compliance (identified by their unique Ids) can be determined by searching for those in common with any two spaces designated as firecells. The IFC property set
**Pset_WallCommon** has a **FireRating** property that can be checked for compliance. Additionally, any door on each wall can also be identified and checked for compliance by looking at the **FireRating** and **SelfClosing** properties of the door’s **Pset_DoorCommon** property set. Similarly, any service penetration through the wall can be identified using **IfcOpeningElement** and checked for the **ProtectedElement** property of the **Pset_OpeningElementCommon** property set. The design requirement specification is represented in LKM in the form of a schedule of rooms that have been designated as firecells. The required fire rating can be specified in an LKM or it can be calculated by the CDP based on the activity type of the rooms, which can be queried from another LKM representing the relevant building code document. For this example, it is assumed that the fire rating is specified by the user.

### 3.2.2. Auditing Procedure

The CDP is instructed to read the specified schedule of rooms from the LKM, identify common walls between those rooms, and to check the properties of each wall and doors to see if the fire rating information has been specified in the building model. Additionally, the **SelfClosing** property of fire-rated doors must also be set to TRUE, which is also a legal norm that can be established by the CDP if necessary. The level of human-guidance in a CDP determines how specific or generic the procedure is for future reuse in different projects.

### 3.2.3. Compliance Audit Outcome

Similarly, an exemplar outcome could be in the form of a report highlighting a list of walls, doors, and wall penetrations in the model that do not comply with the design specification.

### 4. Summary and Conclusion

A practical human-guided method of auditing an architectural design represented by BIM for compliance with a set of normative standards represented by LKM has been described above. The method maintains the conventional procedures that designers use, but formally documenting them in an open standard CDP process model for machine processing. The method advocates the use of open standard legal knowledge interchange standards, particularly the emerging LegalDocML and LegalRuleML, to represent normative information against which design information can be audited.

Like the conventional process, each design discipline can be audited separately. This would require obtaining a model view (MVD) or a subset of the building model to audit with. Sharing building information digitally is now possible with BIM, but there is still a considerable amount of work required to encode building regulations, normative standards, and other requirement specifications into machine-readable LKM, before they can be used by the automated process. Ultimately, each legal document or requirement specification should be represented in LKM and published in parallel with the paper-based documents including every amendment. Having each legal document represented as LKM independently of the compliance audit system ensures that it can be maintained and released officially by the same government agency that publishes the paper-based documents. This would also ensure that the user of the automated compliance audit system is using a LKM representing the latest version of the document.

The ability to check routine items automatically would enable the design reviewer to focus more on high level compliance that requires human intervention. The approach described in this paper is certainly applicable as part of the design process and intended to help achieving a compliant design at an earlier
stage so as to minimise any redesign effort resulting from the discovery of non-compliance issues at the consenting stage.

References


Information Visualization for Multivariate Schematic Design

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Abstract: While BIM modelling continues to become the most pervasive software in the AEC industry, we must address the fact that it remains little more than method for collecting direct inputs about the creation of building elements. As a profession, we ought to strive to integrate how we evaluate our building designs in meaningful ways early on the design process (when it can most readily affect our decision making). This paper will describe a series of visualization methods developed as part of tools designed to work with Autodesk Revit and Dynamo to integrate analytical information into the schematic design process. Each tool tested a myriad of methods for mapping and delivering information often including, two-dimensional heat mapping, three-dimensional(voxel) mapping, and other methods for mapping data sets with even more dimensions, often as a user navigates into a model, data increases its density (just-in-time). More dimensions of data types can be mapped by using clustering algorithms to constrain and find zones where relationships between different data types are located to better understand the underlying relationships.

Keywords: BIM; design software; visualization; design process.

1. Introduction

As Building Information Modelling (BIM), continues to grow in its usage and adoption, usability and tooling are still largely aimed at the creation of two-dimensional drawing sets. The application of multivariate data integration through BIM improves building design performance when compared with typical design strategies (Wang et al. 2005). As the integration of simulation tools provide access to, and afford the use of large complex, overlapping, and often contradictory data sets, which will inevitably continue to create usability and accessibility problems. BIM works adeptly at defining what is to be constructed from the model but is incapable of identifying why it is to be built. Through this, BIM only maintains the status quo of how we are to design with computation, and does nothing to propel us forward as a profession which feels the constant pressure to become wholly computational.

This work is the result of a research collaboration between Autodesk and the School of Architecture at UNC Charlotte. The problem statement for the series of three studios was focused on supporting integrated design operability by creating tools focused on multivariate conceptual design. The collaboration between the academy and software professionals allowed access to a suite of design simulation tools (both those currently available and those currently in development). This suite of tools was integrated with current research about how to better integrate visual cues about the impacts of
design decisions on the performance of the building. The tools which were designed were based upon past design methodologies which the students had explored. They in turn attempted to create a method for first automating analysis and then visualizing the important information derived from that analysis. The students subsequently integrated methods for looping the evaluation so that various design iterations could quickly be compared and evaluated against one another as they pertain to their particular design criteria. The product of these tools allowed for advanced comparative analysis of various simulations which allowed the designer to parametrically develop a project capable of performing at a higher level across all of the identified performance criteria equally. The final goal was to hone methods for visualizing multiple types of information and embedding their evaluation into the design model for future reference as the project develops. Thus, collapsing the distance between analysis and design, creating the ability to immediately understand the impacts of design decisions as they are made. This paper will outline a series of proposals developed to imagine methods for integrating multivariate information (typically visual) into schematic design decision-making and modeling.

2. Background

Autodesk’s CTO Jeff Kowalski described in his keynote from Autodesk University in 2015 this ‘directive relationship’ with our tools, noting that “the tools are passive and they do exactly what we tell them to do, nothing more”. AEC industry software is generally designed to meet the historic expectations of development defined through step by step contractual markers. This staged set of completion markers define the character of the work to be completed by each participant and notes when payments are made based upon the completion of a stage (schematic design, design development and construction documents). This method makes for an easily understandable set of metrics, but it does not afford for, or even acknowledge that design is an iterative process. The best products of which, are often developed analyzed and redeveloped over and over, balancing inputs from an owner, project consultants, engineers and contractors.

Further hindering a more integrated method of design optineering is the assumption that this method is a manual activity costing hours (and therefore dollars), without a clear end goal, only endless refinement. This process is also typically not easily repeatable across multiple projects further exacerbating the inefficiency. The continuous and rapid growth in software and computing power creates another layer of inefficiency as even when a consistent technological method is developed by a firm, it is often quickly outmoded, needing redevelopment and often rethinking to keep pace with technological advances.

However, the manual activity of iterative development is inefficeint primarily because of human’s inability to adroitly move between tasks. As cognitive psychologists have proven, true multitasking is not humanly possible (Meyer, 1997a). What is perceived as multitasking is in reality, quickly switching between tasks. Alternatively, computers are built to understand and visualize multiple streams of information at once, and given the appropriate context, to map the relationships between them. As the design profession continues to ‘become computational’ it’s essential to develop methods for relying on computing power when appropriate to help navigate these complex relationships.

Exacerbating the ability to visualize complex layers of information, proprietary file formats and contrasting data taxologies limit the ability for interfacing between software. New file formats are often developed simply to attempt to alleviate these issues. In the 1970s the U.S. Air Force developed the IGES format which was intended to create a uniform format for use on CNC machinery. This tool however was never successfully adopted for a variety of reasons, including a huge variety of processor types, and
software modeling methods (meshes, Nurbs, etc...). Contemporarily the .CSV (Comma Separated Values) has by default become one of the most useful formats as it is most simply organized and can be read by most any software or integrated using simple scripts or plug-ins. This file format by default has become the only way to move between the huge variety of data types created, by BIM models, Complex Fluid Dynamics (CFD), Finite Element Analysis (FEA), Radiance, or any of a myriad of other simulation types.

3. Looking Forward...

Augmented design tools placed on top of existing software will also further enhance our ability to visualize and intuitively integrate analysis as we work to develop a design. Jeff Kowalski in his 2015 keynote went on to note that we are heading towards the ‘Augmented Age’, where Digital systems will cognitively augment our design decisions. Kowalski describes software which is able to become a ‘partner in design’ evaluating the performance and effectiveness of design as an architect works through its development. He notes that even the “most sophisticated design tools won’t be able to work without our help”, and that the integration of humans and computers is crucial to this development. He closes by noting that “We used to have to learn a new design tool- now the tool will learn us”. To that end, the methods which we use to visualize our design and the subsequent layers of information will be essential components to this shift in our working methods.

The integration of cloud computing affords the designer much more immediate methods of running complex evaluations and storing that information in an accessible way, available to multiple software packages on multiple devices. Scalable cloud computing will (hopefully) result in building analysis tools which allow a designer to constantly monitor any number of simulations in real time as the building unfolds, simply becoming an information resource and not a verification tool once design is complete. As a profession we have already moved toward integrated collaboration, which is supported by cloud and server based services. This same efficiency should eventually allow for automated evaluation tools, operating as collaborators alongside the design team.

Examples of other work looking to expand the ability to represent this knowledge which is meaningful to either their design partners, consultants or clients include; Core Studio at Thornton Tomasetti (Figure 1), the Human UI by NBBJ’s Digital Practice which creates clean visualizations of information over a model and integrates with Rhinoceros and Grasshopper interfaces. Autodesk is also developing Fractal, a cloud based product for Autodesk Dynamo, which built upon Akaba, a three- dimensional tool for exploring program organization parametrically, and allows for integrated generative design and visualization.
Design Explorer

Figure 1: Thorton Tomasetti Core Studio's Design Explorer, which offers multiple methods for evaluating a design analysis, in both graph and individual mapping layers.

4. Examples

The proposals outlined here are the product of a series of plug-in tools intended to take a variety of kinds of information and map them into the Autodesk Revit environment to assist a designer in their early decision making process. Each of the tools tested, analyzed a range of data typologies both qualitative and quantitative. When linked together, the resulting information was often very difficult to manage and visualize. Typically, the points which are applied to each data point are not in the same spatial location, and the data types require a method for measuring their impact on the building, whether through performance or cost, or another variable. To respond to these misalignments, we have developed a Python based component called ‘Closest Points in Points’ which when deployed on multiple datasets derives the best fitting point location and relative data point to align with any other set of points and their relative dataset. The examples and their iterative development which follow are intended to explore these visualization methods based upon their functionality, and ability to quickly respond to a designer. Each tool was tested as part of its development and implemented through the development of a design project to exemplify the impacts of the tool on the design process.

Each tool tested a myriad of methods for mapping and delivering information often including, two-dimensional heat mapping, three-dimensional (voxel) heat-mapping, often as a user zooms into a model data increases its density (just-in-time). More dimensions of data types can be mapped by using clustering algorithms to constrain and find zones where relationships between different data types are located to better understand the underlying relationships. The simplest method of evaluating the given conditions of a project is to map the information through color onto a mass or floor. The pixel size for each of these evaluations is often limited by computing power, and while they are often simplified in these examples, we presume that in short order these can become far more specific in their definition, through parallel processing and cloud computing.

Using the views which are available from a given location on a floor plate out into the city is a simple method for taking a geometric evaluation and mapping it to monetary value. In this way a leasing agent can more precisely evaluate and sell a given piece of a floor plate based not necessarily only on height but
by having a more precise understanding of the actual views. The user can define the level of precision and respective ‘values’ of each view. (Figure 2) Further the geometry of the massing study can respond to these values optimizing for the ideal conditions.

Figure 2: View Value Tool, Using ‘Closets Point to Points’ Tool to map unique data locations to one another on a floor plate.

Terrapin Bright Green defined a logic for evaluating the characteristics of Biophilia on a given site. While the 14 characteristics (i.e. views, wind, sunlight, attractors and detractors) they define are relatively simple to evaluate individually, they create a highly complex and often contradictory map when added together into a complete evaluation of the site. This set of criteria provided the basis for a test set of visualization methods. The results can use typical mapping methodologies but also give the designer the ability to compare, contrast, and evaluate the various relationships between each characteristic. The final iteration of this tool included an exploded set of layered information (Figure 3) which allowed the designer to see each individual layer and then collapse them down to see the complete evaluation based on their user defined criteria.
Figure 3: Multivariate data types mapped over a site condition.
Figure 4: Example design scheme developed using Biophilic mapping tool.

To be able to iterate through a design process and map both the impacts but also retain the intent behind a design, the visualization tools we use need to infer a logic based on the users goals. This next visualization demonstrates a simple variation of this. The tool intended to map solar radiance to define the ideal location for an atrium space through a given massing. The tool recursively takes the amount of square footage a designer allocated for an atrium and finds the ideal location for the cut through the mass. First solar incidence is mapped to the roof of the building and a percentage of the square footage is allocated based on the number of floors the atrium should reach, then each subsequent floor is continually evaluated to create an optimized design based on user inputs (Figure 5).

Figure 5: Recursive heat mapping of solar radiation incidence, to create an atrium space.

A more complex understanding of a given site can be accomplished by using a three-dimensional pixel or voxel, which have long been employed by designers. While more intensive in their required computing
power, they once again can become more organic in nature through advances in technology. The articulation of solar irradiance onto a site as though it were a code and zoning evaluation tool (like that of Google Flux) creates a scenario where information which is essential to early massing studies can be used at early stages of the design process, when it is most valuable, not after the fact. The ability to map the ideal conditions based on the climatic zone of the site, and the existing neighboring building forms, can provide a far more precise mapping of passive solar strategies through a site. This tool can be used literally ‘top-down’ to again recursively map the impacts of design decisions. The user can use the tool to place a roof geometry at its given height on the site and the tool will calculate the impacts of that surface on floors below and create each subsequent optimized floor shape (Figure 6).

As we continue to layer more and more information onto a project, there are inevitable limits to our ability to see and process all of the relevant information. Other computing methods exist which allow for logically inferred visualizations of reduced dimensions of data. Using Density-Based Spatial Clustering of Applications with Noise (DBSCAN) clusters within large dimensions of data can help to better visualize this information in a simple three-dimensional space. Figure 7 demonstrates the use of DBSCAN to show twenty-five dimensions of data created by a user who was testing a neural network based generative tool. The neural network is simply a series of tests to see which solutions trigger similar or unique solutions using a particular tool. By using these triggers to map the decision tree of a user we can start to develop better strategies for delivering this information to designers, at the moment when it is most useful. Presumably this kind of method could be used to infer not individual layers of analysis over a design but instead to optimize the pertinent information which represents multiple dimensions of data at once. Given the impossible number of options for how a given design can be evaluated this method will become inevitably more valuable and necessary.
Figure 6: Voxel based mapping of solar radiation values on a site, mapped to its climatic zone.

6. Future Work

Based on a series of user studies we hope to learn and develop better strategies for deploying large multivariate datasets to improve user experience and performance. Vast improvements in speed and scale of parallel computing have created a realistic scenario where design software can help a designer to
navigate the vast amount of relative information so the human user can better focus on the tasks that
they are more capable of completing.

Figure 7: DBSCAN clustering of 25 dimensions of data.

While designers (and most first world citizens) feel increasing capable of managing multiple tasks and
compiling incredible amounts of information into their work, we know that as humans are not naturally
adept at speedily shifting between tasks. There are many different scientific evaluations of human’s
capabilities almost all of which uniformly agree that we are not effective at managing this much
information at once. Nevertheless, we also know that the amount of information a designer or a design
team must incorporate is constantly growing. We must embrace our cognitive limitations, and recognize
what we are good at and work to develop tools which allow us to work effectively alongside automated
computational tools which allow us to quickly interpolate the impacts of our decisions and iterate on top
of them.

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Towards the Development of Pre-Occupancy Evaluation Framework in New Zealand

A Literature Review on Limitations to Green Building Rating Systems

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Abstract: Green rated buildings have come to attract people’s attention, although there is a diffused scepticism on whether their performance will comply with design expectations throughout the building’s life. This paper provides a literature review on limitations of the rating system. According to previous studies, barriers to facilitate certification schemes are still present in many countries. Some of the main reasons are related to i) high costs, ii) insufficient knowledge about certification, and iii) time-consuming procedures. Inexperienced clients have difficulties in understanding the assessment process, as third-party organizations do not have a suitable system to show guidelines and approaches for a client, such as Pre-Occupancy Evaluation. To date, researchers have conducted some studies on Post-Occupancy Evaluation in order to show the effectiveness of certified buildings. However, no attention has been paid to Pre-Occupancy Evaluation by the rating tool based on a customer’s self-assessment which enables clients to estimate costs, a rating level (or total point) and implementation time in advance, selecting suitable options in the building information and requirements of each credit. This paper shows that identifying existing obstacles is essential to further develop and improve rating systems so as to be more acceptable in New Zealand. This preliminary investigation will also inform future studies on the development of the Pre-Occupancy Evaluation framework for New Zealand.

Keywords: Green Building Rating Systems; certification process; barriers; pre-occupancy evaluation; Green Star NZ.

1. Introduction

A global trend of implementing a green buildings rating system and of certifying as a green rated building is widely prevalent and their significant development has a positive impact on the environment, the building performance, operating cost savings and occupants’ health and well-being. However, while green building rating tools have succeeded considerably in encouraging the building industry and stakeholders to adopt and accept green buildings, there still remain major barriers to green building certification schemes in terms of cost, knowledge and time issues in general, which could hinder the potential interest
and growing demand for green building certification. As shown in Figure 1, the main reasons for not pursuing green building certifications were considered to be the cost (51%), the lack of information on certification requirements (38%), the difficulty of the certification process (35%) and the time of the certification process (33%), based on Green Building Market Report which is a questionnaire about respondent’s experience and opinion (e.g. developers, architects, engineers) throughout South East Asia (Krups et al., 2014).

![Figure 1: The main barriers to achieve green building certification](image)

This paper presents a literature review of challenges raised by the use of green building rating systems in many parts of the countries and then understands the green building marketplace and the use of rating tools in New Zealand. The objectives of this paper are to:

- Conduct a literature review on barriers to the use of green building rating tools in the world.
- Identify the comprehensive understanding of existing rating tools available in New Zealand and the main challenge faced by Green Star NZ.
- Discuss the recommendation of a new framework for Pre-Occupancy Evaluation which all users can experience and recognize subjectively.

### 2. Barriers to the Promotion of Green Building Rating Systems

Barriers that impact green building certification have already been identified in the literature and were reported most recently. There are still recurring problems with those people lacking interest and experience in the green certified project and the rating tool. They are usually faced by barriers such as high costs and lack of information for clients about advantages associated with adopting green building technologies. This may be the cause behind people’s indifference and unreliability toward the benefit of green rated buildings.

A number of researchers point out that the reason why people are still yet to be convinced is caused by the public hesitation and unwillingness to accept green building standards. They have not decided to make a plan for the development of the green project yet (Hashim et al., 2016). In addition, Perrett (2011) suggests that green buildings have lost their appeal, reporting that unenthusiastic people refer to the idea as a contemporary trend. Moreover, Byrd and Leardini (2011) identified that it is questionable whether the use of rating tools is designed to act as a strategy for a more sustainable environment, rather than being used as an instrument for enhanced brand advertising.
Darko and Chan (2016) found that the major reasons for avoiding green building certification were higher upfront cost, lack of knowledge, lack of incentives from governments, lack of interest and demand from clients and lack of green building policies and regulations. Samari et al. (2013) also stated that the most significant barriers were associated with the vague cost assumption such as the lack of initial asset, the low capital investment, lack of interest from the people and low demand as well as higher expenditures for completion. Ahn et al. (2013) discussed the main barriers involved in green building assessment being the high cost estimates at the first stage, long time for pay back, a conservative trend toward keeping conventional standards, subcontractor’s ignorance and techniques.

2.1. Perceptions of Cost Impacts on Green Building Projects

A cost is connected directly with different factors such as shortage of funds and incentive programmes from the Government as well as the use of labour to implement green building projects. When conducting green building projects for the first time, cost is the most important factor that needs to be concerned with to start the green building certification for all contractors, clients and architects. This is because if an upfront capital commitment to the first design stage are required, most clients are reluctant to use costly rating tools that are usually generated by a quote for a registration fee, a third-party assessment and other additional optional choices, which make it more difficult to adopt the schemes voluntarily. Consequently, the initiative and execution of current green building rating tools will be expected to make slow progress in the future.

Firstly, the most widely reported of these obstacles was known as an additional finance in the first investment of adopting green-design projects (Hargreaves, 2005). For example, Geng et al. (2012) argue that progressing toward green building practices that require consideration of the additional costs involve new technologies applicable to renewable energy sources, such as solar and geothermal heat, initial expense of establishments to satisfy specification, and the employment of skilled workers in comparison to constructing common buildings. Since many studies showing the financial advantage of green buildings have not been done yet in New Zealand, the leading challenge is the lack of markets showing enthusiasm for the additional cost involved in building green (Perrett, 2011).

Moreover, similar studies discuss that one reason for not ‘going green’ is that it is comparatively more expensive for green buildings to be built and operated than traditional buildings (Bond, 2010), and the public is still yet to be convinced because of unclear estimates and insufficient data on upfront costs (Ang & Wilkinson, 2008). Additionally, despite a number of studies on the benefits of green rated buildings, Ade (2011) stated that the perception of green rated buildings being costly is regarded as one of the main impediments to building sustainable growth. Kubba (2017) mentioned that the capital expenditure of choosing the Green Globes® rating system required a separately-billed consultant fee, an annual usage fee for the online tool, a third-party’s assessment fee and their travel expenses as well as depending upon project size (hectares/ acres) and location. Another big hindrance is the high capital investment in applying a new technological requirement for design and construction method (Bandy et al., 2007), which means the higher quality level of the green building certification would give rise to the cost increase.

Secondly, incentives also play a relevant role as a key driver in pursuing green building certification. Hashim et al. (2016) noted that financial Incentives directly connected to the flow of funds act as a tool of interest that draws the attention of most developers. Many governments in different countries have demonstrated a strong commitment to the public for activating green building rating systems through a variety of incentive programmes such as low-certification fees, tax credits, subsidies and low-interest rates (Olubunmi et al., 2016).
On the other hand, Geng et al. (2012) reported that the application of eco-friendly and innovative technologies for implementing green building schemes is not an easy option for developers due to lack of incentives. Developers would prefer to choose simpler, cheaper, more energy and water efficient methods over complicated and costly ones despite the benefits included by achieving a higher rating score using green techniques. Pottelsberghe et al. (2003) identified that government incentives that are currently available do not draw key players’ attention to promote and develop green projects. Lastly, Bond (2010) refers to a controversial issue of split incentives between property owners and tenants about the beneficial factors gained from investing in green buildings.

2.2. Insufficient Knowledge about Certification Process

Knowledge can be interpreted in many ways such as understanding, familiarity and awareness, gained through information, skills, education or experience. Therefore, barriers to adopting green building certification are closely related to lack of knowledge on green building rating system. Darko and Chan (2016) argue that the absence of definite proof about credible green building research and lack of education may cause insufficient information, which is an impediment to approaching public awareness and expertise or knowledge on green building. For example, the reason why it is difficult to persuade the public who have not enough knowledge to acquire green building information is because of a ‘pay per view’ system that charges an expense related to registration fees and consulting fees (Perrett, 2011).

Samari et al. (2013) claimed a low public awareness, limited knowledge of the benefits of green building technologies and construction professionals as one of the barriers to adopting green building rating systems. Perrett (2011) asserted that insufficient education and training programmes, reduced public awareness and inadequate comprehension of green building certification can be another barrier affecting the property industry. Bond (2010) remarked on the shortage of well-trained technical professionals for building high performance buildings and that “there appears to be somewhat limited knowledge amongst the respondents of the financial performance or benefits of incorporating these design features, technologies and building materials” (Bond, 2010, p.38). In most cases, consultants are required to provide more detailed explanations regarding requirements of each criterion for their clients to ensure comprehension.

2.3. Difficulty Estimating Amount of Time

Effective time management and time estimation of a project is one of the most essential aspects. However, all clients and stakeholders need to have patience considering the amount of time required for all the details in question to be rectified: the assessment process, estimated payback period and meeting the criteria needed for the certification process to be completed before deadline. In previous literature, protracted and extended periods of project time made it difficult to fit in green building rating schemes (Ang & Wilkinson, 2008). According to the Green Building Market Report (Krups et al., 2014), owners, contractors and professional services are concerned about the additional time needed for training on green building processes and researching suitable materials. Projects often take a long time because of the submission form of the traditional assessment programme, collecting and managing the documents and passing through the documentation, which has been a barrier to the uptake of rating tools. Another barrier is that clients with a focus on making money fast from real estate are not as likely to be interested in green building options. (Perrett, 2011).

Furthermore, most people are more interested in the immediate response from the building cost than the life time building cost. Olubunmi et al. (2016, p.5) identified that “most private clients need a payback
period of between seven and twenty years and it is difficult to convince them to inject the extra investment involved while the potential of the resulting green building premium to offset its high initial cost at all is still being debated, and remains inconclusive”. This means that those barriers hinder key decision makers drawing attention to green building certification because all clients want to know how much time their project will take and often judge whether the project has succeeded or failed only depending on whether it has been delivered on time and on budget.

3. Limitations to Using Building Rating Tools in New Zealand

3.1. Current Assessment Tools Available in New Zealand

A wide variety of assessment tools for ‘building green’ have been established in New Zealand. For instance, LEED™, NABERSNZ™, Living Building Challenge™, Green Star NZ™, and Homestar® have been currently in operation with different purposes and methods for the built environment. They are affected by factors such as which type of building is involved, which target markets, concerns for environmental impacts as well as whether the evaluation takes place at the design stage or is based on the past (Hargreaves, 2005). Therefore, there is no doubt that an understanding of both pros and cons of various rating tools will continue to be useful to future research, as it is necessary to recognise challenges and opportunities in each green building assessment tool so that appropriate strategies will be developed to leap over the barriers. Table 1 summarises the main features of green building assessment tools available for the New Zealand construction market.

<table>
<thead>
<tr>
<th>Name</th>
<th>LEED™</th>
<th>NABERSNZ™</th>
<th>LBC℠</th>
<th>Green Star NZ™</th>
<th>Homestar®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acronym</td>
<td>Leadership in Energy and Environmental Design</td>
<td>National Australian Built Environment Rating System</td>
<td>Living Building Challenge</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Organization</td>
<td>USGBC</td>
<td>NZGBC</td>
<td>Living Future Institute</td>
<td>NZGBC</td>
<td>NZGBC</td>
</tr>
<tr>
<td>Launch date</td>
<td>1998</td>
<td>1999</td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
</tr>
<tr>
<td>Type of buildings targeted</td>
<td>All Buildings (New, Existing)</td>
<td>Energy performance for office building (Base buildings, Tenancies or Whole buildings)</td>
<td>Building, Renovation, Infrastructure, Landscape, Neighborhoods, Communities</td>
<td>Commercial building (Office, Education, Industrial buildings, Interior fit-outs, Custom)</td>
<td>Residential (stand-alone homes, multi-unit dwellings)</td>
</tr>
<tr>
<td>Rating Option</td>
<td>A web-based online</td>
<td>A free online self-assessment, Independent certified rating</td>
<td>Documentation for submission</td>
<td>A free online self-assessment</td>
<td>Documents or visits completed projects</td>
</tr>
</tbody>
</table>
### 3.2. Incurring Three Limitation for Implementation Of Green Star NZ

This paper looks especially at Green Star NZ™, which is one of the most widely used in New Zealand and currently activated showing the highest number of certified buildings. According to a New Zealand Green Building Council report (NZGBC, 2014), the demand for Green StarNZ™ rated buildings increased gradually since the tool was introduced to the market. However, although the number of certified projects show the highest growth in 2009, its trend seems to deteriorate and is still comparatively low after 10 years, with more than 100 certifications across New Zealand (Figure 2). Therefore, it is anticipated that this growth is less likely to increase easily in these circumstances and the current scheme in the delivery of the green rated buildings is not viewed as a great success in New Zealand.

<table>
<thead>
<tr>
<th>Assessor</th>
<th>GBCI, Third-party</th>
<th>Self-initiated, Accredited</th>
<th>Third-party</th>
<th>Credited person</th>
<th>Third party</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating on a scale</td>
<td>40-49 (Certified)</td>
<td>0-6 (Living building, Petal, Zero Energy)</td>
<td>0-10</td>
<td>6-10 (Typical home: 3-4)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2: The number of Green StarNZ™ certified projects in New Zealand between 2007 and 2017.
As mentioned in Section 2, the most significant issues arising from three barriers regarding cost, knowledge and time often exist within the assessment process of Green Star NZ™ that is posted on the NZGBC website (Figure 3).

![Figure 3: Barriers related to the assessment process of Green Star NZ™.](image)

First of all, in order to officially conduct the Green Star NZ rating tool will incur additional costs associated with a registration fee, which can be changed depending on the size of the project. Also, clients who pay NZGBC membership dues can obtain their qualification for membership at a discounted price from the original registration fee. In addition, other fees can be charged in some situations, such as additional reviews and appeals before NZGBC final approval, and even additional project enquiries and additional credit interpretation requests.

Secondly, without employing consulting services, new clients may be in trouble in approaching the assessment process by themselves and feel difficulty understanding at first sight how every part of the credits is processed and approved holistically, resulting in repeated explaining of the details about the requirements of every criteria, unless they are trained to take the education or the course of the green star.

The third problem is caused by the fact that unskilled clients cannot imagine how long their own projects will need to the time normally required to collect the required information and input the data. Based on the notification on NZGBC website, there is no specification about when certification should be achieved, but it informs that the design rating stage is generally achieved prior to construction, and the built rating stage is conducted after practical completion. Hence the entire assessment process would take roughly 14 to 18 weeks per building. To develop the most effective mechanisms and solve these barriers, this research focuses on developing a new framework to support Green Star NZ™ across the certification process in order to make it more acceptable from the client’s perspective.

4. Consideration of a Conceptual Framework for Pre-Occupancy Evaluation

Researchers have already found that Post-Occupancy Evaluation (POE) is one of the main research methods focusing on evaluating building performance, investigating on the degree of client satisfaction and maintaining a building’s investment (Preiser, 1995; Zimmerman & Martin, 2001). However, most clients may still have to worry about how their own buildings perform when adopting the rating tool. This
is because “POE can be performed after a specific time when the building is available for residents. The long-term analysis is hardly available” (Kim et al., 2015). Although much work has been put into researching eventual barrier to using the rating tool, there is very little research about Pre-Occupancy Evaluation that provides clients with an effective method to show easy, trustworthy and predictable approaches in advance of a decision regarding implementation of the rating tool.

For example, there are two types of clients, the potential and the non-potential client. They both have one thing in common: inexperience. What they do not share is the interest. Although they can both still be convinced towards implementing the rating tool, taking the first steps towards a green project can prove to be complicated. Thus, “it would be good to have a checklist of ‘easy first steps’ to encourage companies to embark upon the sustainability journey” (Perrett, 2011, p.48). On the other hand, there are potential clients who have little experience or knowledge in the education of rating tools. To encourage those clients to engage in the rating system, the interface also allows PrOE against these requirements, and the result of each client response is recorded and stored in a database as attributes throughout the design process. Furthermore, there are plans under contemplation to set up user performance criteria that have trustworthy and inclusive strategies for buildings in New Zealand (Baird, 2009), so the limited experience of clients would be decreased through the efficiency of this framework process. Therefore, this study sought to contribute to the development of a Pre-Occupancy Evaluation (PrOE) framework to evaluate and predict cost estimation, time period of rating process and final rating level (or total point) by inputting clients’ building information based on the requirement of green building rating tool prior to the beginning of certification.

Firstly, this framework will help the client to identify actual costs required in the process of assessment such as certification fee and third-party assessment, preventing the additional cost regarding the consultant service, a high registration fee and other unexpected options. Myers et al. (2008) asserted that if the financial evidence for an investment in green buildings is proven, the applications for green buildings would be promoted faster and higher in green growth. The interaction between cost-estimation tools and project management tools would make it easier to identify how this PrOE framework is implemented by the track of time flow and where any cost barriers to green building certification have happened.

Next, it is based on an online self-assessment for all clients and stakeholders which enables them to develop basic knowledge and increase their awareness by implementing the rating tool more completely by awarding a final rating when selecting the suitable answer based on client’s basic project information and requirements of each credit. For instance, the Green Globe® self-assessment process can be read as a successful precedent for the development of a PrOE framework to support Green Star NZTM. Kubba (2017) mentioned that in Canada and the US, the Green Globes® rating system is used as a self-assessment, online-based evaluation system. This is useful to avoid extra costs for a third-party assessment and certification fee, to help clients to identify the score awarded based on the answers to the online questionnaire and clients’ basic project information as well as to offer suggestions and comments for raising the client’s credit score after completing the questionnaire.

Finally, it shows the estimated time required for the rating process to complete the final certification in advance without uncertain assumptions and long waiting times and also illustrates step-by-step procedures during the rating process. According to Shen et al. (2013), the design of an optional choice interface is being used as an evaluation tool for clients to review the design, help develop further requirements and to remind them of what is already established. Zwart and Voordt (2015) found that it is essential to measure the building performance at a comparatively early (during design) stage because an alteration in buildings that are built and occupied is likely to be a complicated work and costly in the
future. This study will explore the possibilities of measuring the assessment results for client satisfaction before the design rating phase by applying analytical methods.

5. Conclusion and Future Work

Starting from a literature review about the barriers regarding implementation of rating tools, this paper found that changes in the public perception of the green building rating system are necessary because the existing obstacles have been a recurring problem for rating tools in New Zealand, particularly Green Star NZ. In order to have great success in sustainability and promote green rated buildings in New Zealand, one of the expected contributions of this study is the development of Pre-Occupancy Evaluation framework that provide all customers with the necessary outcomes in a straightforward, reliable and predictable way, in an attempt to help them in rating tools to identify a comprehensive assessment procedure for their proposed buildings based on the project information and requirements of each credit of rating tool.

One of the major barriers is that most clients often have the initial perception that pursuing the green building certification costs more than constructing a non-green building, which makes it more difficult to carry out the execution of rating tools. To overcome this issue, this PrOE will help the client to predict real expense required such as certification fees and third-party assessments to prevent the additional or unexpected costs occurred in the process of assessment. Moreover, this conceptual framework is to give the first-hand experience to all clients and stakeholders to support decision-making, as well as enhancing and developing basic knowledge and increasing their awareness to implement the evaluation process more completely. Lastly, the assessment process of rating tools is generally known as a ‘lengthy and complex system’, contributing to unenthusiastic reactions concerning green building projects. The proposed PrOE framework provides the clients with an estimated time needed to identify how long it will take for their green project to process the each credit requirement of green rating tools, to collect the required documentation and input data from the very beginning of rating to final approval.

Therefore, given the recent tendency of decreasing the number of green rated buildings in New Zealand, the proposed PrOE framework can be recommended as an effective method to overcome existing barriers and to process Green Star NZ successfully. Consequently, this preliminary investigation will be functional to future studies for developing a Pre-Occupancy Evaluation framework, and thus the development of PrOE would be actively dealing with the international convention on Environment such as climate change in the next 50 years.

References


Thick and Thin

The Future for Walls as Solid Masses or Delicate Layers

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Abstract: While houses built from engineered timber products such as cross-laminated timber are an excellent structural construction solution, the mass house construction market in New Zealand still sticks with more traditional construction methods centred on individual sticks of timber. These traditional methods are however still reliant on timber sizes that are relatively weighty and volumetrically large, in relation to more advanced cladding systems such as cars or planes, where thin skins of cladding are carefully wrapped over a lightweight but structurally rigorous framework. This paper examines current and future walls, including possible structural solutions such as the stressed skin matrix and monocoque construction methods that are widely used in vehicles. Comparisons are made with other technologies where recent advances in large-scale 3D printing have created entire houses fabricated from liquidised amorphous substances. Can they be reliably considered as practical building systems for the future? Recent advances in 3D printing are multiplying, including the ability to sinter solids directly from sand, being explored as a possible future for building “off-shore” constructions. The paper draws upon advances being worked in freeform 3D printing and real-life building projects as well as examining the future of student-led research into digitally-led building construction systems.

Keywords: 3D-printing; structure; stressed-skin; wall.

1. Introduction

In any wall thickness, various different requirements are required to be met, including structural support for the roof, seismic resistance to lateral loads, thermal resistance and sufficient insulation, internal finishing, vapour barrier, provision of a zone for services including electrical wiring and plumbing pipes, and last but not least: complete external moisture resistance and control. Increasing or decreasing wall thicknesses will have effects on all those requirements. Making a wall fatter can give more room for structure, greater thermal resistance and increased insulation, etc., but this opportunity can also incur extra build costs and use up precious floor space in smaller buildings. Creating a thinner wall brings all these functions closer together and risks conflating the issues and creating new problems of its own. New Zealand is lucky to sit in a moderate climate zone, with temperatures across most of the country for most of the year sitting comfortably between 5° and 25° Celsius: no Nordic winters of -20° nor Arizona summers...
of +50°. As an example, the capital Wellington has a mean daytime working temperature of 13.7°, with steady winds up to 13m/s, 14MJ/m² of annual sunshine and an average of 1226mm of rain annually. The climate in Wellington is exceptionally moderate, except for the wind. A wall system in New Zealand therefore has to meet only moderate demands in terms of insulation, but also has to be able to resist wind forces that in other areas of the world may be considered excessive.

While humankind’s early building systems of thick and heavy masonry and adobe / brick walls are still in active use in numerous countries around the world, many developed nations have moved on from mass building materials to more complex and more lightweight systems of framed construction, using systems of graded timber framing or light gauge steel framing. This in itself is nothing new. F.R.S. Yorke noted way back in 1939 that a search for new cladding materials was underway:

“Technicians are experimenting with new and more suitable materials, and technical problems still remain to be overcome. It is certain that the ideal material, combining properties of weather resistance, lightness, smoothness of surface, good colour, insulation, ease of fixing and economy has yet to be found” (Yorke, 1939, p93).

Yorke’s search for the best cladding material still goes on today. This paper does not examine traditional construction systems such as brick or stone masonry, commonly used in Europe and the United Kingdom. While traditional masonry houses are thermally massive, they are also slow and messy to construct, with walls that are physically thick, dimensionally variable, crudely built and in earthquakes they can be subject to catastrophic collapse. There is little functional incentive to consider changing towards this sort of construction system in a seismically active country such as New Zealand.

The paper also sets aside thermally inefficient houses such as those proposed in the peak of the Modernist era, where (predominantly commercial) building systems primarily utilised materials such as glass and steel for wall construction. This is exemplified by the Farnsworth House (architect: Mies van der Rohe, 1951), where the walls are only one sheet of glass thick (approx. 12mm) with little thermal resilience, requiring a massive input of energy to heat and cool, as well as requiring an entirely separate structural solution (in this case Farnsworth’s iconic steel columns). The Farnsworth House is therefore essentially all windows with no solid walls (via floor to ceiling glazing), this will tend to make this style of building very expensive to build, to own and to operate. A fully glazed house is perhaps suitable for remote rural settings, but not at all appropriate for the dense, medium-density urban housing that New Zealand so badly needs. Prefabrication has long been argued as the logical means of progressing the housing construction issue, with Yorke again succinctly noting the issues:

“The same argument applies to the building itself. It is uneconomical to build single houses and isolated blocks of flats... things that are bought or made in small quantities are expensive, and therefore in order to produce, one at a time, buildings at a price we can afford, everything is reduced to a minimum in size and quality” (Yorke, 1939, p131).

In order to build better, quicker, cheaper, and more often, we need to work with a better construction system. So, what modern construction wall systems should we be looking at instead?

2. Timber-based Wall Construction Systems

At the thick, fat end of the wall spectrum, Cross Laminated Timber (CLT) is a definite contender for new wall systems in New Zealand and around the world. A house constructed of CLT has several distinct advantages: immense structural stability and strength, some inherent thermal resistance, as well as
excellent sequestration of large amounts of CO₂. Some of the other advantages of a machine-cut CLT house include huge steps forward in levels of quality, accuracy, and a significant reduction of time spent on site (Sutherland, 2014). Window openings can be pre-cut into the panels with millimetre accuracy and the remaining wall panels are warm, satisfying to touch and pleasant to look at straight out of the box. An alternative view is that a CLT house also has some distinct disadvantages as well: the very heavy weight of floor and wall panels that are bulky and difficult to manoeuvre without a crane, potentially problematic acoustic transmission, the fragility of the exposed finished surface demanding delicate handling, the completed construction requiring extra insulation (usually to the exterior) and the requirement for waterproof cladding layers; all exposed and debated by Sutherland in his 2014 thesis Design Fabricate. Reticulation of plumbing and wiring also needs to be considered during the design phase, with some CLT systems (such as the Huf Haus system) routering channels for wiring within the CLT panels, and others fixing the plumbing and wiring externally prior to the installation of the external cladding layer. The CLT system also has issues, perhaps, of material over-kill: is that timber resource being put to its best use? If all new houses were built out of CLT, would we run out of timber?

At the opposite, thin end of the wedge sit exploratory building systems constructed from very thin and relatively lightweight materials such as plywood, metal and plastic. These include predominantly plywood-based projects using the WikiHouse system or Click-Raft system, with some introductory information available in past research (Sutherland and Marriage, 2016). Moller’s proposals for Click-Raft advocate an entirely separate cladding enclosure over the top of the structural plywood, while Marriage’s work shows that it is possible for the Click-Raft system to be integrated more fully into the construction. Research into these systems is ongoing with students at Victoria University, and will be published separately in 2017/18 (Finch, 2017). Environmental performance of these thin skin plywood wall systems is very different from the heavy, CLT-based systems: there is virtually no thermal resistance nor acoustic mass in ply wall systems, requiring the separate cladding to provide this requirement. While plywood systems can be very strong in a structural sense, they can also be vulnerable without excellent associated waterproofing systems.

As a structural wall system, timber framed walls sit squarely in the middle between the thick wall and the thin wall, at least in terms of thickness. The existing, largely New Zealand Standard (NZS) 3604 based, predominant house building construction system features wall and floor constructions that are heavily focused on traditional timber framing as the answer to everything. In New Zealand, timber houses are built predominantly from NZS 3604 compliant 90x45 timber framing and feature wall thicknesses at a minimum of 110mm thick (allowing 10mm plasterboard internal lining and 10mm fibre-cement external cladding); or, now more likely, a minimum of 140mm (including external weather-boards over a drained and ventilated cavity). Given that a NZS 3604 wall stipulates, for the most part, a minimum 90x45 stud wall, it is therefore extremely difficult to get a structurally compliant wall that is even thinner. A 90x45 framed wall is however relatively poor at adequacy of insulation, integration of services etc. The studs effectively facilitate large cold-bridging issues at every stud and dwang; and the typical ‘traditional’ way of cladding this external wall surface, with just a single layer of building wrap before the thin cladding, is amateurish and severely outdated. It is a relatively reliable system for New Zealand housing when built well, although regrettfully it is often not built well at all. The use of high quality prefabrication systems should alleviate some of those construction problems, especially with regard to issues of bad workmanship on site. The use of better material in building wraps and the now widespread inclusion of a drained and ventilated cavity system have had a beneficial effect overall, but poor quality construction practices still persist.
The leaky building crisis has exposed the flaws in the longevity of the overall wall composition (Murphy, 2011), while alternative systems featuring a thin layer of plaster skimmed over external polystyrene insulation have been largely eschewed by those New Zealand architects and builders keen to avoid litigation. Howden-Chapman and others have written extensively on the dangers of ill-health caused by our inadequate house building systems (Howden-Chapman et al, 2009), a large part of which can be blamed on the design of our standard wall construction and their ability to trap moisture and provide a location in which to grow toxic mold. All of this points out strongly that new, better and certainly cleverer wall systems need to be developed and encouraged. While Chi Tran’s work on wall claddings completed some significant research into modifying the standard wall construction system for the New Zealand market place with an excellent range of cladding types investigated, the wall construction system behind the cladding was not examined for alternatives (Tran et al, 2016). We need to be looking far further afield for our next solutions.

3. Alternative Construction Systems

The automobile industry may be taken as an indication of where the house construction system needs to go. Just as we do not expect a new car to be delivered in a truckload of pieces for someone to assemble on site over a period of months, in the rain, sun and snow, neither should we expect this to be the best solution for building a house. Just as a new car can be purchased in minutes and driven immediately with an expectation of complete reliability, so too it should be with a house. It should be quite reasonable to expect a house to be built in a factory and delivered, fully working, to the site of your choice with a minimum of fuss. Currently though, this is not the way it is working in New Zealand, despite the best efforts of a number of industry players, including the author’s participation through First Light Studio. We therefore need to be looking at fields well outside our existing, traditional, badly flawed construction models.

There are precedents for using metal as a monocoque construction system, both amongst cars and also in housing. While Jean Prouvé started in 1931 working primarily on furniture, by 1936 Atelier Jean Prouvé was using folded sheet metal for the construction of buildings (Prouvé, 2003). The Beaudouin, Lods, Prouvé, Strasbourg (BLPS) holiday cabin was a 11m² prefabricated steel vacation dwelling weighing under two tons and capable of being assembled by a group of five workers in under five hours (1937-38). In his Ferembal Demountable House (1948) the building featured a core of steel portal frames with a lightweight aluminium cladding, while later houses included the Maison Tropicale (1949) for use in Africa and the Maison des Jours Meilleurs (House of Better Days), a dwelling house of 57m² (1955) constructed largely of aluminium (Prouve, 2003).

While Prouvé is rightfully lauded for his pioneering steel and aluminium constructions, the thin metal shell was perhaps misguided as a suitable housing system for a baking hot continent such as Africa: the designs lacked the necessary amounts of insulation to provide a comfortable house in that climate. Whilst spectacularly speedy in erection and capable of being flatpacked inside an aircraft hold, the houses were not a great commercial success, and remaining examples are extremely rare today. What Prouvé did leave behind however, was the concept of using thin metal sheet as an external structural skin. Automobile construction has moved on from the concept of a steel chassis and a separate body (such as Prouvé used) to a more monocoque-like system known as the unibody, where the strength is in a stressed external skin connected to internal structural members, all working concurrently together as one structural unit.

This concept is still open to being explored for housing construction and the path remains open for thin skin production to be paired with mechanized structural fabrication to form a monocoque or unibody
housing construction system. Perhaps the closest the housing industry has got to using metal monocoque is the caravan and campervan industry in New Zealand, or the mobile home industry in the USA. So far mobile homes have not been taken up as a major part of the New Zealand construction industry, although the Tiny Home movement is growing: but still mainly focused on using traditional timber framing.

While there are some houses being clad in metal skins, none have been found using monocoque systems currently, although work with container housing is commonly advocated and structural insulated panel (SIP) systems are being produced with steel or plywood facings. Environmentally however, external unibody/monocoque construction of houses is subject to issues that would be obvious to anyone who has returned to their car on a hot sunny day: the external surface of the car can be extremely hot and the internal conditions can be stifling, even lethal.

Finch’s work at Victoria University is exploring the notion of plywood unibody construction, using plywood as part of this structural matrix. CNC routing of plywood panels enables low cost flat plywood sheets to be transformed into complex interlocking three-dimensional (3D) structures using minimal amounts of cost-effective wood-based material (Finch, 2017 and Holden, 2017). An alternative approach is to specifically manufacture a three-dimensional matrix directly out of a liquidized base material, and for that we need to look at another technology: 3D-printing.

4. 3D-printing and Robotic Construction

The growth in new methods of technology is having electrifying effects in many industries such as product design, with advances in technology such as CNC (Computer Numerically Controlled) cutting tools, 3D CAD (Computer Aided Design) drafting, and more recently, 3D additive printing (itself a technology that is over 30 years old). In additive printing, a computer-designed shape is built up by adding extremely thin layers of material to build up a completed shape. Recent developments in 3D-printing have varied fast and are mutating widely and becoming more architectural, according to recent research published by Isabella Molloy, who notes that:

“...current applications of freeform 3D printing are predominantly proto-architectural. These projects often look at large-scale building solutions for complex structures, taking a structural space-frame approach in creating three-dimensional printed forms.” (Molloy, 2017).

There have also been changes in the printing media used, ranging from the now ‘traditional’ plastics including acrylonitrile butadiene styrene (ABS) or polylactic acid (PLA) - both relatively standard as printing mediums at small scale, to far more substantive materials since 2013. An article from 2013 recorded the first mention of 3D printed components being used in at least three different countries, such as the roof an office building in London, the 3D-printing of a canal house in the Netherlands, and experiments in building in California (“Printing houses”, 2013). In larger projects, foamy cement-based fluid concrete has been used at large scale to 3D additive print entire houses (“3D Printing Builds Up Architecture”, 2014). Developments have taken place in both USA, England and China, with each claiming a lead (“3D printing houses with giant robot arms”, 2014). The Yingchuang Building Technique (Shanghai) Company claims that their houses can be printed at a rate of 10 per day (Winsun, 2016); while Quartz magazine reports that a 400 square foot house can be printed in under 24 hours using a concrete mixture that will last for 175 years (“A San Francisco startup is 3D-printing entire houses in just one day”, 2017). Environmental aspects of 3D printed houses do not yet appear to have been formally assessed, with the inherent drawbacks of mass concrete construction (cold bridging, vapour permeation, lack of insulation, lack of
reinforcing, lack of weatherproofing, extreme mass, poor quality levels of finish inside and uncertain cladding outside etc.) being raised in a 2016 article with some healthy degree of skepticism:

“If you don’t trust a system of fibre-cement sheeting not to leak, why do you think a system of fibre-cement gloop would work any better? How would you reinforce the wall against seismic forces and how do you seal in flashings to stop them leaking? Where is the vapour barrier? How do the costs stack up to ‘print’ a house in situ, as opposed to printing it in a factory and taking segments to the site?” (Marriage, 2016).

Further recent changes in 3D printing include advances in the methods of actually printing itself: 3D-printing, 3D-sintering, 3D-stereo-lithography, and also a newcomer: 3D freeform printing (an extrusion based printing method using self-supporting build material that solidifies upon extrusion during spatial movements). Molloy’s work on 3D freeform printing indicate some of the many possible ways forward for this system, including the possible interfaces with architectural construction. While Molloy’s work has concentrated so far on 3D-printing artefacts, the increase in quality level of freeform deposition modelling (FDM) printing over the now more traditional 3D additive printing is obvious and immense. Practicalities for its use in building construction are rife, especially if combined with the other recent advances noted above. Choi and others note that 4D printing is the next big item on the agenda: 3D-printed material that can change shape over a period of time (Choi et al, 2015). However, many researchers in this area have already been experimenting with this for a number of years, including Tim Miller at Victoria University’s School of Design.

Variations in the printing media have also included the use of wood-dough (a mixture of plastic resin and timber dust) and even sand with Markus Kayser’s experimental fabrications in the Sinai desert: the Solar Sinter project (Kayser, 2011). Tim Miller’s extensive experimentation in 3D-printing wood-dough is as yet unpublished, but the examples produced so far show a potential way forward for product design and possibly also for architecture, including flexibility and parametrically generative design. Kayser’s work with solar-powered 3D printers sintering glass objects directly from a base matrix of silica (desert sand), offer an intriguing vision of the house-building robotic printer of Yingchuang being ‘cross-bred’ with Kayser’s completely autonomous solar-powered droids. From there it is a small but very believable step to conceiving of a solar-powered automaton - a self-propelled automated fabricator - 3D-printing entire houses directly from the sand, creating new housing in the desert, with minimal human input.

While this may sound like a fanciful notion, it is far from fiction. The international architectural practice Foster and Partners is actively planning for the use of such 3D-printers to work with regolith, an extremely fine powdery dust found only on the Moon. This site-specific project (commenced 2012) for the European Space Agency involved planning how remote-controlled autonomous agents would be shipped to our smaller celestial orbiting partner and programmed to craft regolith-fabricated solar-sintered dome constructions as a form of lunar housing. The lunar base would be constructed as a series of interconnected domes, with layers of regolith built into a dome as a protective shell to offer protection from meteorites and gamma radiation. To ensure sufficient strength, the shell’s walls will be made by taking the regolith and extruding it as a closed-cell structural foam of considerable strength and thickness (Foster and Partners, 2017). Issues of intense lunar temperatures will need to be accounted for with insulation but more importantly, vapour control and indeed complete atmospheric sealing will be needed to avoid the atmosphere inside seeping away in the low gravity. This may be one small first step for
robotkind, but a giant leap towards settling on Mars, which is perhaps the ultimate aim of any housing project looking for an answer to overcrowding on Earth.

5. Future Directions for Construction over the Next 50 Years

This paper set out to research possible directions for future wall construction within New Zealand. At present, 3D printed parts are generally not used here in housing construction, but printed-material strength is increasing. As an example, New Zealand’s Rocket Lab uses 3D-printed rocket engine parts, in order to send their Electron rockets into space. Rocket Lab proudly note that their Rutherford engines (there are nine Rutherford engines on each Electron rocket), recently fired from the Mahia Peninsula into space, are rather special in terms of 3D-printing: “Rutherford is the first oxygen/kerosene engine to use 3D-printing for all primary components” (Rocket Lab, 2017). Rocket Lab’s CEO Peter Beck states that this is for reasons of ‘Ultimate Manufacturability’ with an engine print time of just 24 hours. The additive manufacturing materials for the engine parts are titanium-alloys fused together via electron beam melting, with the metal powder being melted in a high vacuum by an electron beam, rather than a laser:

“Rutherford is also producing via electron beam melting, an advanced form of 3D-printing. Its engine chamber, injector, turbopumps, and main propellant valves are all printed and assembled into a lightweight shape” (Gush, 2015).

On a similar, related matter, Airbus and other manufacturers are already using 3D-printing of aeroplane parts (structural brackets, parts of the jet engine itself, etc) in order to save weight and reduce material usage. Analysis of the brackets revealed excess weight could be eliminated from the structural prototypes, and Airbus claim that 3D-printing can “decrease total energy used in production by up to 90 percent” and allow them to print new, compliant parts for planes directly from the digital original (Airbus, 2014). Clearly if a structural bracket or engine can be 3D-printed as a working part and directly incorporated into an actively flying airliner or an orbiting space rocket, then this indicates that structural strength in 3D printing can be dismissed as an issue of concern.

The issues of wall construction when compared to rocket science may appear very small and simple, but the issues of wall construction compared to simple artifact production appear correspondingly large. Points noted previously include the need for structural support and stability, thermal resistance, internal lining, vapour barrier provision, and not least: external water resistance. Clearly not all of these are currently possible to resolve with existing 3D technology, but the way forward is clear: 3D-printing and CNC control of certain building materials are already firmly in the pipeline from the future. Some of these solutions are well underway already. Fletcher Aluminium state that they are using 3D-printing to prototype certain parts of their window systems and many architects are now using in-house 3D-printing rigs to fabricate building models at a small scale, or occasionally, fabricate complete prototype building elements at 1:1 scale. As Molloy notes, the adoption of the Form Responsive Method (FRM) of 3D printing, “which fully utilises simultaneous x, y, and z axis movements with regards to the intended form”, allows for greater control over how the material can be deposited by the 3D printer. “FRM poses opportunity for embracing functional, aesthetic and tectonic applications of material, prospering upon the predominantly structural pursuits currently in the field.” (Molloy, 2017). The quality levels apparent in the work of Molloy and Miller indicate that there is a strong future for quality construction materials and systems being fabricated in the 3D-printing world.

Issues over the environmental considerations of 3D-printed building parts have potentially far higher ramifications than those considering CLT or plywood however. Plastic-based media in building
construction will have similar issues to plastics already used elsewhere – construction waste makes up approx. 40% of the world’s landfill but much of that at present is either non-malignant or is compostable. A move towards a more plastic-based construction waste would be even more catastrophic for the world’s environment and resources. Examples being showcased by Branch Technologies featuring extensive plastic 3D-printed matrices for potential buildings merely outline how much more potential waste will be generated, a problem that the world does not need (Branch Technologies, 2017). Experimental wall designs already being constructed show walls composed of a 3D matrix of plastic printed structure infilled with an expanded polystyrene foam insulation (“This Architect-Designed Wall System Has a 3D-Printed Core”, 2015). This insulation system may be common in the north America, but in this case, the two materials are now intricately woven together, permanently co-mingled and therefore probably highly unrecyclable. It would seem obvious that this is not sustainable and therefore not the correct route to be going down.

The real questions still remain to be investigated further in future research: can structurally-sound walls be feasibly generated via 3D freeform printing cost-effectively, at a very large residential scale? And importantly, in order to facilitate the use of more environmentally-friendly materials in the construction chain, can the 3D-printing medium be an ecologically produced, biodegradable wood-dough?

6. Conclusions

While methods of timber-frame construction may appear to be stagnating on the building sites of New Zealand, it is clear that there is at last considerable research going on into how to make wall construction, better, warmer, faster, stronger, as well as more breathable and less accommodating to spores of mould. New Zealand needs these systems to be taken forward and commercialised in order to make gains in housing over the next 50 years. Building involving CLT is already well past the prototype stage and production facilities in New Zealand cannot currently keep up with the demand, but there is no consensus that CLT is the best way forward. The myriad combinations of plywood as a medium for residential construction are being experimented with (Holden, 2017); while prototypes and completed buildings are being constructed as we speak (Finch, 2017). Further work is required into the use of 3D-printing as a structural system for building with, but it seems at least conceivable that a freeform 3D-printing robot could utilise a timber or metal based thermoplastic medium to fabricate a 3D matrix of sustainable structural wall components as part of new house designs in New Zealand. Whether this remains a desirable goal over the next 50 years remains to be seen.

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Potential for Prefabrication to Enhance the New Zealand Construction Industry

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Abstract: The New Zealand construction industry finds it increasingly difficult to meet the growing demand for housing. There is increased demand over the whole country but particularly in Auckland, where some 30,000 new homes are needed in the very near future. New Zealand’s population is growing at a rate that will see it rise to some 6 million by 2068. To meet demand, the construction industry will need to produce housing more efficiently than it has been doing to date. This paper investigates the potential for increased use of prefabrication techniques to address these challenges. Prefabrication is well understood to be faster, more energy efficient, cleaner and safer than traditional construction methods. The uptake of prefabrication methods in New Zealand was around 32 percent of all new houses in 2013, which lies somewhere between 90 percent uptake in Sweden and around three percent in Australia; two countries with which New Zealand is often compared. The paper discusses the current needs of the construction industry and, after reviewing the potential benefits of prefabrication, speculates over how these methods could help address the current crisis of housing supply in New Zealand.

Keywords: Prefabrication; housing crisis; benefits and disadvantages.

1. Introduction

in the wake of vast destruction during World War II, shortages of materials, resources, and labour led to a need for more effective methods of building. Prefabrication, or off-site construction, had been proven to be faster and more efficient than the traditional methods of the day and many turned to these methods to address these needs (Waskett, 2001; Turner and Partington, 2015). The new methods were effective and “some 156,623 temporary bungalows were produced for rent under the aegis of the 1944 temporary housing program, each with a design life of 10-15 years. Many have lasted much longer” (Vale, 1995).

It is also significant that the planet is facing significant challenges due to the effects of climate change and limited sources of non-renewable energy. The Network (2016) report advises that humans are using the earth’s resources at the equivalent rate of 1.6 times that which is available. Contributing to this excessive consumption is the built environment, of which it has been noted that “buildings are responsible for more than 40 percent of global energy use and one-third of global greenhouse gas emissions, both in developed and developing countries” (UNEP, 2009).
With reference to these and other similar studies, it can be noted that prefabrication methods have considerable advantages in comparison with traditional methods, including lower construction waste, greater energy efficiency, lower financial cost, faster speed, higher safety levels, fewer construction defects and a potential reduction in other environmental impacts. Others have suggested that using prefabrication techniques could decrease consumption of non-renewable sources of energy and reduce environmental hazards such as Green House Gasses (GHG) emission (Gorgolewski, 2005).

Apart from energy and environmental concerns, other pressures such as the need to provide accommodation for a growing population, have led many people to consider other ways of building. Prefabricated construction has many advantages over more traditional methods and, because of these, may provide useful solutions, not only to meet present demand but also to push the country forward and keep New Zealand green and liveable for next generation.

However, despite the well-understood benefits of prefabricated construction, only 27 percent of all new houses in New Zealand made use of prefabrication techniques in 2012 (BRANZ, 2013). Figure 1 compares the percentage of prefabricated buildings in New Zealand (Housing Sector only) with those of other countries. It is important to recognise that most of these prefabricated buildings simply use prefabricated building elements (trusses, roof and etc.) and less than 2% of all buildings were completely prefabricated. It would seem that the number of houses with at least one prefabricated element would begin to approach 100%, but all sources consulted in this review have pointed toward the 32%. More importantly, this comparison indicates that the industry contribution in New Zealand (32%) is low compared with other countries like as Finland (50%) and Sweden (90%).

2. What is Prefabrication?

The term prefabrication can be considered in the context of a time horizon, as the term is commonly misconstrued and suffers from historical misperceptions. Sir Richard Rogers once said “When we first
started seriously to think about the prefabricated home, everybody jumped to the conclusion that it would lead to monotony. I say it offers us a way of building truly imaginative and exciting homes” (Arieff, 2002). Vale (1995) describes Le Corbusier’s opinions on prefabrication, which derived from a comparison with the automobile industry. Once production of individual cars by hand was replaced with an assembly style process, cars were made more affordable. Le Corbusier believed that if house production followed a similar process and became streamlined like cars, then these manufactured houses could be more practical and acceptable than traditional ones. Adrenaline mentions people’s understanding of prefabrication including a wide range of description, “From ‘cheap and flimsy’ New Zealand classrooms from the 1970s to 21st century modern luxurious and highly energy efficient prefabricated homes offered by some European prefabricators” (Betz, 2015). Finally, it can be said that standardization, assembly, off-site or modular building, which we call prefabrication, means:

Elements (from one component to a complete building) that have been manufactured in a factory some distance away from the final location, the pieces are sold, purchased and carried as a kit (or complete building), and the end result coming from assembling the kits (or attaching complete building to foundation) is usually a one-storey (or more), detached, eco-efficient house, built according to sustainable construction criteria. (Seratts, 2012).

![Figure 2: Different Types of Prefabrication](image)

It is worth noting that, different types of prefabrication could be classified in different ways including, materials, system or degree of prefabrication. In the classification, based on degree of prefabrication (which is one of the most popular ways) this method is divided into five sub-categories (Figure 2). This classification ranges from component (lowest level of prefabrication), to panel, volume (3D module), hybrid (volume + panel) and complete building (highest degree of prefabrication).

### 3. A Brief History of Residential Prefabrication

Wherever ancient people were interested in migration or had to migrate due to external threats or environmental conditions, they required houses that were easy, fast and cheap to assemble, disassemble and transport (Herbers, 2004). So, the history of prefabricated houses can be understood to date back to the beginning of nomadic life. It can also be noted that “prefabrication in architecture is a tale of necessity and desires” (Smith, 2010).

In the industrial age, the first prefabricated iron framed house was built in England in 1830 (Herbers, 2004). However, it was after World War II that the idea of manufacturing a house in a factory was realised
on a larger scale (Vale, 1995). As Phillipson (2001) notes, following World War II, the international community was faced with vast areas of destruction and shortages of materials, resources and workforce. At the time, construction practices were changed from traditional, on-site methods to off-site prefabrication to help meet needs within prevailing constraints. According to Xu and Zhao (2010), the contemporary prefabricated housing industry grew with the mobile houses at the 1950s in the United States. These houses were the first steps toward more industrialised production of housing in the years that followed.

The prefabrication industry in New Zealand started with importing prefabricated houses for individuals around 1833. Early houses were dispatched from the United Kingdom, the United States and Australia as kits and pre-cut frames (Toomath, 1996; Bergdoll and Christensen, 2008). During the early period of colonisation, settler numbers rapidly increased and many had to spend their first days under canvas or in a crude shelter. The construction industry developed and expanded rapidly in response to the needs of migrants, who sought to live in permanent dwellings (Isaacs, 2008). Later, in the final decade of 19th century, the New Zealand Railways Department became the first producer of prefabricated housing in the country (Bowron, 2007).

4. Advantages and Effects of Prefabrication on Users and Society

Prefabrication methods have a number of tangible advantages that can help make the New Zealand construction industry more efficient and effective. Potential benefits arising through use of prefabrication can influence the overall performance of New Zealand’s economy, as the building and construction sector is the fifth largest in New Zealand, contributing to 40% of landfill and employing more than 175,000 people (BRANZ, 2013). In the following sections, the nature of these advantages are briefly discussed.

4.1. Time

Time efficiency is one of the most important advantages of prefabrication when compared with traditional on-site construction techniques. Demand for construction has been increasing by up to 10% per year for some time in New Zealand, so it is very important to replace traditional methods by faster and more efficient ones (Prefab New Zealand, 2014). A 2012 study by BRANZ showed that a reduction in house construction time can mean a saving of between $1,000-$1,600 per week (BRANZ, 2012). These savings will be significant when considered in the context of an entire nation.

Prefabrication could be 35-55% faster (Phillipson, 2001; Britto and al, 2008) than traditional (on site methods). Shorter construction times will become increasingly important in New Zealand as the population continues to grow. The population has increased significantly between 1948 and 2016 and this trend is predicted to continue at least through 2068, when it will rise to some 6 million (see figure 3). The increased demand will be over the whole country but particularly in Auckland, where some 30,000 new homes are needed in the near future (Prefab New Zealand, 2014). It can be assumed that the country’s need for residential housing will follow a similar upward pattern, which would advocate for faster, high-quality construction methods.
4.2. Environment

Increasingly, New Zealand and other countries of the South Pacific will face significant changes to climate as a consequence of human activities in different sectors, including the building industry. Figure 4 shows that CO₂ emissions in New Zealand have followed an upward trend from the late 20th century and is predicted to keep growing if changes to reverse this trend are not made. As a consequence, mean temperatures are predicted to increase 0.3 degree Celsius by 2040 and 3.0 degrees by 2110 (Mullan, 2016). There is an obvious need to change behaviours to keep the country green and moving forward in a sustainable manner. In the construction sector, this could potentially happen by replacing traditional methods by prefabrication due its environmental benefits. Prefabrication methods can reduce the amounts of waste (40%) and other environmental impacts (30-70%), and CO₂ emissions (35%), substantially. Such reductions could enhance public health as well as help combat climate change. Moreover, prefabrication uses less energy (55%), water (30%)and raw material (40%)resources (Gorgolewski, 2005; Britto and al, 2008). Using supplies of water, energy and raw material more efficiently can help guarantee that these resources will continue to be available for the next generation.

Figure 3: New Zealand population, 1948-2068 (Source: Statistics New Zealand (June year))

Figure 4: New Zealand’s total and net greenhouse gas emissions and removals (historical and projected), 1990–2050(Source: Environment, 2009).
4.3. Quality and Safety

Phillipson (2001) notes that, as prefabrication methods are faster than traditional ones, components, materials and workers are less prone to natural hazards such as cold/hot temperatures, wind and rain. As a result, the quality of outcomes will be higher and the process is safer for all involved, particularly for those working on building sites. As control over the conditions of manufacturing and of the materials is increased in factory conditions, the components have a higher quality than equivalent parts constructed on site. The construction site is also less susceptible to damage that construction activities can cause.

Employing safer methods of construction through prefabrication is also very important because the construction sector in New Zealand has a worker fatality rate that is almost triple that of any other sector (BRANZ, 2013). This report identifies a 75% reduction in fatalities per unit of construction with factory-based construction. Accordingly, there are significant opportunities for cost savings to the Government in ACC and other government subsidised medical services. These savings could then be invested in different sectors and to enhance infrastructure.

4.4. Economy

Shahzad (2014) has found prefabrication to increase general (labour and construction) productivity between 7-11%. Hunt (2016) reports that a 1% increase in labour productivity is worth $300M to the NZ economy. This is a similar finding to Nana’s (2003) report that a 10% increase in labour productivity would increase GDP by $2B in the New Zealand economy (Prefab New Zealand, 2014).

Increased prefabrication uptake leads to growth in New Zealand industry productivity by 2.5% (Productivity partnership, 2013). The Value Stream Mapping study points to savings of up to $113M per annum on a total construction turnover in New Zealand of $4.2B. These savings are made up of increased client education, reduced tendering, reduced changes on work in progress, faster construction, reduced rental costs for clients, and reduced weather delays (Employment, 2013).

5. Disadvantages of Prefabrication

“There can be no mass production without mass marketing” (Kelly, 1951).

Although prefabrication has many benefits, there must also be some disadvantages perceived by those who make decisions about building methods, as there are clear preferences for traditional building methods based on the statistics (see 1. Introduction). A review of earlier studies undertaken in different parts of the world indicates that many other countries also face obstacles to the uptake of prefabrication. Figure 5 identifies the countries in which the four most significant barriers to prefabrication uptake are most prevalent, according to El_Abidi and Ghazalia (2015).
Potential for Prefabrication to Enhance the New Zealand Construction Industry

Figure 5: Obstacles against prefabrication extension in different countries (Source: El_Abidi and Ghazalial, 2015)

Public comprehension of prefabrication has an important role in the general acceptance of prefabricated buildings (Marquit, 2013). Rehfeld says this conception is greatly influenced by historical views and the imagination of the general public. This means people’s perceptions are based on mobile houses and manufactured homes that are light, loose, temporary and uneconomical. Most users think prefabricated buildings are low-quality buildings, without aesthetic value, and which are the output of a repetitive, fully standardised and non-creative mechanical process (Jabar, 2014). As the prefabrication industry is relatively new, rules and standards through which the industry can be monitored have not yet been developed. Moreover, the industry is faced with shortages of skilled workers (Wilden, 2002).

Economic factors create one of the main barriers to increasing uptake of prefabrication methods. The general approach of people toward prefabricated houses is that they depreciate over time – contrary to dwellings constructed through on-site process, which generally appreciate - and that they are not appropriate as a rental investment (Phillipson, 2001). Financial institutions have little or no interest in granting loans for prefabricated construction, as large funds are needed for purchasing parts from a factory without the security of being fixed on a site (Khatavkar and Joshi 2015; Laing and al, 2001).

Other important barriers to prefabrication derive through limitations of transport. Transporting large and heavy prefabricated elements can demand significant time to prepare for legal and logistical requirements. This adds cost to projects with little apparent benefit. Transport restrictions (size and weight) can also limit designs. Often as a consequence, prefabricated houses have less design variety than traditional buildings and, in conjunction with limitations created by on-site erection processes, can only be erected on flattish sites (Stephen, 2012). Attempts to create diversity in design outcomes are often thwarted by the limitations of transport to site and installation processes.

5. Discussion and Conclusion

This paper has discussed the potential role of prefabrication technology on the future of the New Zealand construction industry. As the building industry is the fifth largest in New Zealand, the effects of prefabrication uptake may be tangible throughout the whole country. Replacing old and traditional (on-site) construction methods with prefabrication (off-site) will enable the country to directly benefit from
the recognized advantages of this method and move forward. Such benefits could be classified in two categories; short-term benefits (present time) and long-term benefits (future).

In the present view, using prefabrication methods can enable the country to save money by decreasing direct and indirect expenditures during the build, utilisation and demolition/recycling stages of the building lifecycle. Process efficiencies can help to increase the gross domestic product (GDP) by around $2B with direct savings of up to $113M per annum on a total build value of $4.2B. The savings are made up of reductions in the number of building defects and in workplace injuries, reductions in the number of changes to work in progress, improved speed of construction, reduced cost of financing, and improved quality. Moreover, as the demand for construction increases in New Zealand at a rate of 10% per year, the recognized benefit of increased speed of construction would give the country a better chance of meeting government targets on housing numbers and quality.

Looking beyond the immediate housing crisis, which simply demands more housing to be built, New Zealand should be moving forward toward more sustainable development in order to guarantee future generations the access they will need to resources and the opportunity to thrive. Prefabrication can reduce amounts of waste (40%), environmental impacts (30-70%) and CO₂ emission (35%) substantially and use energy (55%), water (30%) and raw material (40%) resources more efficiently.

Taking into account potential limitations of energy resources, increasing environmental threats and ongoing population growth, the potential benefits of prefabrication can push the country forward. However, replacing traditional methods with prefabrication need will likely require stakeholders and users to change their perceptions of prefabrication and for deep seated, institutional barriers to be uplifted. This will require the cooperation of stakeholders such as builders, manufacturers, financiers, regulators and designers. Attitudes will need to change in order that appropriate guarantees, financial support, regulation and design capability can be provided to align with the characteristics of prefabricated construction. By paying more attention to stakeholder needs and expectations, and by enhancing perceptions of users toward prefabrication, this industry could become an effective alternative to traditional buildings methods in New Zealand.

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Potential for Prefabrication to Enhance the New Zealand Construction Industry


Barriers and Strategies to Streamline an Efficient BIM Workflow within the New Zealand Construction Industry

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Abstract: This paper will be demonstrating a research framework on the need to boost the productivity and efficiency of design-to-manufacture within the New Zealand construction industry. We outline and address how the implementation of BIM can be an effective approach to streamline the flow of information through design-to-manufacture for the construction sector. However, there are also many issues which surround the application of BIM that also affects its value. Many users within the design-to-manufacture supply chain mostly are unable to utilise BIM to its full capabilities. The research aims to propose an effective strategy for which information of a BIM project can transition seamlessly throughout a design-to-fabrication workflow. This improvement is to reduce conflict, minimise data loss and allow for a smoother transition and handling throughout the design and construction process. The research is to be delivered through six key stages. Currently, this research is in the initial stages of stage 2. Therefore this paper will address the outcome of stage 1. The stages are as follows: (1) Recognise and identify barriers; (2) Data collection; (3) Result analysis; (4) Formulate recommendations; (5) Pilot implementation; and (6) Project review. While this research project is currently ongoing, this paper intends to provide awareness for those involved in the New Zealand construction industry.

Keywords: Building Information Modelling; design-for-manufacture-and-assembly; lean; productivity.

1. Introduction

The Construction industry plays a significant role in New Zealand’s economy, contributing strongly to employment, businesses and gross domestic profit (GDP). It is New Zealand’s fifth-largest sector by delivering up to $18.9 billion to the country’s GDP and 10% of national employment (PWC, 2016). While the construction sector is currently operating in a boom phase, it is also one of the most fragmented due to poor productivity development and coordinating issues (Burns et al., 2016). Estimate figures from the New Zealand National Pipeline Report (2016) published by MBIE show that the cost of poor productivity in our building sector range as high as 20%, costing the New Zealand economy up to $1.2 billion annually. The Value of the New Zealand Construction Sector report published by PWC (2016) states that labour productivity in the sector is well below the national average. Whilst this is not uncommon amongst labour-intensive industries, there is scope for significant improvements to advance the performance of the
sector, thus also further benefitting the country’s economy. To challenge this issue, it requires engagement from government, the industry and clients/consumers. One of biggest reasons for this lack of advancement has been defined as to be a combination of the collaborative needs in performing construction projects, the level of skill and education required combined with the disjointed nature of multidisciplinary disciplines within the Architecture, Construction and Engineering (AEC) industry (Lindblad, 2013). The effect of poor productivity causes poor information flow throughout the supply chain of a project. Thus causing disputes and rework which can lead to cost overruns and project delays; ultimately resulting to extension times (Figure 1). Building Information Modelling (BIM) is presented as a method to improve communication, coordination and interoperability, thereby improving productivity in construction projects (BIM Acceleration Committee, 2016).

![Cause and Effect Diagram of Rework in Construction]

2. Background

The New Zealand BIM Handbook 2016 defines BIM as “a digital representation of physical and functional characteristics of a facility. A building information model is a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition”. BIM is fundamentally an approach of working and managing information more efficiently, for which all disciplines collaborate to create, use and embed data within a centralised digital As-Built Model – to be utilised throughout all phases of before, during and after construction (Figure 2). The accessibility and management of embedded data is used to improve the understanding and decision-making from conceptual design right through to the operations and maintenance phase, thus increasing the efficiency of a project. It is important to recognise that BIM is not all about the three-dimensional modelling or the process itself, but the information being developed, managed and shared, in support of better collaboration. The focus is on managing projects to get the right information to the right places at
the right time. Effective collaboration and consistent information is essential to a successful BIM project (BIM Acceleration Committee, 2016).

BIM is changing the AEC industry and the way that project teams work together (Figure 3). Collaboration between consultants, architects, engineers, contractors and fabricators not only increase project efficiency but also reduces risk and resolves conflicts before construction even begins. It is simply a better way to build – faster and more efficiently. BIM goes well beyond the effective application of 3D CAD, as a three-dimensional visualisation can better depict the story of how the systems and building elements are to interact together (Corser, 2010).

Figure 2. BIM Project Life Cycle (BIM Acceleration Committee, 2016)

Figure 3. An integrated workflow (Corser, 2010)

3. BIM in New Zealand

While BIM has the capabilities of streamlining the efficiency of AEC industries within New Zealand, many barriers are hindering the growth and effectiveness of BIM. This is due in large part to the lack of BIM understanding and user capability (Cunningham, 2015). A 2016 report led by Traffic in collaboration with the BIM Acceleration Committee, conducted a series of interviews with eight leading industry professionals within the design to manufacturing and construction industry. It outlined that participants
within the New Zealand supply chain lack the BIM competence required to use the tools and processes necessary for an efficient and streamline workflow. Often information delivered down the construction supply chain were either incorrect, missing, duplicated or too complicated for the downstream user requirements. It was thought that different members of the design-to-build process do not have clear and mutually agreed expectations of the downstream user needs for professions such as contractors or fabricators. Ironically, these barriers are hindering the efficiency of the workflow for a BIM project, leading to difficulties in achieving full collaboration through the design and construction process (Traffic NZ Ltd, 2016). While recent surveys and reports from Eboss (2016) have shown a gradual increase in the implementation of BIM within the New Zealand construction industry, many challenges still need to be addressed to ensure that its real advantages are realised. Small and Medium Enterprises (SME) are predominant in most economy structures around the world; therefore SMEs is essential for exploiting the improvement of BIM (Machado, Underwood, & Fleming, 2015). New Zealand has not taken the same approach as the UK regarding mandating BIM for all construction projects, and this mainly due to the lack of government drive and client demand. To achieve this, it requires a cultural and technological shift (Cunningham, 2015).

4. Lean and BIM

BIM represents a technology change but also a people and process change. The emphasis of streamlining an organisations processes and workflows also align with Lean philosophies. Lean which is also short for lean production or lean manufacturing is a systematic method for delivering a product or service, while also maximising value (from the client perspective) and minimising waste - without also having to sacrifice productivity. Lean aims to enhance productivity by simplifying the operational structure enough to understand, perform and manage the work environment. The management principals of lean were derived mostly from the car manufacturer Toyota. Ever since the growing success of Toyota, the core principles have been adopted in other manufacturing sectors (Abdelrazig, 2015). The construction industry uses lean to manage and improve the building process to profitably deliver customer requirements. While Lean construction and BIM are both independent initiatives, each of which can be applied without another, we can argue that there are synergies between them. Sack et al. (2010) recognises these potential synergies and argue that any BIM implementation project enables, or is the catalyst for a leaner organisational process. To effectively link design through to fabrication with the use of BIM, a breakdown of the complete supply chain from the architectural design process through to construction is required. Around the world different industries with complex manufacturing projects such as the automotive and aerospace industry, are constantly innovating and improving their productivity, focusing on the process of design and manufacturing components to be later assembled (Building and Construction Authority, 2016). The construction industry can learn from these industries in streamlining processes of design and construction, which can thereby reduce the time of projects while creating value for the client.

5. Design for Manufacture and Assembly (DFMA)

Design for Manufacture and Assembly (DfMA) is a combination of two methodologies; Design for Manufacture, which stresses the design for the ease of manufacturing parts that will form the final product, and Design for Assembly, which underlines the design of components for the ease of assembling
the final product. The purpose of DfMA is used to guide the design team by helping them identify, quantify and eliminate waste or inefficiency in a product design. The solution starts by understanding the end product. Therefore, DfMA is a component of Lean Manufacturing (Building and Construction Authority, 2016). With offsite fabrication saving both time and cost along with sustainable benefits, the use of DfMA is increasing in the construction sector. The process of DfMA has three main components: digital design tools using a computer-aided design (CAD) system, specifying how the digital design model is to be manufactured using a computer-aided manufacturing (CAM) system, and a computer numerical control (CNC) machine to fabrication. The application of DfMA can reduce the time to the finish of the final product, thus reducing the overall product cost. Collaboration between the design and delivery is essential for the use of DfMA. Therefore, BIM can be influential to support this coordination to facilitate and work in harmony with DfMA. Implementing BIM into DfMA could enable the use of digital fabrication tools, such as CNC machines to improve the construction performance and quality of products. By using digital models and extracting the embedded data from within, it can streamline the processes of manufacturing and assembling components for the final product. Therefore, the adoption of Lean construction together with BIM can reduce the gap between designs to manufacturing. However, there is a need to address the slow uptake of BIM to achieve integration across the whole supply chain (Machado et al., 2015).

6. Research Methodology

6.1. RESEARCH FRAMEWORK

![Research Framework Diagram]

Figure 4. Research Framework

The study is to be delivered through six key stages: (1) Recognise and identify barriers; (2) Data collection; (3) Result Analysis; (4) Formulate recommendations; (5) Pilot implementation; and (6) Project review.
(Figure 4). This research aims to contribute to these stages by; (a) reviewing the BIM skills gaps in the industry as it applies to different members within the construction supply chain, (b) identify and outline best practices of BIM, (c) illustrating the application of BIM in design-to-fabrication workflow, and (d) interviewing and surveying industry participants and reviewing recommended case studies.

6.1.1. Stage 2: Data Collection

Primary data will be gathered from case studies, supplemented by interviews and surveys to deepen the understanding of the constraints and opportunities for improving design-to-manufacture workflow.

i. Case Studies

Case Studies will be used to support current design-to-manufacture workflow within construction industries. The proposed case studies are to be either precedent or current ongoing projects from local or worldwide practices. We aim to identify best practices of successful BIM projects from design-to-manufacture. Case studies are to also provide good secondary data for the analysis of this research. The objective is to use a project example to understand a typical workflow from design to fabrication, analyse potential blockages and review opportunities to get the most out of the supply chain participants (skill and knowledge).

ii. Interviewing industry experts

The purpose of interviews is to complement the case studies and provide a deeper understanding of the constraints of workflow within design-to-manufacture workflow in the construction sector. Those that will be interviewed will have some expertise and connection with BIM within the design to the fabrication process in the New Zealand construction industry. The interviews will be of a semi-structured type with much freedom to elaborate both on the workflow processes and opportunities to improve. Interviews will also target automotive and design fabricators, to gather further knowledge of their workflow in comparison to the construction industry. The Traffic report (2016) of “Accelerating the introduction of BIM” can be used to identify and further support ongoing issues within BIM projects.

iii. Surveying participants within the design-to-manufacture supply chain

Surveys will be allocated to specific organisations within the New Zealand construction industry, to gather information from participants within the design-to-construction supply chain. We hope to achieve a deeper understanding of the overall BIM knowledge and skill level of individuals, to identify the areas of the supply chain that are hindering the workflow needed for improvement. The Eboss survey report (2016) can be used to supplement data.

6.1.2. Stage 3: Result Analysis

This stage will be used to process and review the collection of data gathered from all methods of Stage 2: Data collection. Data is to be grouped and summarised, as a means for analysis. Key information is to be extracted from the raw data, for a detailed review and analysis of each of the organisation’s current issues. We will analyse key gains, risks and problems, and map out which areas of the design-to-manufacture supply chain that require the most attention for improvement. From there, we will look at the best established BIM workflows from around the world found through literature and compare the collected data with the successful workflows.
6.1.3. Stage 4: Formulate Recommendations

Based on the data captured in the previous stages, a customised BIM-based collaborative strategy plan is to be formulated to streamline the flow of information through design-to-manufacture for the construction industry within New Zealand. The proposed strategy is to be carefully plotted to establish areas of improvement gain followed by processes, procedures, systems, practices and people capabilities.

6.1.4. Stage 5: Pilot Implementation

Stage 5 is to implement the developed BIM-based collaborative strategy for design-to-manufacture through an identified pilot project. A pilot implementation will be required to test the proposed strategy for viability. Collaboration with an existing organisation is required for this stage. Therefore, it is critical to link with an organisation within a DfMA environment that is willing to test and provide results. However, due to nature and time constraints for this research, there will be limitations regarding testing the full viability of the proposed strategy. If in that case, it is recommended that only a small part of the proposed strategy will be tested for this research.

6.1.5. Stage 6: Review

A project review and evaluation along with further academic and industry dissemination of the results will be presented. We will provide an impact assessment of the implemented strategy and its effectiveness within a BIM-based design-to-manufacture working environment. It is also important to address that in terms of workflow strategies, there will be different workflows required for different project types and for different variables; not all projects will be applicable for the proposed workflow strategy. We understand and acknowledge the limitations to this study, and while the objective is not to provide a workflow strategy to fulfilling all BIM projects, we hope to provide evidence of methods for a seamless flow of information from design-to-manufacture.

7. Discussion

This paper recognises the concerns surrounding the productivity and inefficiency of the New Zealand construction industry. While BIM can be thought of as the driving catalyst in injecting effective approaches into the design-to-manufacture workflow, there remain many factors which hinder the value of BIM altogether. It is believed that the issue lies with the need of a technological and cultural shift to get individuals engaged with BIM. However, it is also important to recognise and focus on change management strategies for continuous improvement in a learning organisation. Currently, this research is at stage 2 of 6 stages. Although we are at an early stage of the research project, the purpose of this paper is to address these current issues and provide awareness for those involved in the New Zealand construction industry. The following proposed stage of Stage 2: Data Collection will be hugely significant to the direction of this research; to find information gaps and approaches to improve on. If successful, the collected data will be used to deliver an efficient strategy, for which information of a BIM project will transition seamlessly throughout a design-to-fabrication process. From this, we hope to validate established key benefits and confirm new advantages (if identified) and clarify the direction and objective for future BIM research. However, due to nature of this project and possible time constraints, it may not be feasible to come to a complete conclusion. Therefore, it is important to address these limitations and provide recommendations for potential future work to further this research and provide for an efficient built environment.
References:


A Possible Future for Building Codes

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Abstract: Building designers prepare project specifications in part to demonstrate building Code compliance. Checking the specification for compliance is done manually, and is not easy to do well. This paper proposes a method in which specifications and building Codes could be developed to facilitate compliance checking, including automated Code checking which, to date, has evidently not considered the specification. This method entails embedding the building Code in the local national master specification systems (NMSS). Building information modelling (BIM) has a major part to play – use of a BIM-compliant NMSS could support automated compliance checking. The paper uses the Australian ABCB National Construction Code (NCC) and the UK’s RIBA Enterprises NBS Create BIM-ready NMSS to illustrate the proposals, as good examples of a single national Code and a BIM-specification respectively.

Keywords: Specifications; building Codes; BIM.

1. Introduction

Conventionally in building legislation, both project drawings and project specifications are required to be submitted for building Code approval. Code compliance checking of both drawings and specifications must be done. This paper focuses on the compliance checking of project specifications, particularly those derived from national master specification systems (NMSS). Because these and derivative project specifications address the minimum quality levels set in building Codes, which are themselves a type of specification, NMSSs could be designed to facilitate the compliance checking process.

Over 20 years ago the author proposed some ideas whereby project specifications could facilitate project compliance checking (Gelder, 1995). One of the ideas was that an official (i.e. endorsed by the Codes agency) national compliance ‘skeleton’ specification should be produced, structured parallel to the Codes (e.g. by attributes such as Fire performance), prompting for choices to be made where the Codes offer options, and so producing a project compliance specification which should be able to be subsequently incorporated into the project construction specification, with its trades structure (e.g. by Systems such as Steel structural framing systems) and extra material.

This paper focusses on implementation of this recommendation, and variants of it. A partial implementation is NATSPEC’s Simple domestic specification (2017b), which is specifically labelled as ‘2017
compliant’, and is endorsed by the Australian Institute of Building Surveyors (AIBS), whose members deal with National Construction Code compliance. But it is paper-based, has a conventional specification structure, describes many non-regulatory requirements, excludes project-specific choices, and is not endorsed by the Australian Building Codes Board (ABCB). It is, however, a step in the right direction, and probably adequate in respect of compliance for simple domestic construction.

The arrival of a new breed of NMSS intended for use in BIM provides an opportunity to look at this proposal afresh, for larger-scale projects, and perhaps to realise it, with the long-term objective of greatly simplifying the verification of a construction project’s Code compliance.

2. Automated Code Compliance

Since 2000 there have been several attempts to automate Code compliance, including the following:

- Norway: ByggNett (Holte Consulting, 2014)
- Singapore: CORENET e-Plan Check System (Teo Ai Lin, 2006)
- UK: The RegBIM Project, 2014 (Sutton, 2013)
- USA: ICC SMARTcodes, 2007 (Khemiani, 2015)

None of the project partners were publishers of national master specification systems, though each of these countries have them. This omission suggests that work on automated Code compliance has focused on the geometric part of the BIM, and has not addressed specification compliance. The approach suggested in this paper could complement rather than compete with the work done to date on automated Code compliance of project geometries, though there will be overlap.

3. The BIM-Specification

The specification is sometimes described as the ‘I’ in BIM (Waterhouse, 2012) – it is a part of the BIM, along with the BIM-geometry. BIM-specifications are organised around a hierarchy or schema of object classes, ideally as defined in ISO 12006-2:2015. These ISO object classes include Entities (e.g. buildings and tunnels), Elements (e.g. walls and roofs), and Products (the objects that a trade will assemble to make a System). The BIM-specification will comprise text held in an object-oriented database for each object, for which all the required attributes or properties are co-located (rather than being distributed as they are in building Codes). These properties will include structural performance, fire resistance, health and amenity and energy efficiency, which are the subject of building Codes. They will also include properties outside the building Codes, such as colour, erection tolerances, manufacturer and cost. The specification is conventionally reported in sections (or chapters) aligned to a trade-based classification system, such as the Systems table in Uniclass 2015 (RIBAE, 2017d; Gelder, 2015), though a BIM-specification can be reported in other ways.

The section substructure of each national master specification system is consistent. These substructures (Table 1 shows three) generally follow a timeline, from design to operation and maintenance, with a view to supporting the various types of procurement in the industry, such as design-build-operate-transfer. SectionFormat is used by all NMSSs in North America (CSI/CSC, 2009).

Table 1: Specification system substructures
Many of the publishers of NMSSs are members of the International Construction Information Society (ICIS, 2017). Other NMSSs include Sweden’s Byggtjänst AMA, Malaysia’s MoW Standard Specification for Building Works, Hong Kong’s ASD General Specifications, Japan’s JASS, CROW in the Netherlands, and BSD and NAVFAC in the USA.

In the UK, NBS Create is a NMSS that was devised, prototyped and co-developed by the author, working for RIBA Enterprises, over a 10-year period, and published in 2012. It is a ‘BIM-ready’ specification. It has an appropriate hierarchical data structure, includes outline or compositional clauses for modelling, is delivered in an SQL relational database, exports to COBie, and links to the project geometry in Autodesk Revit, Graphisoft ArchiCAD, the NBS National BIM Library (RIBAE, 2017c), and to other tools such as the NBS BIM Toolkit (RIBAE, 2017a). Accordingly, NBS Create exceeds UK government requirements for ‘BIM Level 2’, mandatory since April 2016. However, it does not yet import or export using the neutral IFC (industry foundation class) data file format needed to support ‘open BIM’ (buildingSMART, 2016).

The BIM-specification serves, or is capable of serving, the entire project lifecycle, from inception to demolition. That is, it can be used for briefing, design, compliance, construction, operation and maintenance, and deconstruction – this is the ‘lifetime specification’. NBS Create will do this by providing compositional specifications down through the Uniclass 2015 object hierarchy, from Complexes (considered at the early stages of a project) to Products (considered at the later stages of a project). At the moment, only Entity-to-System, and System-to-Product mappings are provided, but Element-to-System mapping has been prototyped. NBS Create will also deal with the timeline of each class of object, but is currently focused on Systems – their performance, composition, assembly, and operation and maintenance.

4. The Building Code

Building Codes are generally organised around attributes, including structural performance, fire resistance, health and amenity and energy efficiency. Within the sections or chapters addressing each attribute, requirements for various objects will be described, but the secondary structure of the sections – even within a single Code – is not consistent. Some will have subsections dealing with sub-attributes (e.g. Smoke hazard management), some will deal with objects (e.g. Lift installations), and some will mix the two concepts (e.g. Protection of openings). Requirements for a given object can be scattered within and between Code sections, making design for compliance problematic: How do designers find all the requirements? A standard object-based secondary structure would be very useful.
In Australia, the same edition of the NCC is used in all Australian jurisdictions. It is easy, and sensible, for NATSPEC to align with it. The NCC incorporates the BCA (Building Code of Australia, in two volumes, for residential and non-residential construction) and the PCA (Plumbing Code of Australia). This is delivered free online, and is performance-based, with deemed-to-satisfy (DTS) provisions. In order to encourage use of the performance route, its publisher, the Australian Building Codes Board (ABCB), has consolidated all the performance requirements into a separate volume, available as part of the NCC Suite (ABCB, 2016).

5. Compliance Checking

Compliance of the project specification with the Codes is checked manually at present. None of the compliance tools mentioned can interrogate a specification digitally, whether the specification is BIM-ready or not. The proposal in this paper would help with manual checking as well as automated checking using BIM-specifications.

Checking the compliance of project specifications against building Codes is difficult to do. The structure of the two documents is different, as is their scope (see Table 2). On the other hand, both documents have much in common. They are text-based, they reference Standards, they describe building objects, and they set quality levels – both are specifications. This commonality suggests that it should be possible to readily assess the compliance of project specifications against the building Codes.

Table 2: Structure and scope of building Codes and specifications compared

<table>
<thead>
<tr>
<th>Structure</th>
<th>Building Code</th>
<th>Paper-based project specification derived from NMSS</th>
<th>BIM-ready NMSS: NBS Create</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary structure (sections) organised by properties or attributes, e.g. Fire resistance, Structural performance</td>
<td>Primary structure (sections) organised by objects, conventionally of two classes – Systems and Products</td>
<td>Primary structure (sections) organised by objects – currently Entities, Elements, Systems and Products</td>
<td></td>
</tr>
<tr>
<td>Secondary structure addresses objects, of many classes, e.g. Spaces, Elements, Systems, Products; not standard</td>
<td>Secondary structure addresses properties or attributes, using a standard section structure</td>
<td>Secondary structure addresses composition (modelling), and properties or attributes, using a standard section structure</td>
<td></td>
</tr>
<tr>
<td>Content not classified</td>
<td>Content classified</td>
<td>Content classified using Uniclass 2015</td>
<td></td>
</tr>
<tr>
<td>All buildings, but some types more than others, e.g. residences are well-covered, but prisons less so</td>
<td>One building and all the objects in it</td>
<td>Enables specification of all buildings, but less common objects may not be included</td>
<td></td>
</tr>
<tr>
<td>Regulatory (minimum) quality</td>
<td>Project (optimum) quality, ≥ regulatory quality</td>
<td>Enables any quality level to be selected, ≥ regulatory quality; regulatory text identified in the guidance</td>
<td></td>
</tr>
<tr>
<td>Generic, i.e. references Standards but not brands (though some brands</td>
<td>Mix of generic and proprietary (brands)</td>
<td>Enables full generic, full proprietary, and anything in between</td>
<td></td>
</tr>
</tbody>
</table>
may be certified as complying)

<table>
<thead>
<tr>
<th>Text-based, with some diagrams</th>
<th>Text-based</th>
<th>Object-based database</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTML versions include hyperlinks to Standards, and to related internal text and diagrams</td>
<td>No links</td>
<td>Hyperlinks to Standards, manufacturer’s literature and industry guidance, to related clauses (for automated specification assembly), and to corresponding objects in the project BIM geometry (Revit and ArchiCAD), the NBS National BIM Library, and the NBS BIM Toolkit</td>
</tr>
</tbody>
</table>

### 6. Content

In terms of content, there are four ways of manipulating the NMSS (and hence all project specifications derived from it) and the building Code, to facilitate manual and automatic compliance checking:

- Map the NMSS to the building Code.
- Restructure the building Code to deal with objects.
- Restructure the NMSS to deal with attributes.
- Embed the building Code in the NMSS.

This paper explores the last possibility. In each case the NMSS and the building Code could be delivered using non-BIM or BIM formats. As noted, NBS Create is an example of a BIM NMSS. There are no BIM building Codes, or BIM Standards.

In terms of digitising Codes and Standards, relevant projects include the European project for Standardized Transparent Representations in order to Extend Legal Accessibility (ESTRELLA, 2016), and relevant organisations include the Organization for the Advancement of Structured Information Standards (OASIS, 2016). Though some researchers have looked into converting DTS provisions of the building regulations (e.g. Scottish Technical Handbooks) into legislation data models such as CLML and Akoma Ntoso (McGibney & Kumar, 2013), and into XML and HTML, and BSI is working to convert all its standards (building sector and otherwise) into XML and HTML (NISO, 2017), no-one seems to have looked into converting either Codes or Standards into IFC. The use of BIM formats for both document classes would greatly facilitate automated compliance checking.

This proposal could be extended to deal with planning compliance as well as building compliance, if the NMSS is extended to deal with higher-level objects such as Complexes and Entities. The proposal can also be extended to deal with Codes and NMSSs used in other sectors, such as transport and utilities infrastructure.

#### 6.1 Embed the building Code in the NMSS

Building Codes can be seen as specifications describing required (or suggested) regulatory quality. Indeed the NCC itself contains a series of deemed-to-satisfy specifications (e.g. Specification C1.1 Fire-resisting construction), building Codes cite standard specifications in the form of national Standards, and in South Australia (for example) the NCC is supplemented by Minister’s Specifications. Just as for contractual specifications, the Codes can be expressed in terms of performance or prescription, can be self-contained or rely on Standards, and can describe objects of all classes (particularly Spaces, Systems, and Products).
Project specifications build on the regulatory minima, describing required project quality levels, again in terms of Standards and bespoke text and, in the private sector at least, in terms of brands. We have seen that project specifications in many developed countries may be based on NMSSs, developed and maintained centrally by specialist publishers. The NMSSs are aligned, of necessity, to the regulatory minima described in the building Codes. This can be difficult where the jurisdiction served uses mixed Codes (as in the USA), but is simple where the jurisdiction uses just one (as in Australia).

Where the regulatory regime is entirely prescriptive, as for the bulk of the ICC Codes in the USA, the building Code does not need to be incorporated into the project documentation because it applies automatically. However, the specification must be careful not to repeat or conflict with these prescriptive requirements, and must provide choices where they are offered – this is the nature of alignment in that regime. Where the regulatory regime is performance-based, as it is in Australia and the UK, the relevant requirements of the building Code must be incorporated into the project documentation (perhaps in the form of a complying brand), whether one is working with DTS or performance solutions. The project documents must advise which DTS solutions are being used, if any, as well as describing any non-DTS solutions which are being used.

One way of doing this is to embed the building Code, both performance and deemed-to-satisfy requirements, into the NMSS. To some extent this embedding of the building Code is a normal part of the NMSS. For example, the NATSPEC *Brickwork and blockwork section* (2016) includes the following text, which aligns to the BCA as shown, though the section does not say so:

1.3 STANDARDS
- General
  - Materials and construction: To AS 3700. [cited in BCA Volume 2 clauses 3.3, 3.10 and 3.11]

2.2 MATERIALS
- Brick and block units
  - Standard: To AS/NZS 4455.1 and AS/NZS 4455.3. [part 1 cited in AS 3700 – above]
- Mortar materials
  - Cement: To AS 3972. [cited in AS 3700 – above]
  - Lime: To AS 1672.1. [cited in AS 3700 – above]
  - Pigment: To BS EN 12878. [cited in AS 3700 – above]

But this is not done wholly (i.e. many Code requirements are missing, often because the relevant objects such as spaces are not included in the NMSS), explicitly (i.e. such text is not necessarily flagged at all), or officially (i.e. the Codes developers have not endorsed these NMSS versions of the Codes).

It is suggested that, at least where alignment is simple, the building Code should be wholly, explicitly and officially embedded in the NMSS. For paper-based NMSSs, this offers several advantages:

- Code-based clauses could be marked as such, facilitating manual compliance checking, and ensuring they are not substituted during the project.
- Project quality levels would be guaranteed to meet the building Code, if this text was ‘locked down’ (e.g. through an uneditable ‘reference’ specification) – the specification would be ‘safe’.
- Work on the project specification would begin at the compliance stage, rather than towards the end of the documentation phase as happens so often, which would result in a better and more useful project specification.

For ‘BIM-ready’ NMSSs, a number of extra benefits could flow from this embedding:
• The specification (NMSS and project) could pivot between the compliance view and the project view.
• The project geometry would be linked, bringing it into the specification’s compliance functionality (and vice versa).
• National standard object libraries would be linked, and could themselves have Code compliance embedded where relevant. For example, the ‘accessible WC package assembly’ objects in the UK’s NBS National BIM Library are Code-compliant ‘out-of-the-box’.
• If the specification supported automated compliance checking, this could be used for both Code compliance and project compliance, rather than using different tools for each.

Property: value pairs dealing with building Code requirements (e.g. ‘Fire doors: To BCA Specification C3.4’) would be given ‘smart tags’, which flag the clause as being regulatory, but also enable the production of a building Code report with the same structure as the Code itself, so the report and the Code can be read alongside each other, facilitating manual compliance checking. In this case the property: value pair would be tagged ‘BCA Volume 1 Clause C3.4(b)’. In the building Code report, only items with these tags would be included (the rest of the specification is not relevant to compliance), and they would be reported in sequence, e.g. this item would be followed by specification text dealing with Clause C3.5. NBS Create supports this level of tagging.

In the original specification, Code-related text would be blended with non-Code text. Provided the project specification is delivered digitally to the BCO, the BCO can toggle between both versions – blended (to specification structure) and compliance (to Code structure). A free reader for the BIM-specification could enable this functionality.

Embedding the Code into a BIM NMSS effectively produces a BIM version of the building Code, and meets Caplehorn’s suggestion (2017) that ‘we should consider drawing up new regulations and regulatory formats for digital platforms’. It could in principle be reported in its entirety as a BIM Code. A BIM Code would facilitate automated compliance checking – the project BIM could be checked against the BIM Code. This requires the development of specific functionality.

7. Functionality

The BIM specification should support self-compliance, enabling the back-checking of decisions against earlier ones, e.g. checking that a selected brand complies with a prior contractual performance specification for that object (and its parent). This would need to work with both prescriptive and performance specification content. With this capability, the BIM specification would also be able to deal with regulatory compliance.

This requires consistent use of qualifiers such as ‘minimum’ in the specification – always included, always in the same location, always using the same (‘smart’) words. The compliance tool would recognise these terms and interrogate the specification and geometry accordingly. The Code deals with minimum requirements – designs, especially those produced by professionals, should be better-than-Code. Compliance should be a given. To this end compliance can be built into NBS Create clauses and the NBS National BIM Library. The default values for these objects should be better-than-Code, and no sub-Code values should be permitted – the software should lock them out. Requirements approved by the BCO, or set as minima by the Code, should be locked so they cannot be varied post-compliance – metadata explaining this should be attached to such objects. For example, BCA Volume 1 Clause G1.2 would appear in part thus in the specification:
Automated compliance checking of performance Codes and performance requirements is very difficult. For example, BCA Volume 1 clause FP4.5 (a performance requirement) states: ‘Contaminated air must be disposed of in a manner which does not unduly create a nuisance or hazard to people in the building or other property.’ This raises several questions for a compliance tool. What is contaminated air? What constitutes nuisance? How should the word ‘unduly’ be interpreted? How distant might the ‘other property’ be? The BCA offers no Verification method for this clause.

On the other hand, prescriptive Codes and DTS solutions are relatively simple to check (Caplehorn, 2017). For example, BCA Volume 1 clause F4.8 (a DTS clause) states: ‘Sanitary compartments must not open directly into: (a) a kitchen or pantry; or (b) a public dining room or restaurant …’ Provided that the compliance tool can recognise these Space types (due to the use of a classification system such as Uniclass 2015), it only needs to count doors between them. Two or more doors are compliant. In this case the tool would use only the project geometry (for another example, using an IFC model and the ICC IBC, see Nassar & Nguyen, 2005).

For an example where the BIM-specification would need to be interrogated as well, BCA Volume 1 clause F4.12 (a DTS clause) can be used: ‘A commercial kitchen must be provided with a kitchen exhaust hood complying with AS/NZS 1668.1 and AS/NZS 1668.2 …’ If the ‘Commercial kitchen’ space in the project geometry contains an object titled ‘Kitchen exhaust hood’ (again using Uniclass 2015 for both), which links to a BIM-specification clause which names these standards, or which names a proprietary hood that meets them (which in turn requires a hyperlink to readable manufacturer literature that names the standards), then the design complies.

This may be more computationally simple than checking against a performance requirement, but the difficulty should not be underestimated. However, NBS Create provides the necessary links to and from the project geometry, and contains both generic (to Standards) and proprietary (to brands) clauses for objects such as Kitchen exhaust hoods. The proprietary clauses are delivered using the NBS Plus service, in which the clause guidance itself identifies the standards, so there is no need for the compliance tool to find the manufacturer’s own literature, which is probably held online but in a ‘dumb’ (i.e. unreadable) PDF. It only has to read the clause guidance. Because this guidance is not in the project specification itself, the tool would need access to the NMSS, where this information is held.

Table 3: Refrigerated chambers

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Guidance</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exit doors:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inside latch:</td>
<td>Manual, not</td>
<td>BCA Volume 1 Clause G1.2(a)(i).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>keyed.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width, clear</td>
<td>600 mm.</td>
<td>The Code minimum is 600 mm.</td>
<td>BCA Volume 1 Clause G1.2(b).</td>
</tr>
<tr>
<td>(minimum):</td>
<td>750 mm.</td>
<td>Default is 750 mm.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>900 mm.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height, clear</td>
<td>1500 mm.</td>
<td>The Code minimum is 1500 mm.</td>
<td>BCA Volume 1 Clause G1.2(b).</td>
</tr>
<tr>
<td>(minimum):</td>
<td>1750 mm.</td>
<td>Default is 1750 mm.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2000 mm.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8. Conclusion

Currently, the verification of compliance of the project specification with the building Code must be done manually, and is difficult to do well. The specification appears to have been bypassed in work on automated Code compliance. The specification is a key part of the ‘information’ in BIM. BIM-ready NMSSs are coming onto the market, an example being NBS Create. A BIM-specification is delivered in an object-oriented database, features a compositional object hierarchy, and includes both Code and non-Code objects and requirements.

Unlike Codes, the specification section structure is about objects, not attributes, and is classified, with a standard substructure. Codes and NMSSs have a lot in common, though, and could readily ‘talk to’ each other. For example, both are specifications, describing objects and requirements for them, and both make use of Standards.

If the Code is embedded wholly, explicitly and officially in the NMSS, this ensures that all Code objects and requirements are incorporated in the specification, so ensuring that Code compliance is highly likely, particular if the Code component of the NMSS is ‘locked down’. If the NMSS is delivered in a database, then this would also enable the production of both a compliance specification and construction specification from the same tool. Given that BIM-specifications link to BIM geometries, this would begin to integrate compliance checking of both project specifications and geometries. Having the Code, the specification and the geometry in the BIM would also facilitate automated compliance checking, both against the Code, and within the project timeline.

The development of automated compliance checking functionality within the BIM-specification is a complex task, and has not yet been started. Verifying compliance – manually or automatically – would be relatively simple between prescriptive Codes content and prescriptive specification content, and perhaps between performance Codes content and performance specification content, but would be difficult between performance Codes content and prescriptive specification content.

The endorsement of the Code publisher is very desirable. The Code and NMSS publishers might consider developing this proposal for commercial use, ideally collaboratively.

References


CSI (Construction Specifications Institute) and CSC (Construction Specifications Canada) (2009) SectionFormat, CSI/CSC, Washington.


An Intelligent System for Actuating Windows of Naturally Ventilated Residential Houses

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Abstract: In New Zealand’s (NZ) mild climatic conditions, most residential houses are ventilated naturally, mainly by opening windows. However, maintaining the indoor thermal comfort characteristics of a house by modulating natural ventilation is particularly challenging, as the solution is not explicit. Determining a solution requires a technique that adjusts openable window area while encapsulating the complexity, dynamics, and nonlinearity associated with the natural ventilation driving forces and building thermal behaviour. This work examined the feasibility of predicting the air temperature time-series of an occupied naturally ventilated house by an Artificial Neural Network (ANN) model. It was found that the ANN technique could be used to predict the occupied space indoor air temperature time-series of the naturally ventilated house and that this can be used as part of an intelligent window control strategy for naturally ventilated residential houses.

Keywords: Natural ventilation; thermal comfort; artificial neural network; residential house.

1. Introduction

In NZ’s mild climatic conditions most residential houses are ventilated naturally, mainly by opening windows (Ryan et al., 2008). Previous studies have found that an overwhelming proportion of housing stock performs poorly from both a thermal and health perspective (Fitzgerald et al., 2014); however, there is significant scope to regulate the thermal behavior of relatively airtight and insulated naturally ventilated residential houses to address this (Pokhrel et al., 2016).

Finding a solution to modulate the natural ventilation by regulating the window openable area could help maintain the thermal comfort condition in the occupied space, however, it is particularly challenging, as the solution is not explicit. One of the key rationales behind it is the difficulty in accurately predicting the potential of natural ventilation because of highly fluctuating nature of associated driving forces, the uncertainty of occupant preference on temperature and airflow movement and different geometric dimensions and configuration of the naturally ventilated buildings (Tan, 2005). In naturally ventilated house, the occupants usually try to improve the indoor comfort condition by manually operating the nearest windows to modulate natural ventilation. However, due to the non-linear relationship between buoyancy and wind driving forces of natural ventilation (Hunt and Linden, 1999) and a varying
requirement of the thermal comfort level in occupied spaces both governed by various non-linear and dynamic factors, an occupant decision of manual operation of the window(s) cannot ensure desired thermal comfort level all the time. Therefore, determining a solution requires a technique that adjusts openable window area while encapsulating the complexity, dynamics, and nonlinearity associated with the natural ventilation driving forces and the building thermal behaviour.

In this respect, the problem appears to be well suited to the application of an Artificial Neural Network (ANN). ANNs are widely accepted as a tool offering an alternative way to tackle complex and ill-defined problems; and are able to deal with nonlinear problems. Once trained, ANNs can perform predictions and generalisations at high speed making them well suited to dealing with these situations (Kalogirou, 1999). Previous studies (Krauss et al. 1998 and Salque et al., 2014) have successfully demonstrated the use of ANNs for predicting and controlling the building indoor environment, typically the air temperature in a closed occupied space. In achieving this, the researchers used an ANN technique to predict the solar radiation and the outdoor air temperature. Similarly, a recent study for forecasting time series global solar irradiance in NZ locations verified the applicability of the neural network technique with specific reference to Nonlinear Autoregressive with Exogenous Input (NARX) ANNs (Ahmad et al, 2015).

In other studies (Stavarakakis et al., 2012; Kalogirou et al., 2001), the ANN based technique was used to address the complexities and the nonlinearity associated with the natural ventilation for optimizing size and location of windows and also evaluating the air flow through a naturally ventilated test set up. In their work, Atthajariyakul et al. (2005) used an ANN to compute the Predicted Mean Vote (PMV) thermal comfort index of a HVAC system.

As such, the ANN technique appears to be able to address the issue of nonlinearity and complexity associated with natural ventilation, as well as to predict the closed occupied space thermal behavior. Building up on this knowledge base, this work particularly focuses on investigating the potential of the ANN technique to predict the thermal behavior of a partially opened occupied space in terms of the indoor air temperature and hence be the basis for developing an intelligent controller for actuating windows of the naturally ventilated residential house.

2. Methodology

In order to determine the time-series thermal behavior of the occupied space this work followed the generic procedure of identifying a neural network model as outlined by Lawrynczuk (2014). In doing so, it consisted of three main steps: selecting the model structure (the choice of model inputs and the number of hidden nodes), training the model (optimizing the model parameters-weights and biases) and validating the model. Figure 7 illustrates a typical structure of a feedforward ANN, which consists of K outputs.

![Figure 7: A typical structure of an ANN (Atthajariyakul et al, 2005)](image-url)
(y_1, ..., y_k) that are transferred from the I inputs (x_1, ..., x_i, ..., x_l) through the hidden layers with J neurons (z_1, ..., z_j, ..., z_l). The output of an ANN model can thus be determined as shown from Equations 1 and 2.

\[
y_k = f_y \left( \sum_{j=1}^{J} w_{kj} z_j + c_k \right) \quad (1)
\]

With,

\[
z_j = f_z \left( \sum_{i=1}^{I} w_{ji} x_i + b_j \right) \quad (2)
\]

where, \( w_{kj} \) is the weight from neuron \( z_j \) to neuron \( y_k \), \( c_k \) is the bias for the neurons \( y_k \), \( w_{ji} \) is the weight from neuron \( x_i \) to neuron \( z_j \), \( b_j \) is the bias for the neurons \( z_j \). Similarly, \( f_y \) and \( f_z \) are the nonlinear activation functions, generally having a sigmoid shape.

Therefore, to predict the occupied space air-temperature time-series, an ANN model was developed using the NARX approach, similar to that described by Ahmad et al (2015). In doing so, the work investigated the possibility of predicting future values of a time series \( y(t) \) from \( d \) past values of that time series, \( d \) past values of another time series \( x(t) \), and if required, \( d \) past values of any additional time series as shown in Equation 3 (MATLAB, 2017).

\[
y(t) = f(y(t-1), ..., y(t-d), x(t-1), ..., (t-d)) \quad (3)
\]

To achieve this, the ANN model was trained with the results of dynamic simulations of a coupled thermal-airflow building model in TRNSYS (TRNSYS 17, 2009) for various operating conditions.

### 2.1. Coupled thermal-airflow model

To determine the performance of the coupled thermal and airflow environment in a typical NZ building, the TRNSYS Type 56 model was used in conjunction with a COMIS (COMIS, 2005) airflow analysis based on a network model of the building. In doing this, the temperature was calculated in the thermal model at each time-step and passed to the airflow model so that updated information was used to estimate node pressure and mass flow. For this study, a single room of 3 m length, 3 m width, 3.6 m reference height and with an internal volume of 19.75 m³ as shown in Error! Reference source not found. was modelled.

Furthermore, it was assumed that the room was occupied randomly by 0 to 5 occupants producing heating of 100 Watts per person (sensible-60 and latent-40) and had an un-controlled ventilation equivalent to the level of an ultra-airtight building with 0.03 Air Change per Hour (ACH), thus meeting the passive house airtightness standard (Passive House Institute, 2016). It was assumed that the building was located in Auckland NZ at 36.85° S, 174.76° E, with each wall oriented with respect to the cardinal directions and a single window on the north face.
The building facade details are shown in Error! Not a valid bookmark self-reference., where it was assumed the building facade was constructed with R-values just meeting the current NZS 4218:2009 standard schedule method for non-solid construction (Standards New Zealand, 2009). To achieve the ventilation a Large Vertical Opening (LVO type 1) (COMIS, 2005) with a maximum opening size of 0.9 m (width) by 1.5 m (height) as shown in Figure 8 was used to model a sliding window. In doing this, a Window Opening Factor (WOF) defined as 1 for fully open and 0 for fully shut was applied. Further, intermediate WOF values of 0.1, 0.25, 0.5, 0.75 were considered to explore the effect of the size of the opening on the thermal conditions. Finally, the thermal behaviour of the zone was assessed by computing the indoor room temperature for the free running condition, with no additional heating, cooling or plug loads.

Table 2: Building facade description

<table>
<thead>
<tr>
<th>Building Facade</th>
<th>Description</th>
<th>R – Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Wall</td>
<td>Timber frame direct fixed cladding</td>
<td>1.9</td>
</tr>
<tr>
<td>Floor</td>
<td>Suspended floor with lining under the joists and gap between insulation and lining</td>
<td>1.3</td>
</tr>
<tr>
<td>Roof</td>
<td>Timber frame skillion roof</td>
<td>2.9</td>
</tr>
<tr>
<td>Window</td>
<td>Double glazed sliding window (1.8 m. width x 1.5 m. height) fixed vertically on the Northern wall</td>
<td>0.34</td>
</tr>
</tbody>
</table>

2.2. ANN Model

To predict the indoor room temperature time series, an ANN-NARX network model was developed using MATLAB (MATLAB, 2017). In developing the NARX model a time series database to be used as the network inputs comprising hourly values of: ambient temperature, wind speed, outdoor relative humidity, time, solar radiation, number of occupants and WOF’s (0, 0.5 and 1) was developed from the coupled thermal-airflow simulation. Similarly, the hourly values of the indoor room air temperature predicted by the TRNSYS simulations formed the target time series database.
In the development of the ANN, input quantities with low correlation with the indoor air temperature were eliminated so that the final ANN model could be as simple as possible without compromising the accuracy. Subsequently the input and target vectors were randomly divided into three sets such that 70% of the data was presented to the network for training, 15% for validation and 15% for generalization. In performing the training, the Levenberg-Marquardt algorithm was implemented in a bid to fit the input and target. While doing this, the first network was constructed considering default values for the number of hidden layers (10) and delays (2). Illustrating the regression (R) values, Figure demonstrates the performance of training, validation, and testing, of the NARX model with default NARX architecture.

Figure 3: Neural network performance with default architecture

Despite the performance demonstrated by the default values, to identify the most appropriate values of hidden layers and delays for the proposed NARX network, a sensitivity study was carried out with various combinations of their values. While doing this, the average values of the Regression (R) and corresponding Mean Squared Error (MSE) for each combination of hidden layers and delay was assessed for at least three training runs. As seen in Figure, increasing both resulted in better performance (R value close to 1), however this is offset by the expense of increased time required for the training; and also the increased likelihood of overfitting the network.
Therefore, considering a balance between the time required for the training and achievable performance, a ANN-NARX open loop (series-parallel) architecture, as shown in Figure 4, with 15 hidden layers and 4 delays was considered for further assessment. The weights-\(W\) and biases-\(b\) as illustrated in Figure 5 were optimized while doing the network training in order to minimize the MSE.

3. Results and Discussion

Having developed the coupled thermal-airflow model leading to the ANN-NARX model of a naturally ventilated building, it was decided to explore how well the ANN model predicted the indoor room temperature in comparison to the coupled thermal-airflow model developed in the TRNSYS. Initially, the ANN model was trained with the hourly input and target values corresponding to the WOF (0, 0.5 and 1) for a year. As the generated function is the core for the deployment of the control concept, the robustness...
of the function needs to be verified so that the function can be used globally for any value of WOF between 0 and 1.

To illustrate this point, a comparison between time series of the indoor air temperature generated by both models with WOF values of 0.25 and 0.75 is shown in Figure 6 and Figure 7 respectively, for the first week of January and July as representative months at the peak summer and winter. Both of these figures demonstrate that the predicted time series from the ANN model corresponds quite well with the time series generated by the building thermal model of TRNSYS. This confirms that the prediction capability of the ANN model for the indoor room air temperature is quite reliable at WOF value of 0.25 and 0.75.

![Figure 6: Indoor air temperature from the ANN and TRNSYS model, WOF 0.25, (January and July)](image)

Exploring this further, a comparison between time series of the indoor air temperature generated by both models for WOF values of 0.1 for the first week of January and July is shown in Figure 8, as a representation of peak summer and winter respectively. Figure 8 again demonstrates that the predicted time series from the ANN model matches the time series generated by the building thermal model of TRNSYS. This confirms that the prediction capability of the ANN model for the indoor room air temperature is quite reliable. Moreover it shows that the prediction from the ANN model is reliable even at small opening areas, where the balance of the in and out flow from the space is restricted in nature and thus increases the nonlinearity.
Figure 7: Indoor air temperature from the ANN and TRNSYS model, WOF 0.75, (January and July)

Figure 8: Indoor air temperature from the ANN and TRNSYS model, WOF 0.1, (January and July)

To illustrate the reliability of the prediction for an extended period, covering entire months and throughout the year, the comparisons were extended for the months of January, July, April and October as shown in Figure for WOF 0.1. As expected, the time series of the indoor room temperature produced from the TRNSYS model is in excellent agreement with the time series produced from the ANN model.
This illustrates that the prediction holds extremely well for extended time periods and throughout the year for the lower opening area. Further investigation showed that with increased opening area (WOF value of 0.25 and 0.75) a similar pattern was observed. Thus, it confirms that the prediction holds extremely well for any opening area throughout the year.

![Graphs showing temperature predictions](image)

Figure 9: Indoor air temperature from the ANN and TRNSYS model (January, July, April, and October)

On this basis, by reversing the operation of the ANN (i.e. determining the WOF required to achieve a desired indoor temperature with given ambient conditions) a controller could be developed that modifies the WOF in order to try and obtain the desired indoor temperature. Such a controller could be extended to actuate auxiliary systems if the desired conditions are not met and to assess the thermal comfort of the residential house in terms of Predicted Mean Vote (PMV) or adaptive thermal comfort index criteria. As such, the resulting time series function/algorithm of the thermal comfort index could be used as a basis to devise an intelligent model predictive control strategy with an objective function to maximize the indoor thermal comfort level of a naturally ventilated residential house.

4. Conclusions and Recommendations

This work has demonstrated that the ANN technique could be used to predict the indoor air temperature time-series for an occupied space subject to natural ventilation. Hence, it can be used as the basis of an intelligent window control strategy for the next generation of sustainable naturally ventilated residential houses.

Given the information from the thermal model is robust, and irrespective of any value of WOF and time of a year, the prediction of the time series of the indoor temperature from the proposed ANN-NARX
model could be adequate for actuating windows of the naturally ventilated house. Obviously, the enrichment of the ANN-NARX model in terms of training, including various operating conditions (airtightness, envelope insulation) different geometry, size and location of windows and orientation would be necessary for an improved predictive model. However, in summary, the use of ANN appears to offer some promise in the development of intelligent control of actuated windows in naturally ventilated buildings.

**Acknowledgements**

The authors would like to thank Callaghan Innovation for supporting this project.

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Timber 4.0

A Computer-Vision Approach for Visual Grading Low-Grade Plantation Hardwood

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Abstract: The objective of this study was to develop a proof-of-concept for using low-cost, off-the-shelf RGB-D computer vision techniques to assess grading and defect features in low-grade plantation hardwood. It is framed within a wider research project that proposes the integration this data within a Cyber-Physical System allowing real-time design and material feedback within a computational design and fabrication workflow.

Keywords: Computer vision; plantation timber; digital fabrication; computational design.

1. Introduction

The value-capture of low-grade plantation hardwood (LGH) is fundamental to the long-term viability of Australia’s timber industry. The majority of plantation hardwood in Australia is managed for pulplog production (Downham and Gavran, 2017), which is maintained as un-thinned and unpruned, resulting in material unsuitable for traditional construction applications. The emergence of novel softwood-based engineered-timber solutions in Europe, such as cross-laminated-timber (CLT) and Glulam, has seen the implementation of smart manufacturing pipelines that demonstrate a paradigm shift away from timber as a simple material resource towards an increasingly digital-based ecology.

The introduction of computer vision (CV) enabled grading methodologies and cyber-physical smart-manufacturing pipelines provide opportunity to harness Australia’s extensive reserves of LGH. Intermixed with bespoke computational design and robotic fabrication, the potential for new value-propositions and innovative construction systems in utilising LGH is even greater. The coupling of a low-cost CV system and fabrication process, integrated into a design methodology accommodates the utilisation of LGH at a bespoke, end-user level.

The scope of this paper describes a proof-of-concept, technical approach to RGB-D (red, green, blue and depth) CV in order to qualify benefits of automated assessment of timber boards versus current
industry practice. Following, the paper discusses immediate and long-range research goals of CV techniques within a digital fabrication or cyber physical production pipeline.

2. Context: Australian Low-grade Hardwood

Australia’s plantation timber reserves comprise of approximately 1,037,000 hectares of softwood and 928,000 hectares of hardwood forests. While softwood plantations are almost exclusively managed for sawlog grade timber, 82% of hardwood plantations are primarily managed for pulplog production (Downham and Gavran, 2017). Consequently, softwood plantations are directed towards profitable structural grade materials for the construction industries, while hardwood plantations are destined for low-value fibre industries such as chip, pulp and paper.

Sawlog grade plantations are managed and maintained to ensure straighter, larger trees that contain minimal defect features for a high-value market. Pulplog plantations however, are generally left to grow without regular maintenance, allowing the trees to grow irregularly, demonstrating a significantly higher defect feature rate. In a low-value fibre market the highly featured nature of LGH is of little importance. The demand for sawlog grade hardwood is still present and is met by either logging native forest reserves or, the increasingly common importation from overseas (Derikvand et al, 2017). Australia’s hardwood plantation is primarily Tasmanian Blue Gum (E. globulus, 52.7%) and Shining Gum (E. nitens, 25.2%), both of which are unsuitable for high-value markets when managed as a pulplog resource.

This mismatch between demand and quality presents a significant opportunity to investigate alternate material and fabrication methodologies that lend themselves to value-adding to the LGH market.

3. Related Work

While the introduction of CV techniques in the timber industry is not new, there is little research into its application with LGH grading and processing. Due to the length of the timber production cycle (grow, harvest, sawmill, drying, grading) a variety of techniques can be applied at different stages of the production process. While this study focuses on timber assessment at the point of fabrication using low-cost methodologies, there is significant precedent concerning the use of low and high-end CV techniques in a variety of forestry and production industries.

3.1. Computer vision in forest management

Significant developments in LiDAR scanning (Light Detection and Ranging) has allowed forest management to be increasingly optimised. When coupled with GPS enabled airborne systems LiDAR has the capacity to scan entire stands of forest and measure the topography of land, distribution of plant canopies and likely vegetation structural characteristics (Lefsky et al 2002). When paired with traditional data such as species and age, predictions can be made about the maturity of the forest, potential yield and suitable strategies for further management and harvesting (Lima et al, 2003). While these conclusions can be made using traditional field work and analyses, there is significant cost savings in utilising a digital system (Means et al 2000).

Brouwer (2013) argues that aerial LiDAR scanning remains at a high price point suitable for large forestry companies, and that the development lower-cost methodologies is required for smaller applications and scenarios. Brouwer’s research suggests that RGB-D based scanning can provide low-fidelity data that can contribute to plantation forest assessment and management. Off-the-shelf RGB-D
devices can be restricted by daylight sensitivity and scan range. However, Brouwer found daylight interference was minimal due to scanning being located on the darkened forest floor and that scan range was comparable to traditional methods of forest assessment. Although Brouwer’s proof-of-concept investigates softwood plantations, there is significant cross-over to hardwood plantations.

3.2. Advanced imaging in sawlog processing

Internationally computer tomography (CT) scanning is employed within many sawmills to increase the yield of recoverable material from saw logs (Taylor et al 1984; Fredriksson, 2014). Complimentary research has been conducted that assesses CT imagery via artificial neural networks and machine learning techniques to increase the accuracy and reliability of feature detection within a sawlog (Nordmark, 2002). In simulations Rias et al (2017) found that an average 20% yield increase occurs when CT processes are utilised to optimise log rotation within a sawmill. These studies demonstrated that CT scanning is able to identify a number features (knots, internal checking, heartwood) that increase the yield from the sawlog.

The majority of research in sawlog scanning is situated within the softwood industry, which requires adaptation to a plantation hardwood supply chain as demand for the resource increases. Additionally, CT and x-ray scanning within a sawmill production line is a financially significant investment that, in the context of the Australian market, is unlikely to be utilised widely. This suggests a case for investigating novel digital processes that occur post-sawmill processing that integrate feature identification within a potentially lower grade sawn board. There is opportunity for CV to be employed at the point of design and/or fabrication, utilizing off-the-shelf scanning techniques that provides a methodology for an increase in low-value timber utilisation.

3.3. RGB-D scanning in alternate production environments

Within other production environments a number of research groups have utilised RGB-D scanning techniques in the context of both increasing yield and improving production line efficiency. It is common for proof-of-concept studies to utilise low cost off-the-shelf hardware solutions in order to capture data for assessment of product quality. Both Spoliansky et al (2016) and McPhee et al (2017) utilise Microsoft Kinect hardware as a means of collect real-time data within the livestock industry. These studies couple RGB-D scanning with digital image processing and machine learning to establish a method of assessing physiological characteristics food-based production animals. The introduction of RGB-D based CV in this scenario aims to increase the value, efficiency and yield of production process.

4. Method

4.1 Current hardwood grading practices

A significant challenge to the adoption of LGH for construction purposes is an efficient method for assessing each board’s unique functional, structural and visual idiosyncrasies. Native forest hardwood is generally commoditised as manually graded, clear faced length as per AS2082-2007. This allows sawn boards to be visually graded against a series of features and categorised into 4 structural grades. If a board doesn’t meet one of the criteria, it is downgraded accordingly (Standards Australia 2007). This process is usually undertaken manually within a sawmill and consequently, a large volume of material is dismissed, often due to a single defect, resulting in a significant material wastage and monetary loss.
Feature rich plantation hardwoods are unable to be visually graded for structural use. No equivalent to AS2082-2007 exists for LGH. As demand for hardwood products increases and supply from native forests is reduced and exhausted, new grading standards need to be developed that are able to assess plantation LGH. Additionally, the parallel development of novel construction systems based on the use of plantation LGH need to be commercialised (Derikvand et al, 2017). The understanding of LGH as part of an engineered system could accommodate out of grade material in a manner that maximises usage of finite resources and value adds to the lifecycle of traditional timber production methodologies.

4.2 Scope of prototype

The scope of the proof-of-concept was to establish a low-tech workflow that utilised RGB-D scanning to determine sawn board features (live and dead knots) in plantation *E. globulus* (Figure 9). Live and dead knots present significantly different structural capacities (Kretschmann and Hernandez, 2006) that impact the suitability of a material for a certain task. This suggests that when considered on a board-by-board basis, feature rich LGH has potential in construction, particularly within bespoke manufacturing and engineered system scenarios.

![Figure 9: Live (above) and dead (below) knots in dressed timber boards.](image)

4.3. Timber samples

Dressed 140x35mm *E. globulus* boards were selected for the experiment (Figure 10). The samples originated from a 16-year-old Tasmanian plantation that had been managed for pulplog. They demonstrated a typical range of features including clear wood, gum vein, live and dead knots, at a low-to-medium frequency as would be expected from a pulp-managed forest. 20 samples were used, ranging in length from 450mm to 2100mm.

![Figure 10: A sample of *E. Globulus* boards used for testing](image)
4.4. Prototype

4.4.1. Setup: Hardware

A Microsoft Kinect was selected as the CV hardware for the prototype, providing an adaptable off-the-shelf solution. The Kinect development framework provides access to low-level data streams from the depth sensor (512x424 infrared active, 0.5-4.5m range) and the HD camera sensor (1920x1080, 30 fps) which are utilised within the prototype. The RGB sensor offers 2,073,600 pixels of data at a field of view of 84.1x53.8 degrees. The infrared sensor provides 217,088 depth voxels at a field of view of 70.6x60 degrees (Diaz et al, 2015; Lachat et al, 2015). The Kinect offers relatively high sensor quality considering its purchase price.

The Kinect’s sensors allow an easy transition from proof-of-concept to commercialisation as they are easily substituted for high quality, specialised components suitable for a production environment. Additionally, open software platform support (SimpleOpenNI and libfreenect2) allows the Kinect, or substituted hardware, to be adapted to a wide variety of scenarios.

4.4.2 Setup: Software

The Kinect provides support for a number of software platforms including python, C/C++, Matlab and visual basic. However, as the proof-of-concept sits as a part of a wider project, an architectural CAD package was chosen as the development platform. This choice is critical to the development as it provides a fluid environment in which CV data can be directly integrated and visualised with a design and fabrication software workflow. McNeel’s Rhinoceros 3D 5.0 (Rhino) was selected as a platform, in addition to the Grasshopper visual scripting plugin.

This combination provides a graphical environment to develop within, allowing the datasets to be contained within the same geometry based platform as the wider project (adaptive design and robotic fabrication). A significant difficulty of using a CAD package for live RGB-D is the inability to handle large datasets. The Tarsier plugin (Newnham, 2016) provides Grasshopper with near real-time access to the Kinect data stream by treating the RGB-D voxel data stream as a single point cloud. Tarsier additionally includes a number of parsing tools to filter the stream for environmental interference and data that is out of the prescribed scan range.

4.4.3 Setup: environment

Two scenarios were established to test the Kinects RGB-D scanning fidelity over short-range (600mm) and long-range (3000mm), as shown in Figure 11. The long-range tests were scanned horizontally, while the short-range test was scanned vertically. In both cases, the boards were scanned in a single pass, and the sample and Kinect were aligned to ensure minimal perspective distortion. In a production environment, the short-range scanning arrangement is more suitable due to the increased resolution and lends itself to development as a lineal scanning process (broom-stick) to accommodate longer timber lengths common in production-line manufacturing.

The hardware/software interface was controlled in two stages within Grasshopper, as shown in Figure 12. The first stage controlled the RGB-D scanning and identifies knot locations and type. Additional parsing filters eliminate unnecessary scan data, control the size threshold of a knot (clusters of similar
colours or depths), and compares RGB and depth streams to establish which features are live or dead knots within the board.

The second stage combines the board data (size and features) to a unique ID and exports the information into a text based data format. The information contained relates to the resulting usable length/s of the board in its entirety; usable lengths after dead knots are removed; and usable lengths with all knots removed. The CSV text format allows this information to be either stored in a database for future use or integrated immediately in a production workflow.

![Figure 11: Long-range (left) and short-range (right) experiment setups](image)

![Figure 12: Knot identification and board sorting workflows](image)

The parsed and clipped raw data form the Kinect is shown in Figure 13. The prototype allows for the fine adjustment of the scan feed including depth range, scan density, smoothing and frequency. Live knots are detected in relation to the depth of the scan, compared against the thickness of the board. A depth threshold was set at 5mm, with any voxels having a greater depth greater identified as potential dead knots and clustered together.

The processing of the detected dead knot cluster is shown in Figure 14. If a cluster of points has size larger than the specified diameter it is isolated. The minimum usable length of timber was specified as
500mm and considered against the knot location and the overall length of the board. Figure 14 shows the usable board indicated in green, with the un-marked section too short for use.

![Image](image1)

**Figure 13:** Raw data displayed as coloured voxels (left) and with dead knot detection (right),

![Image](image2)

**Figure 14:** Dead knot isolation (left) and usable length output in green (right)

### 4.5 Results

Figure 15 illustrates typical results obtained from the long-range scans. After RGB and depth comparisons the red zones indicate dead knot locations and the blue zones are linked to live knots. The green areas identify useable lengths within the board after knots are removed, while the uncoloured area are lengths are shorter than the specified minimum-length.

![Image](image3)

**Figure 15:** Live scan and knot identification

The long range tests demonstrated a high level of success in identifying knot defects via RGB scanning techniques. However, the depth scanning technique offered less successful results at this range in determining dead knots. The most probable reason for this is related to the lower density of scan points detected over larger distances, making smaller features harder to detect. The short-range tests were able
to detect much smaller defects in the timber samples and demonstrated a higher level of correlation between RGB and depth data in the determination of live and dead knots. The output of scan results to raw data (Table 3) groups the information according to the sample identification. Although the experiment was conducted in a workshop environment, environmental interference resulting from sunlight was evident. Again, this is a larger issue in the long-range scans.

Table 3: Sample of knot location output

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Length (mm)</th>
<th>Live Knot Location</th>
<th>Dead Knot Location</th>
<th>Usable Lengths (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N001</td>
<td>465</td>
<td>159, 316</td>
<td>62</td>
<td>-</td>
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<tr>
<td>N002</td>
<td>614</td>
<td>249, 401</td>
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<td>-</td>
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<td>-</td>
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<td>1200</td>
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<td>714</td>
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<td>1980</td>
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<td>N020</td>
<td>2100</td>
<td>-</td>
<td>601</td>
<td>1450, 580</td>
</tr>
</tbody>
</table>

A combined 21.6 lm of samples were scanned with 18.0 lm determined as usable. This represents an 87.5% recovery return in system that has a 500mm minimum usable requirement. For comparison, a 54.7% recovery rate was apparent when the minimum length was specified as 900mm.

5. Discussion

5.1 Industry 4.0: Cyber-physical manufacturing processes

The fourth industrial turn, often referred to as Industry 4.0, posits a shift in manufacturing from the automation of generic, dangerous and repeated tasks towards the establishment of reciprocal interactions between physical processes and increasingly aware and intelligent computational decision-making strategies. Sedlar et al (2016) states that:

“Based on the merging of digital computation resources with physical objects, a Cyber-Physical System (CPS) represents a novel paradigm that aims not merely to be able to gather information about the state of the physical world but also to influence it based on the gathered data.”
As such, CPS provides the conceptual and technological framework upon which a smarter, open-ended and resource efficient manufacturing sector can be established. CPS accommodates an unprecedented opportunity to value-add to the existing supply chain of Australian hardwood. Information containing origin, management type, growth rate, feature distribution and density can be integrated, allowing designers and fabricators access to material information previously unviable. Capacity to specify intrinsic visual and performance based characteristics of LGH allows designers and fabricators to match design and supply within a digital manufacturing process to ensure that the highest value and material return is achieved. Additionally, forestry management and harvesting strategies could be enhanced allowing for more productive and valuable methodologies to be established.

5.2. Digital supply & manufacturing

Bespoke modes of production are especially relevant to stick-based timber construction systems that could comprise elements of differing performance (functional grading) and dimensional properties (length, width and depth). The potential of this approach is demonstrated by the recently completed Sequential Roof project at ETHZ, that utilises short length graded timber elements in conjunction with an automated robotic fabrication system (Apolinarska et al, 2016). While this project doesn’t utilise an adaptive CV/fabrication process, it establishes precedent for architectural scale systems consisting of thousands of unique timber parts.

In the context of this research, the proposed RGB-D scanning prototype accommodates the utilisation of LGH within a bespoke design/fabrication process. The prototype essentially creates a database of usable timber that can be integrated into a computational design process – the performance based design solution is adaptable to the material that is immediately available. When coupled with digital manufacturing, complex arrangements of material can be managed with specificity.

6. Future Work and Conclusion

This research provides a proof-of-concept data generation solution for two integrated CPS design-to-production pipelines; intelligence at the point of work (fabrication) and; intelligence in regard to the sourcing of timber from a big-data archive. There is much work to be undertaken in order for it to be utilised within a larger cyber-physical design/fabrication system however.

Empirical testing and comparison of RGB-D results and traditional visual and mechanical grading requires further investigation to allow accurate integration machine learning based predictive assessment of LGH at the point of fabrication. Further work is necessary to determine the type of solutions that are viable with this type of dataset, particularly focused on how it would integrate with performative design workflows that are linked to direct fabrication capabilities.

The proof-of-concept outlined in this paper provides a starting point for the LGH timber industry to reassess its strategies around production and delivery attempting to increase the value of an otherwise overlooked and under-valued resource.

7. Acknowledgements

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References


Timber Frame Construction for a Circular Materials Economy

Alternative Framing Methods and Post-Use Certification

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Abstract: The building and construction sector in New Zealand consumes more than 50% of all raw materials while simultaneously generating more than half of all waste sent to landfill. These unprecedented levels of consumption are set to continue as demand for residential housing continues to grow rapidly. This research suggests that building construction methodologies and compliance infrastructure could be established that would enable the widespread reuse and recycling of building materials. Design experimentation shows that an efficient, flexible and affordable reusable wall system can be fabricated using a range of commonly available construction materials. Practices for the post-use certification and strength testing of materials are proposed to validate widespread adoption of material reuse in the construction industry. Visual strength grading of recycled timber is highlighted as a critical factor for enabling the widespread and affordable reuse of this material.

Keywords: Material Reuse, closed loop design, cradle to cradle, sustainability.

1. Introduction

Architects and building professionals, as key figures in the building sector, have a responsibility to implement systems that reduce the impact of our industry on the environment. This research sets out to eliminate key barriers for material reuse in New Zealand. There is inherently two dimensions to this work. Buildings must be designed to enable the reuse of material and crucially, the integrity of those second-hand materials, at the end of their first life, must be assured.

1.1. The Waste Problem

In New Zealand the building and construction industry produces more waste than every other sector combined (Inglis, 2007; Storey et al, 2005). The industry has been optimised for economic efficiencies and in doing so has adopted the widespread application of single use and composite materials (Curtis, 2014). These materials, although adaptable, durable and cost effective, have no reuse value as they are either damaged on removal or not approved by building codes for reuse. Products such as plasterboard (drywall), treated framing timber and reinforced plaster monolithic claddings are all single use materials that are found in most residential structures built in New Zealand (Curtis, 2014. Baker-Brown, 2017). These ‘engineered’ materials are fixed in a way that makes removal without damage an impossibility and are
also difficult to recycle or reprocess in a meaningful way (Baker-Brown, 2017). Furthermore, these materials are often treated with chemical stabilizers to prevent the ingestion of water, notably copper, chrome, arsenic (CCA) treated timber. When landfilled these chemicals will delay the decomposition process, damage neighbouring ecosystems and potentially contaminate groundwater (Parisio, 2006). Based on current building trends we can expect to see the dumping of increasingly toxic building waste (Curtis, 2014; Inglis 2007; Keene and Smythe, 2009).

1.2. Eliminating the waste problem long term: Reusing Building Materials

A tightly regulated building industry makes it difficult to simply replace chemically enhanced building materials with natural alternatives. The widespread use of treated timber in New Zealand buildings today reflects the recent ‘leaky building crisis’ where water penetrated the cladding and rotted untreated structural timber framing (Ridley, 2003). Legislation was introduced in 2004 to resolve this issue that made the use of treated timber mandatory for all structural applications of the material (NZS3602:2003). This measure ensured that even if water contacted the timber frame rotting and decomposition would be significantly delayed (NZS3602:2003). Consequently, reverting to the use of untreated or partially treated timber for structural framing of building is unlikely due to the recent leaky homes issues and would face significant opposition (Harris, 2017). Modern building practices dependence on chemically enhanced materials that have the potential to cause significant harm to the environment dictates that we must develop effective methods for reusing these materials.

Fortunately, the benefits of reuse are remarkable. Reusing building materials prevents potentially hazardous substances (such as CCA) from being deposited into landfills (Chini, 2001). Reuse also helps to lock in carbon and significantly reduce the industry's demand for new ‘virgin materials’ (Storey et al, 2005). Furthermore, through the reuse of so called ‘waste’ material we have the potential to stabilize the cost of materials in the construction industry, reduce our reliance on petrochemicals, improve the air quality of internal spaces all while minimising the impact of building on the environment (Baker-Brown, 2017).

2. Redesign: Closing the Loop

2.1. Closed Loop Materials Design

Fundamental barriers to widespread material reuse in the construction industry are the result of economic imperatives. These imperatives dictate the use of low cost fixing methodologies and the uninterrupted supply of quality certified building materials. A highly regulated building industry also means demands the use of specialist, non-removable and adhesive fixings. Materials fixed using these methods are often damaged on removal, lowering both the resale value and reuse potential of that material. For this reason any product that is to be reused must be recertified to prove that it will retain the required integrity for the next lifespan/use.

To successfully eliminate hazardous waste products from the construction industry architects must design for a closed material loop (Baker-Brown, 2017). This process ensures that every material contributes positively to its surrounding environment at all stages of its life cycle - thus creating a closed loop where the devaluing (downcycling) of a material is carefully controlled and there is ‘no waste’). Ideally each stage of a materials life cycle should feed intrinsically into its next. Materials used in construction today typically fall into 3 categories of reuse ‘loop potential’ (Braungart and McDonough, 2010; Baker-Brown, 2017).
• **Technical Cycle** - refers to materials that are highly engineered and often energy intensive to fabricate. These materials are generally highly durable and resistant to damage and corrosion. Providing they are jointed in a way that enables deconstruction these materials can be used again and again without producing any waste. Materials with such properties include aluminum and steel.

• **Organic Cycle** - refers to materials that feed into a natural waste management process. Often decomposition transforms these materials, over time, back into the nutrients that the materials once grew from. Materials matching this description include untreated timber, lime based plaster renders and unbound stone.

• **Compromised** - refers to materials that are either designed poorly or compromised in some way over their lifetime. These materials cannot be naturally decomposed without causing harm, nor processed by humans without losing their integrity. CCA timber is a leading example of a material that has a compromised potential to be effectively and safety disposed of.

### 2.2. What redesign must achieve

The introduction of more effective mounting, jointing and wall systems will enable disassembly and reuse without causing damage to the individual components. The ideal design solution ensures that all the materials put into one building have a place in future buildings. For example, a wall designed for material reuse must fulfil all the criteria of a modern-day walling system, and also allow for ‘economical’ disassembly, relocation and re-erection (Table 1). This means that the dimensional properties of the walls components must be attractive to a broad range of design contexts. Likewise, the finished surfaces of this reusable walling system must be specified to retain a ‘new’ aesthetic right throughout their ‘endless’ lifetime. This ensures that the wall not only meets technical reuse imperatives but also meets the demands of the construction marketplace.

<table>
<thead>
<tr>
<th>Conventional walling system features:</th>
<th>Additional features necessary for reuse:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provide support for overhead members</td>
<td>Allow for economical disassembly</td>
</tr>
<tr>
<td>Be easily transportable to site</td>
<td>Be easily transportable from the site</td>
</tr>
<tr>
<td>Support waterproof barriers and aesthetic claddings</td>
<td>Be undamaged by the process of deconstruction</td>
</tr>
<tr>
<td>Support insulation / thermal resistance</td>
<td>Retain an ‘as new’ external aesthetic quality</td>
</tr>
<tr>
<td>Support internal aesthetic linings</td>
<td>Facilitate the removal of all components</td>
</tr>
<tr>
<td>Allowing the fixing of lights and appliances</td>
<td>Account for all material at end-of-life</td>
</tr>
<tr>
<td>Carry electrical and wet services</td>
<td></td>
</tr>
</tbody>
</table>

### 2.3. Analysis: Existing Solutions

Conventional construction methodologies are examined and categorised qualitatively based on the essential features of a closed loop wall design (outlined in Table 1) in Table 2. Factors determining the potential for reuse have been equally weighted when rating a construction method for reuse. Specific features of a system that significantly impact the reuse potential have been noted to highlight the range of factors that determine the potential reusability of the materials in each construction method.

Table 5: Common existing wall construction options in New Zealand & their potential for material reuse.
<table>
<thead>
<tr>
<th>Construction System:</th>
<th>Specification:</th>
<th>Deconstruction Notes:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Steel Framing (LSF)</td>
<td>90mm x 40mm galvanised 0.55mm Gauge steel, lipped ‘C’ section. Riveted.</td>
<td>Moderate potential for reuse. Rivetted connections slows deconstruction and can damage the material. Frame often damaged by lining fixings and adhesives - time intensive to prepare for reuse. Plasterboard lining damaged on removal, ‘downcycled’, contaminated and dumped.</td>
</tr>
<tr>
<td>Structurally Insulated Panels (SIPs)</td>
<td>165mm polystyrene foam (XPS) with 18mm Orientated Strand Board (OSB). Screwed.</td>
<td>Limited potential for reuse. Large panel sizes make the deconstruction process more expensive. Edges often sealed with an adhesive based foam that is inherently single use. Custom cut panels cannot be reused readily. Expanding foams make extraction without damage challenging.</td>
</tr>
<tr>
<td>Insulated Concrete Forms (ICF)</td>
<td>40mm polystyrene foam (EPS) formed blocks with reinforced concrete infill.</td>
<td>No potential for reuse. Initially modular but compromised by reinforced monolithic concrete to create composite single use system. Expensive, messy and disruptive to remove. Requires single use fixings of linings and claddings. Waste material downcycled or landfilled.</td>
</tr>
</tbody>
</table>

2.4. Key Issues to Resolve

The analysis of existing wall construction methods (Table 2) illustrates key areas of concern with regards to material reuse. A critical concern is the layering and fixing of engineered materials to create monolithic finishes. This is an area of significant waste that is difficult to mitigate as the monolithic surface, generally plasterboard, is a highly desirable aesthetic that also aids in the sound and draft proofing of spaces. A similar concern is the dependence of conventional walling systems on adhesives, silicon sealants, and fragile fabrics to form the waterproof barrier of the building. Reuse of such materials is difficult and strictly prohibited as such practices are deemed a risk to the water-tightness of the building envelope. Collectively these two issues become the focus when designing a walling system that will eliminate waste.

2.5. Analysis: Designed Solutions

Common wall construction techniques (Table 2) generally fall into three categories: monolithic, panel based and framed. Framed solutions, such as LTF, are listed has having the most potential for reuse due to their inherent separation of materials into discrete, removable, layers (Chini, 2001). This separation allows materials to be deconstructed into their individual components more readily and without significant damage. Panelised wall options (i.e. SIPs) have similar characteristics but are often too large to handle and transport easily without significant expense. Monolithic walling systems, such as ICF’s, have no potential for reuse as they are generally composite and to large, heavy and fragile to relocate effectively. Unfortunately, framed wall designs are often clad both sides with monolithic plasterboard and
reinforced cement plaster render finishes. Although these materials do not damage the structural frame upon removal they are too fragile to be removed without ‘catastrophic damage’ and therefore become waste. Monolithic surface finishes are also commonly found on panelised wall systems. These issues have been addressed collectively in design based experiments (Table 3 & Figure 1).

In response to these issues a range of alternative wall framing and assembly methods have been evaluated. The selected systems are a combination of existing experiential methods, not specifically intended as a cradle-to-cradle solution, as well as construction methods explicitly designed to promote material reuse. Existing experimental systems have been selected based on their perceived ability to meet the ‘additional features necessary for reuse’ outlined in table 1. The inclusion of these systems is intended to indicate the potential feasibility moving to reusable construction approaches. New and alternative wall assemblies have been designed in direct response to the criteria outlined in table 1.

Table 6: Summary of experimental wall designs and their deconstruction and material reuse potential:

<table>
<thead>
<tr>
<th>Construction System</th>
<th>Specification:</th>
<th>Deconstruction Notes:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Click-Raft (designed by Chris Moller Architects)</td>
<td>Computer numerically controlled (CNC) router cut structural square edge plywood sheet. 2400<em>1200 CD Grade 12mm CCA H3.2 Treated. 450</em>350<em>900 Straw Bales with CNC router cut structural square edge plywood sheet. 2400</em>1200 CD Grade 24mm CCA H3.2 Treated.</td>
<td>Moderate potential for reuse. Multi-use structural fixings where necessary, generally minimal fixings required, no damage to structural material. Lightweight, easy to disassemble and transport. Self-bracing, allowing conventional linings to be fixed alternatively - preventing likely dumping. Good potential for reuse. Multi-use structural fixings where necessary, generally minimal fixings required, no damage to structural material. Largely organic, quickly renewable and non-contaminated material basis. Monolithic, purposely sacrificial, decomposable finishes. Strong potential for reuse. Multi-use structural fixings where necessary, generally minimal fixings required, no damage to structural material. Lightweight, easy to disassemble and transport. Self-bracing, allowing conventional linings to be fixed alternatively - preventing likely dumping. Massively modular in plan and elevation. Integrated cladding and lining ‘fixingless’ system.</td>
</tr>
<tr>
<td>Click-Cell Straw (author modified ModCell Ltd Straw Panel System)</td>
<td>CNC router cut structural square edge plywood sheet. 2400*1200 CD Grade 18mm CCA H3.2 Treated. Self-Braced.</td>
<td></td>
</tr>
<tr>
<td>‘XFrame’ (by author)</td>
<td>90*45 KD PG SG8 Radiata Pine Timber Studs CCA Treated with Nogs @ 800ctrs. Bolted and Pegged.</td>
<td>Good potential for reuse. Multi-use structural fixings with reusable steel interlocking plates. Like current LTF system and deconstruction friendly but significantly costlier. Self-bracing, allowing conventional linings to be fixed alternatively (clipped)- preventing dumping/downcycling of materials.</td>
</tr>
</tbody>
</table>
XFrame and Click-Cell Straw (see figure 1) both assemble using fully reversible compression based joints and mix technical materials with ‘sacrificial’ natural materials to create assemblies that have significant potential to eliminate construction waste. These alternative solutions are derived from the self-braced Click-Raft frame developed by Chris Moller and the ModCell glue-laminated timber straw bale system popular in the United Kingdom. The XFrame system (figure 1) uses readily available and replaceable materials in a pattern that is self-bracing, requires no additional fixings and provides the foundation for fixing free waterproof cladding and internal wall lining to be added. The components of this system can be handled, assembled, and disassembled, by a single person with only the use of a simple wooden mallet and a step ladder. The wall, and its linings, can be scaled in size in 600mm intervals and facilitates the easy installation and removal of plumbing and electrical services.
3. Certifying Materials for Reuse

The proposed reusable design solutions are dependent on approval by the New Zealand Building Code (NZBC) as an *acceptable alternative solution*. To achieve this, it must be proved that reused materials, like those specified in the proposed design solution (figure X), can perform to the necessary strength requirements stipulated by the industry. In New Zealand however there is currently no legislation for the reuse of structural timber. Accreditation and formal legislation is essential to streamline the evaluation process of reused materials and assure their reuse potential. For this reason a possible process of post-use certification has been studied and associated technical challenges considered.

3.1. The need for post-use certification

Current New Zealand building standards do not require specific engineering in simple light timber frame construction. This practice dictates that the supplied material must be certified to perform to a minimum standard to ensure it is adequate for all potential use cases. This presents an issue for material reuse. Research in the field shows that the strength of a timber member will vary over its lifespan. Inconsistencies such as the duration, size and nature of an applied load can all affect strength over time (Crews et al, 2008). This is expressed through a common denominator, the ‘K-Factor’, which explains how a constant load can degrade a timber member over a given period (Crews et al, 2008). There are other scenarios which can also affect the grade of the timber after its first life such as fixing extraction and damage incurred through transportation. Collectively these variations impose uncertainties in the structural abilities of second-hand timber, effectively requiring each member to be re-tested against established codes of compliance. This testing ensures that the material is of an adequate level of performance and will structurally bear the load which is placed upon it.

3.2. Strength Certification Methodologies

To test for structural integrity of timber the industry uses a range of grading techniques. Traditionally the building industry utilized *Visual Strength Grading* (VSG) as its primary method of quantifying the potential strength of a timber member. All material was sorted on site and timber with impurities (knots or rot) or of a low quality was removed and assigned to areas with low structural requirements such as dwangs or nogs. This system proved highly economical as it allowed the builder to recycle and reuse timber without the need for independent testing. Today however mechanical grading has been introduced throughout the industry and the grading requirements are much more stringent. Mechanical strength grading has replaced all VSG and is achieved either using a three-point bending test machine or the more sophisticated method of acoustic strength grading “that uses sound waves to measure timber stiffness” (Scion, 2008). These testing methodologies are outlined in detail below:

*Three Point Bending Strength Grading*

Traditional mechanical bend testing is achieved through a three-point hydraulic system which is manually controlled by an operator applying pressure through a jack handle. The applied force is represented through a pressure gauge which reads both the imposed BAR and PSI pressures acting on the timber through the hydraulic ram. This figure and the displacement distance of the timber is multiplied with the area of the ram to give force acting on the member. Testing with this machine can see varied results due to the need to accurately calibrate the pressure gauge and hydraulic ram. Consequently the accurate grading of reused timber in the field using this method may be difficult.
Acoustic Strength Grading

The New Zealand based crown owned research institute Scion developed, in association with Falcon Engineering, an automated acoustic strength grading machine in 2005 (Scion, 2008). Acoustic strength testing is achieved by “a pneumatic hammer producing a tone in the selective timber member, and a highly sensitive recording device receiving this tone” (Scion, 2008). This tone can then be translated, with all the other known factors; size, weight, density, into the respective bending strength of that timber member (Scion, 2008). This new and experimental grading technology has been installed in several different timber mills around New Zealand.

3.3. Developing a VSG Standard for Recycled Timber

The most desirable method for certifying the strength of recycled timber is visual strength grading (VSG). VSG significantly reduces the cost of grading timber for its second life as specific testing machinery is not required. Likewise, the recycled materials do not have to be transported from their original site to a testing facility and then to a new site. These economic savings can be passed directly onto the consumer and help to keep recycled timber cost competitive with virgin materials. Visual strength grading of recycled timber can also be more accurate than automated acoustic or bend testing processes. VSG calls for a detailed aesthetic inspection of the material which will help to identify common recycled timber issues quickly such as crushed or splintered sections. Mechanical strength grading processes as they are today would not identify such defects.

To achieve accurate VSG standards and guidelines for reusing timbers (such as those specified in the proposed reusable wall designs - figure 1) a series of interrelated strength tests must be carried out. Studies of reused timber with a specific set of defects and the correlation between mechanically strength graded values and visually graded values is a critical first step in this process. Testing will allow for an accurate VSG grading guide to be established for recycled timbers. This testing to establish a standard must be extensive and methodologically documented as it will dictate what damage or defect each timber member can have before it is compromised structurally and becomes unusable.

Sampling reused timber to establish a VSG standard

As part of the process towards establishing grading standards for the use of recycled timber test samples must be selected. Fortunately, 95% of all houses built in New Zealand use a timber framing system that could provide valuable samples for testing (Shelton & Beattie, 2011). However this quantity of potentially recyclable material also creates a problem. For each member extracted for testing and analysis the full history of the timber member must be understood. The timber’s geographic location, nearby environmental conditions and previously attached cladding and wall lining systems will all likely influence the strength performance of it in some way. Such a varied sample base makes defining VSG criteria difficult.

Testing recycled timber samples to establish a VSG standard

The process of testing samples to establish a standard for grading recycled timbers is proposed. The material will firstly be visually assessed as it would be in real world conditions. This will assess the recycled timbers strength based on aesthetic information. This information includes knots, fixing holes, crushed
and splintered material, warping, rot and other deformations. Strength grading standards are based on established VSG literature; specifically New Zealand’s 1998 NZS: 3631, visual grading schedule, and also Australia’s ‘Recycled Timber – Visually Stress Graded Recycled Timber for Structural Purposes’ (Standards New Zealand, 1988) (Crews, Hayward, & MacKenzie, 2008). These documents include the original VSG guidelines for New Zealand prior to the widespread introduction of machine graded timber, and the recently developed interim timber recycling and reuse guidelines for Australia. International standards (ISO) for visually strength grading timber, namely ‘ISO 9709:2005 Structural Timber – Visual Strength Grading – Basic Principles’ will be used to ensure grading processes are in accordance with international best practice.

After the completion of initial VSG, the accuracy of this grading will be measured using a mechanical grading system. While the acoustic grading machine can conduct all necessary measurements at a high turnover rate, acquiring such a machine is both costly and difficult. It is therefore likely that the testing will revert to the traditional mechanical strength testing approach of a three-point bending test. As these tests are to be completed under laboratory conditions the accuracy of the pressure readings can be assured.

3.4. Continuations

Testing of recycled timber samples to establish a visual strength grading system for the proposed reusable wall design is in its infancy. Further research hopes to conduct a comprehensive analysis of recycled timber samples obtained from a wide variety of construction and demolition sites to eventually establish an accurate correlation between mechanical strength tested recycled timber and VSG. This correlation will be largely supported by existing VSG codes available in New Zealand for new timbers and the interim standards for the reuse of timber in Australia (Standards New Zealand, 1988) (Crews, Hayward, & MacKenzie, 2008).

This paper has dealt with two key barriers restricting widespread material reuse in the construction of light timber framed buildings; post use certification and structural assemblies. There are numerous other barriers to enabling the widespread reuse of materials; the cost of dumping vs the cost to reuse, product storage, transport issues, structural compromises, legislation, durability, dismantlability, disaggregate potential and the numerous conflicts between recyclability vs reusability, downcycling and upcycling. It is the intention of the authors to continue their research into these areas.

4. Conclusion

The building and construction industry faces major waste management challenges in the next 50 years. Current building practices that depend on single use materials and adhesive based connections must be eradicated to eliminate the production of downcycled or waste materials. This research demonstrates that waste produced from the demolition of residential structural walls can be all but eliminated with the introduction of alternative construction methods. The proposed methods integrate fully modular and reusable structures with integrated provisions for the fixing free and reversible attachment of waterproof and aesthetic linings. To ensure the feasibility of material reuse adoption by the industry post-use compliance testing processes for timber have been proposed and discussed. Economic issues associated with the process of strength grading materials for compliance at the end of their first life proves to be a significant barrier to the adoption of widespread material reuse. However, the adoption of visual strength
grading (VSG) standards for recycled timber members in structural applications has potential to make certification of recycled timber economical.

Acknowledgments
The authors thank the numerous industry professionals and business who have offered material samples, advice and insight.

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BIM is Easier Said than Done

Calibrating Architectural Education in New Zealand to the Opportunities of BIM

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Abstract: Creating, manipulating, sharing and appraising building information through digital 3D models is one of the most extensive paradigm shifts to have occurred in contemporary architectural practice. Despite the promise of BIM, documented instances of its success and endorsement by governments, the architectural profession has been slow to assimilate BIM into practice. This paper will argue that the nature of the virtual building challenges the architectural designer to reconsider attitudes towards representation and literal engagement with the digital model. In response to this, this paper examines the expectations of the AEC industry regarding BIM and questions the preparation of architectural graduates to meet this challenge. The paper reports on a focus group of recent graduates that confirm the current lack of exposure to BIM in schools. An approach to addressing this deficiency in the design studio is offered and a way forward for the profession to take its place in the future with BIM. It should be noted that the views reflected in this paper is that of the author only and does not necessarily represent the views of Studio of Pacific Architecture.

Keywords: BIM; architectural education; virtual building; design studio.

1. Introduction

Managing building information through the generation, manipulation and sharing of digital three-dimensional models is one of the most extensive paradigm shifts to have occurred in the Architecture, Engineering and Construction (AEC) industry. This shift has ignited such energetic discourse, that within the last 10 years there has been phenomenal growth in the number of books, papers, blogs and channels that discuss and debate the associated changes and implications of BIM (Building Information Modelling/Management) (The B1M, 2017; The BIM Hub, 2017). This excitement is not without reason, as the promise of BIM centres on leveraging technology to achieve high efficiencies in designing, creating and operating buildings now and in the future.
Despite the promise of BIM and documented instances of success, BIM has somehow failed to gain much practical traction amongst practitioners in the industry. This is especially so in the architectural profession where a near 100% awareness of BIM corresponds with only 62% use in the UK (58% in New Zealand) (Malleson, 2017; Reding, 2016). There are several reasons for this slow adoption, which range from the adversarial nature of the industry to a lack of education on the part of clients. One such impetus (it is argued in this paper) for the lethargic acceptance of BIM by the architectural profession is the prevailing attitudes of architectural graduates and the nature of their preparation/socialisation in architectural school to meet AEC industry expectations regarding BIM.

The paper, as written, aims to be a catalyst for discussion and research regarding socialisation in architectural education regarding the use of BIM. It will expatiate on this theme by defining BIM and highlighting the central focus needed for BIM to fulfil its promises. Attention will be paid to the endorsement of BIM by national governments and the profession’s response to required change. Evidence of the lack of preparation in schools of architecture will be presented from a “focussed conversation” with recent New Zealand architectural graduates. The paper will conclude with a discussion about the strategies and reformations schools will have to undergo to respond to the challenges and adequately prepare graduates for a world dominated by BIM.

2. BIM

The idea of BIM is straightforward. Using associated digital tools, participants involved in the production of the built environment create and share computer-generated 3D models that contain the precise geometry and data needed for the design, construction and operation of built assets. Information is literally and figuratively at the centre of BIM as participants interact with information in three ways:

- Manipulation – extracting, querying, analysing and subsequently transforming information throughout the lifecycle of the asset.
- Collaboration – sharing and coordinating information with other participants throughout the lifecycle of the asset.
- Organisation – Welding digital tools and related actions to create and organise information that can be utilised, transformed and shared.

If BIM is done properly, it has the potential to dramatically transform the delivery of built assets by providing information for effective decision making, unlocking more efficient methods of working, and promoting a more structured collaborative approach to project coordination. This, in turn, facilitates “better quality buildings at a lower cost and reduced project duration” (Eastman et al., 2011).

The potential of BIM to revolutionise the AEC industry has been recognised by national governments as a means of reducing construction costs and waste while improving productivity. For instance, in 2011 the UK government undertook several initiatives in an effort to reduce construction costs by as much as 20%. One of these undertakings was to mandate that all government projects use “collaborative 3D BIM (with all project and asset information, documentation and data being electronic) [...] by 2016” (Cabinet Office 2011). This declaration resulted in the development of British standards for BIM practice and an avalanche of blogs, articles, conferences, symposia and assorted information about BIM. Following the lead of the UK, a number of other countries globally began to realise the opportunities BIM promised and are now investing in developing their own capability. This includes the New Zealand government, which allied itself with the AEC industry to coordinate efforts to increase the use of BIM in New Zealand (NZ).
Despite the full scale endorsement from government and a high awareness of BIM, the use of BIM grows slower than expected every year. In the NZ industry only 58% of projects involving architects and engineers use BIM (Reding, 2016). There may be several reasons that prevent widespread adoption. Chief among them would be the prevailing culture of the NZ industry. Added to this might be the adversarial nature of industry, timing of procurement, lack of demand from clients, lack of in-house expertise or as in the case of architects, the need to reconcile the shift in focus “away from representational development (drawings) and towards formal and spatial development (ideas) through the development of the three-dimensional [virtual] model” (Ambrose, 2006).

3. The Virtual Building

Reliability and integrity are characteristics the information in BIM must embody to unlock more efficient methods of designing, creating and maintaining built assets. This reliability and integrity is dependent on the collaborative activities of the team and the quality of information contained in the Virtual Building. The Virtual Building is a digital replica (not a representation) of the building being designed and constructed. The difference between replica and representation in the case of the virtual building is stark. The traditional means of representing information is through “distorted two-dimensional abstractions of three-dimensional space”, whereas the replica is “an object oriented, intelligent component/database synergistic promise of virtual assemblage through simulation” (Ambrose, 2006). The virtual building is literally the edifice (albeit imagined) to be constructed. It clarifies the relationships of the building parts and components to the whole and is subject to the scrutiny of performance evaluations. The information that defines or is contained in Virtual Buildings can be classified as the following types:

- Geometry - A 3D description of the building and its constituents. (e.g. height, width, volume)
- Object Identification - The identity of the 3D objects. (e.g. wall, door, column, floor)
- Attributes - Information that describes the properties of each 3D object. (e.g. materials, position, manufacturer, location, etc.)
- Relationships - Information about the connection between objects. (relationship between a door and the wall it fits in, relationship between a floor and beam).
- Behaviour - How objects would behave within a physical environment. (e.g. If subjected to loads, heat, cold, human action).

A well-executed virtual building model, which incorporates all these information types, creates an intelligent, reliable and wholesome visualisation of the built asset. This allows participants the freedoms to simulate (test and experience) various aspects of the building, from costs and construction sequences to analysis and the prediction of building performance.

Considering the virtual building in the design process challenges the architectural designer to eschew tools of abstraction (2D representation) for a deeper, more literal engagement with the design proposal. This requires an acknowledgement of BIM as a reconfigured way of seeing, thinking and making in the design process. Neglecting this new paradigm would relinquish the architect’s position with coordinating information, denying opportunity to regain control of the information flow in the design and construction process.
4. Lack of Skills in a BIM World

The rise of BIM from an academic vision to the mainstream of the AEC industry has placed architects in a position that requires fundamental change in how they engage with other participants in the design and construction process and most importantly, produce and communicate project information. A progressive attitude and enlightened perception places a high value on the establishment of the virtual building and the creation, manipulation and sharing of the information contained within it. Ultimately this affects how they practice and consequentially the skills required of new recruits in the profession.

This situation has created a significant demand for architectural graduates who can create “intelligent” virtual models that contain information (geometric and non-geometric) that can be modelled, manipulated and shared during the entire project life cycle. This model would be embedded with an understanding of practical concerns balanced with critical and abstract thinking. Unfortunately, the current format of architectural education as it exists in academia, would be hard pressed to supply this demand.

The education of the architect, which has not changed significantly since the 19th century, has come up short in recent years. There has been widespread criticism from the public, profession and industry with allegations that the current model of architectural education is not providing students with the requisite skills sought by potential employers. Schools of architecture have been accused of producing graduates that lack adequate preparation for the demanding world of practice. A recent survey in 2015 undertaken by RIBA Appointments – the recruitment arm of the Royal Institute of British Architects – found that the majority of both practitioners and students think that architectural education puts theory above practical ability and believe graduates lack the knowledge to build what they design (Dobson, 2015). It follows that if graduates lack practical skills or the knowledge of how to build then they would also lack the skills needed to take advantage of BIM (which requires, in part, a practical understanding to create a virtual building). In the same survey, it was reported that BIM was among the top 5 expected core skills required by employers when recruiting graduates. This expectation according to the survey, was seldom met (Dobson, 2015). Criticisms of the lack of BIM skills in graduates have also been voiced in other forums (McPhee, 2016). This situation was verified by a conversation with New Zealand architectural graduates.

5. A Conversation with Graduates

The prevailing attitude of architectural education towards BIM and the preparation of graduates as a consequence is strongly supported by evidence gathered through a focus group session with recent graduates. The scheme of the discussion was fashioned on the Delphi method that was first developed in the 1960s as a means for technological forecasting (Helmer-Hirschberg, 1966; Rand Corporation, 2017). This researcher has used it in the past as a means of arriving at a group consensus about a new issue under investigation through an equitable exchange of information and ideas. In this particular case, five participants employed to the same architectural firm were asked to assist in the probe. All were recent graduates who were 3 years to less than 12 months out of Architectural school. Four of the graduates went to the same university and one went to another university in another city. Participants were sent a statement regarding the issue under investigation at the start of activity by email and invited to respond. The statement was as follows: Modern architectural education is not aligned with the ethos of BIM and can even be considered inadequate to prepare architectural graduates for practice. The graduate responses to the statement were then examined and commonalities used as a means of generating an agenda for a sit-down discussion about the issue. After the sit-down session, the discussion was
summarized and sent to participants. Participants were given an opportunity to agree with the points made as well as clarify any issues.

**Defining BIM:** Participants generally agreed that their definition of and/or introduction to BIM was particularly limited and attained in an indirect manner. There was certainly no formal introduction to the concept in design studio. Some participants confessed to searching Google while to others it was mentioned in support courses like Construction. According to one graduate: "All I remember [when the participant first heard of BIM] was an image of lots of pipes in a building. That was the extent of it!"

**The Virtual Building:** There was no discussion in any of the schools about the concept of a virtual building. One graduate asked if it was the same as the 3D models constructed in Rhino (a modelling tool). When it was pointed out that the Rhino model only dealt with issues of solid and void, shape and form (in addition to parametric data), it was acknowledged that virtual buildings were not a part of the studio. Lessons of assemblage (or how to put buildings together) came from Construction papers, which did not use BIM tools.

**Information:** According to the graduates, design studio was primarily focused on the end result of the design. It was their understanding that this end result was assessed based on design intent, design process, and what the design (building) looked like (form, shape, proportions etc.) or the manifestation of the idea. It was their understanding that they were meant to produce limited information or required to model what was needed to communicate the above criteria. This meant, “sometimes people would only build (in 3D) part of the building (the parts they were going to render)”. Hand-ins tended to be 2D representations (Plans, sections, elevations, selected 3D views) of the building. Model objects in projects lacked attributes and intelligence. Data was shifted between tools and took the format needed for particular tools to function. Data transformation and shifting stopped when the end result was achieved. This was not a problem to the student as it was not necessary to move data beyond the presentation of the design.

**Building Performance:** Students were encouraged or "pushed to the extreme" to create buildings that were interesting (according to the above criteria) and not necessarily functional on a range of levels from structural to egress. For instance, if the studio group was given a programme of rooms and other requirements, often students would not meet the programme as set out. Lecturers were often willing to overlook these deficiencies if “there was something at the heart of it that was really interesting and the student had found this really interesting idea and managed to work it through.” Performance issues, particularly environmental, were covered in supplemental courses – a sustainability course (for instance). The testing of the buildings’ performance (using analytical tools) was often done used a "very boring" building that was "literally like a box". If testing was related to studio, students were asked to use their design models, exporting it to look at its environmental aspects. This did not work because the design was not usually in a condition to use in this way or “never developed enough to get to that level”.

**Tools:** Lecturers, supervisors and tutors “did not interfere with the tools used” in the schools possibly because they “didn’t know what [we] were doing”. One participant declared, “No one ever told us what [tools] to use”. At one school, all students (except a few) used Rhino for design projects despite availability of Revit/ARCHICAD. The whole building was modelled to appropriate detail and projected 2D representations were generated from the model. These 2D drawings were scaled and brought into Photoshop and Illustrator for notes and symbols. 3D images were rendered in Rhino and placed on the “drawing sheet”. In another school, students were actively discouraged from using BIM tools.
New students coming into schools therefore “conformed” by simply using the tools other senior students used. Rhino was used in one school because “we just all started out using Rhino”.

**Preparation for practice:** It was determined within the group that a discussion about preparation for BIM in practice was not possible because the firm that employed the graduates did not “push BIM” or used it to any appreciable level. It would be hard to determine if the experience of BIM in architectural school somehow impeded adaption to practice.

When asked, however, if architecture school prepared students for practice, the response was ambivalent. One graduate said “No. School teaches you to think outside the box but not how to deal with the everyday”. Another wrote “University doesn’t really teach you about how design works in a firm, or give you many tools so you can get to work right away. For example, university places less importance on designing with the building code, and teaching CAD, which would probably be more immediately beneficial for work in a practice.”

### 6. Teaching BIM

The evidence presented has demonstrated that conversations (at least in New Zealand) about the relationship of architectural education to BIM need to take place. It appears that New Zealand schools of architecture have not begun to consider BIM as a seismic shift in how architecture will be practiced in the future. Students are not being prepared for the changes in practice and the wider industry. Students are not being informed about the difference between fragmented abstractions and intelligent data. Students are not being taught that design success not only includes what the building looks like but also performance indices like energy consumption, fire and earthquake safety. Students are not being directed to the relevant tools that will allow a meaningful engagement with the virtual building. Students are not being told about BIM.

It is apparent that there needs to be a revolution in how architectural education considers and intersects with BIM. The depth of change to practice in the future dictates that adopting BIM in education “cannot be solved simply by adding new content and skills to the existing curriculum, but will also necessitate the modification and deletion of some of the existing content” (Kocaturk and Kiviniemi, 2013). The nature of the restructured curriculum must go beyond integrated or specialized courses. It must be embedded in the centre of architectural education.

Architectural design has always been learnt by applying acquired knowledge (theory) to the task at hand (practice). The main instrument for the dissemination of design knowledge in this way is the design studio. The studio has evolved from the practice oriented real-time training of apprentices in the past, to its existence within an architectural education embedded in academia. In the past the student learned the craft in the time and space of actual building sites. Today, studios are places where theoretical notions about architecture are considered without enough grounding in the reality of how the building works or performs. An opportunity now exists to locate design learning in an environment with an actual (virtual) prototype of the building using the most desirable means of teaching architectural students. Any attempt to introduce effective tools and methods in design education that can address the current situation should therefore exist within the design studio.

Within the design studio, regardless of the content and design projects, students from early in the education must be made increasingly aware of the following:

- The difference between abstract representation and object-oriented content.
• Information contained in the virtual building is continuous and grows as the design progresses becoming data rich.
• Building performance is requirement for building success.
• That information in the virtual model can be manipulated for different purposes and audiences.
• The capabilities and potential of BIM for the profession

The objective of the virtual building focussed studio education is the emergence of a student that understands “the underlying concepts of creative and operational modelling and the degree of abstraction, clarity and precision required in both” (Kocaturk and Kiviniemi, 2013). This understanding would translate into an architectural graduate who can create “intelligent” virtual models that contain information (geometric and non-geometric) that can be modelled, manipulated and shared during the entire project life cycle.

7. Conclusion

BIM represents a significant paradigm shift in how buildings will be designed, constructed and operated in the future. Its effectiveness is directly related to consideration of the computer-generated virtual building and how its contained information is created, organised, manipulated and shared. This is a big difference from how architecture has been traditionally represented and communicated for more than a century. The architectural profession has an opportunity through BIM to control information flow and regain control of decision-making in the project. Revitalisation of the profession is therefore dependent on the architect’s ability to make the cultural shift towards a “BIM way of thinking” (Ibrahim, 2014). Unfortunately, the incoming cadre of professionals is none the wiser about BIM.

This paper has defined BIM as a means of creating, managing and sharing information, which is centred on the virtual building. The response of industry has been noted as well as the architect’s position in the adoption of BIM. It has highlighted the current situation in which (it is argued) modern architectural education is not aligned with the ethos of BIM and can even be considered inadequate to prepare architectural graduates for practice. Evidence in the form of a series of discussions (online and face to face) with recent graduates from two schools of architecture in New Zealand has been presented which has indicated that this is the case. Having demonstrated that schools of architecture are not preparing for BIM-oriented practice, the paper has suggested objectives to be realised aligning teaching in the design studio with the BIM way of thinking.

It should be noted that information gathered from five graduates from two schools of architecture in a small country (New Zealand) does not indicate conclusively or generally that architectural education is doing students a disservice by denying them access to knowledge that can help them integrate into practice and participate in a digital environment that will likely characterise the next 50 years. The information, however, enables the beginning of a conversation about the role of architectural education in influencing the practice of the future. This initial probe and consequent future research aims to establish a secure position for the profession for the next 50 years. It attempts to inspire progress towards appropriate responses by academic institutions to the challenges posed by the cultural shift of BIM. By responding to the opportunities and generating new ideas about teaching design, architectural education could be transformed to best prepare graduates aligned with the demands of an evolved AEC industry who can design buildings that are fit for purpose, cost effective, sustainable and a delight to clients and users.
References


Dry Under the Floor

Development of NZ House Sub-Floor Ventilation Requirements

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Abstract: This paper traces the development of sub-floor (crawl space) ventilation from early New Zealand uses of suspended floors to the first formal requirements through to the modern day. This includes council by-laws, nationally developed standards and most recently the New Zealand Building Code. Although sub-floor ventilation was being provided from the earliest European housing, the first minimum gap between floor joist of 100 m was suggested in 1912 but the first local Government by-law recommend was in 1920 when the One Tree Hill Roads Board required 150 mm space. Although the New Zealand State Forest Service's 1924 "Building Conference Relating to the Use of Timber in Building-Construction" suggested a minimum ground clearance of 300 mm with ventilators of 1 in² per ft² of flor area (0.7%), it was not until 1944 when NZSS 95 Part IX required ½in² per ft² (0.35%) that a ventilator requirement was incorporated in local government by-laws. This requirement has continued to the present day (2017), although in 1999 the minimum ground clearance or crawl space was increased to 450 mm. Recent BRANZ research has confirmed these ventilation requirements as being reasonable, although the results may also contribute to a more science based set of requirements.

Keywords: Moisture; timber; dry rot; suspended floor.

1. Introduction

Timber is a resilient, effective, and sustainable construction material provided it is kept reasonably dry. Once moisture levels become too high, the natural agents of decay start to perform their essential role in the nitrogen cycle. While some timbers e.g. New Zealand native totara, can withstand many years in contact with moisture, others e.g. Pinus Radiata, require specialist treatments to be used in such conditions.

The light timber frame, timber wallboard cladding, corrugated iron roofed New Zealand free-standing house developed with a suspended wooden floor. Until the 1960s native timbers were used for piles e.g. totara, joists e.g. rimu and tongue and groove (T&G) floor boards e.g. matai. Even though these timbers were reasonably resistant to moisture driven decay, the sub-floor (or "crawl space") can be an extremely damp environment. Moisture evaporating from the exposed ground or coming from outside due to poor water management can quickly result in the air becoming saturated. The moisture can then transfer to
the suspended timber floor and its structure, creating ideal conditions for decay. Various approaches have been developed to deal with this problem. The traditional approach has been to reduce moisture levels by allowing the free entry (and exit) of outside air, with or without the application of impervious ground cover, although timber preservative treatments are a more recent option (Technical Correspondence School, 1958; 1980). When only piles were used to provide a foundation to support the house unrestricted air flow was possible, but once the perimeter started to be covered with by boards or the use of foundation walls, some form of guidance was required.

This paper is part of a larger project exploring the development of New Zealand building codes. Although the development of the modern New Zealand Building Code explored issues in the then existing building controls (e.g. Searle and Scoular, 1984), it did not undertake a comprehensive historical review. The evolution of sub-floor ventilation requirements provides a case study of the philosophical, practical and research issues considered in the historic building controls. To provide an international comparison, the historical development of sub-floor ventilation requirements in Australia, United Kingdom and the United States of America are also under research for future papers.

2. Suspending the Floor

Early European settlers made use of temporary accommodation of Maori design with earth floors, but quickly progressed to housing with suspended, timber floors. For example, the 1833 Waitangi Treaty House (prefabricated in Sydney) had flooring of Australian ironbark. Janet Bannerman of Otago reported in 1848 of her New Zealand-made house that "the totara lining of its walls was close and sound enough, but the white pine floorboards had shrunk leaving draughty gaps" (Drummond and Drummond, 1967).

In cheaper houses plain wide boards were fixed to joists spanning between the walls, while in better houses the edges of the boards were tongued and grooved (Salmond, 1989). By the 1880s, suspended timber floors were expected, with the various cottage designs provided in Brett’s Colonists’ Guide having P.T.&G. (P.T.&G. = Plain, Tongue and Groove (New Zealand Standards Institute, 1956)) "medium or second-class flooring" (Leys, 1883). For the 2nd edition, specifications were provided:

"Lay the floors with 6in x 1in p.t.g., cramped and double nailed with 2 ¼ brads. Punched in, and the joints planed off flush" (Leys, 1897).

Ingenious solutions were found to lift the floor above the ground in order to provide a ventilated space. Fyffe House, Kaikoura, dates from the mid-1840s and stands on piles made from discarded whalebone vertebrae from the whaling industry (Harris, 1994). Locally sourced, shaped river stone piles still support the house "Ranzau", at Hope, near Nelson, built around 1844. Lady Barker reported on the materials for their high country house being transported from Christchurch in March 1866:

"… two dray-loads of small rough-hewn stone piles, which are first let into the ground six or eight feet apart: the foundation joists rest on these, so as just to keep the flooring from touching the earth. I did not like this plan (which is the usual one) at all, as it seemed to me so insecure for the house to rest only on these stones" (Barker, 1871, Letter VII).

After 1900, square sawn totara blocks were common, but brick piers could be used or, after 1905, octagonal glazed earthenware blocks (Salmond, 1989). By the time of a 1917 plans book, most of the houses for which details were provided used concrete house-blocks (Keyes, Mann & Co, 1917). The Firth Concrete Company was manufacturing concrete precast concrete piles at their Rangiriri site in the late
1920s (Whyte, 2001), and by the 1930s concrete piles were in wide use (Consumers’ Institute of New Zealand, 1972).

One problem not widely found in these early years in was "vegetable decay, or dry rot" in the flooring or its structural supports. Blair, in the first New Zealand published book on building materials, considered this was "on account of the defects in our wooden buildings which give ample ventilation" although it was found in stone and brick buildings (Blair, 1879).

3. Dangerous Air

New Zealand’s comparatively recent European settlement has meant it has experienced the full range of theories of timber decay – miasma, phlogiston and fungi.

The miasma theory of disease was summarised by Vitruvius in the 1st century, although not using the term, as: "Cold winds are disagreeable, hot winds enervating, moist winds unhealthy" (Vitruvius Pollio et al., 1914, VI.3.1). Thus “noxious and prejudicial effluvium” was considered to be the source of timber decay, rather than fungi found associated with it (Papworth, 1803).

By the early 1800s although the miasma theory was still viable, the phlogiston theory was being used to explain the decay of timber. The phlogiston theory assumed a fire-like element was contained within combustible substances. This was released during the process of putrefaction by the action of warmth, air and water, with water being the chief cause of rot. This in turn provided the nidus (place) on which fungi could grow (Wade, 1815).

However, by the 1880s, both theories had been made obsolete by the understanding that damp timber was being consumed by the fungi (Bidlake, 1889).

The common thread in these theories was that “dark stagnant air” was central to timber decay, hence rot could be prevented by reducing the stagnant portion by using a moisture impermeable ground cover, sub-floor ventilation or a combination of the two. However, the ventilation had to be provided in a way which ensured no corners of stagnant air, with entry points at a level above the ground so they could not be closed off by deliberate or accidentally placed earth (Bidlake, 1889).

4. 1880s – 1920s: Early Attempts at Moisture Management

Early European settlers were aware of the need for sub-floor ventilation, although their approach was more ‘ventilation without constraint’ rather than managed. Brett’s “Colonists’ Guide and Cyclopaedia of Useful Knowledge” was the first widely distributed New Zealand book which provided guidance for house builders. In its first edition it provided plans and materials costs for four "Settler’s Cottages" (Leys, 1883), with a fifth plan and a new set of specifications prepared by “Mitchell and Watt, Architects to the Auckland Board of Education” provided in the following two editions (Leys, 1897, 1902). The illustrations show houses with weatherboards from the eaves to the ground and a raised ground floor, with specifications:

“BLOCKS – The foundation blocks are to be hardwood (heart timber) to average 8in x 6in, both ends cut square, spaced not more than 4ft apart, and sunk 18 in in the ground.”

None of the individual house materials cost lists include "foundation blocks." There is also no mention of ventilation grilles or a minimum height for the floor to be raised above the ground either in the specifications or the materials lists for any of the houses in any edition.
The first regulatory reference found (so far) to either the use of suspended floors or sub-floor ventilation is in by-laws for five Maori districts published in the New Zealand Gazette from February 1902 to October 1910. The by-laws gave the power for the relevant Maori District Council to require the builders of a new house to "construct a raised wooden floor" (Clause 5) which if not complied with could result in a fine of either 10s or £1 depending on the location (Clause 6). However, the ventilation requirements were not specified.

Research has yet to be completed into the nine pre-1913 local government by-law documents held in New Zealand libraries, but examination of the by-laws of the Gisborne Borough Council for 1907 (Gisborne Borough Council, 1907) and the Marton Borough for 1912 (Marton Borough Council, 1912) found they dealt briefly with floors but had no requirement for sub-floor ventilation.

In 1912 that the Government's Department of Public Health, Hospitals and Charitable Aid published its "Suggestions for By-laws Suitable for Adoption in Counties, Town and Road Districts" (Department of Public Health, Hospitals and Charitable Aid, 1912). Developed by the Auckland office, it was used by local authorities as a model for their own by-laws (New Zealand Parliament, 1913). As well as general provisions, these provided model by-laws for councils to adopt dealing with issues of buildings, drainage, nuisances, animals, and privies. Three of the sixteen building clauses dealt with moisture under or around buildings. Clause 11 dealt with damp sites, requiring "drainage sufficient to prevent such site from being damp", ensuring water could not flow under the building, and if necessary requiring the ground under the building be "asphalted or covered with a layer of good cement concrete at least 2 in. thick". Clause 12 requires there be a ventilated gap of at least 4 inches (100 mm) underneath "every joist, plate, stringer, and bearer". This is the first NZ by-law clause found thus far with a requirement for sub-floor ventilation. Clause 13 completes the group, with a requirement that external walls have an airspace of at least 18 in (460 mm) from any external ground above the level of the bottom plates.

The 1920s saw the quantification and legislative implementation of requirements for sub-floor ventilation, in both European and Maori districts.

The One Tree Hill Road Board, Auckland, by-laws required a clear space above the ground "in the case of a plate than three inches, and in the case of a joist than six inches" (150 mm) as well as "sufficient and proper communication with the external air for the purpose of ventilation" (New Zealand Government, p. 3006, 1920).

A series of almost identical by-laws were gazetted for 18 Maori districts over the years 1922 (15 districts), 1923 (1), 1932 (1) and 1939 (1). "Each sleeping room" required "a boarded floor" with "a space of 4 in at least" (100 mm) between the lower side and the ground, increased to 6 inches (150 mm) in 1939. The area below the floor was to be "thoroughly ventilated by some effectual method" (e.g. New Zealand Government, p. 76, 1922). Interestingly, the Portobello Road Board, Dunedin, by-laws also gazetted in 1922 had no specific above-ground dimension, requiring that in any existing building there be "adequate underfloor and other ventilation" (New Zealand Government, p. 994, 1922).

5. 1924: Building Conference and Codes

The New Zealand State Forest Service's 1924 "Building Conference Relating to the Use of Timber in Building-Construction" (New Zealand State Forest Service, 1924a) was based on the goal of improving the efficiency of timber production and use through standardisation of code requirements. In 1923 letters were sent to 124 County Councils and 16 City Councils, receiving a total of 37 sets of by-laws. While some councils did not participate in the survey, others not only had no building by-laws but considering "the
matter is not of sufficient importance to justify the sending of a delegate to Wellington" (Blundell, 1924). The received codes were analysed on 28 measures, from the provision of an access way through the house to the rear to the placement in walls of windows and doors, although not sub-floor ventilation (New Zealand State Forest Service, 1924b)

The Conference secretary (A.R. Entrican) had obtained a copy of the American 1922 Building Code Committee report “Recommended Minimum Requirements for Small Dwelling Construction” (Woolson et al., 1923) and used it as a model for the development of the draft code document. This 1922 report was the first designed to provide the basis for a national building code which included not only the various requirements but also guidance as to how to "do better". In the case of sub-floor ventilation the code text required:

"Cross ventilations shall be provided for the space inclosed {sic} by foundation walls, whether it be excavated or not" (Woolson et al., 1923, p. 23)

The appendix provided additional guidance, suggesting 7% of the floor area should be provided as ventilation (10 in² per 1 ft²):

"Where provision is not made for circulation of air within inclosed {sic} spaces next to the ground surface, dampness accumulates and timber decays rapidly. Openings for the admission of air help to prevent such decay and increase the life of the structure. The total area of such openings should be not less than 7 per cent of the ground area inclosed" (Woolson et al., 1923, p. 71)

The New Zealand Conference was held in the Dominion Farmers Building, Featherston St, Wellington from 18 to 20 June 1924. The 42 participants (plus Chair and Secretary) came from local and central government, professional bodies, and trade organisations. Three technical committees considered the various aspects of the draft, modifying, changing or editing it to suit New Zealand conditions. The sub-floor ventilation guidance was included in the proposed code, but after discussion in both the technical committee and the overall conference decided that 0.7% was more appropriate than 7% (1 in² per 1 ft²):

"All timber framing shall have a minimum clearance of 12 in (300 mm) above finished grade-level, and cross-ventilation shall be provided for the space enclosed by foundation-walls, whether it be excavated or not. In outside walls of dwellinghouses under ground floors insert ventilators in foundations equalling one square inch to one square foot of floor area." (New Zealand State Forest Service, 1924a, p. 16)

Based on evidence to date, this is the first time a numerical value was given for sub-floor ventilation as part of the code in any country.

The 1924 structural recommendations were widely applied (ten Broeke, 1971), but the sub –floor ventilation requirements did not have such an immediate impact, Clause 146 of the 1925 Auckland City Building By-laws (Auckland City, 1925) and Clause 145 of the 1934 Nelson Counties Joint Bylaws (Nelson Counties, 1934) each required only a clear space of 9 in (230 mm) between the ground and the "underside of every joist, plate, stringer and bearer", and that this space "be thoroughly ventilated".
6. 1940s: Time for Standards

Although further six Maori Districts gazetted by-laws in 1940 (1 district), 1941 (2) and 1945 (3) they all had the same requirements for a clear space of 9 in (230 mm) plus through ventilation (e.g. New Zealand Government, p. 2117, 1941)

It was not until NZSS 95:1944 Part IX (New Zealand Standards Institute, 1944, Clause 920) that specific requirements finally found their way into the general by-laws. The NZSS 95 series of "Standard Model Building Bylaws" were adopted by local government, who could also make local modifications. Clause 920 "Foundation Ventilation" required foundation vents of $\frac{1}{2}$ in$^2$ per ft$^2$ (1 to 288 or 0.35%), to be spaced a minimum of 6 ft (1.8 m) apart and 2 ft 6” (0.76m) from corners. Vents had to be as close to the bottom plate as possible, vermin proof and designed to exclude animals and poultry. A space of at least 12 in (300 mm) was required before the bottoms of sleeper plates or stringers, which also had to be clear of obstructions in order to provide ready access for inspection.

The post-WWII period saw the development of text books specifically written for New Zealand conditions and legislation, The New Zealand Army Education Welfare Service’s “Carpentry Part 1 Study Course”, written to train returning service men, stated the usual practice was to space 9” x 4½” (230 x 110 mm) ventilators at 8 ft (2.4 m) centres – effectively the same as NZSS 95. The back of the ventilators were covered with “either a cast iron grating or a specially woven wire grill” (Smith, 1944). These requirements were also incorporated in the first edition of "Carpentry in New Zealand" used by apprentices striding for examinations in carpentry (Technical Correspondence School, 1958).

Perhaps surprisingly, the Government’s "Housing Improvement Regulations 1947" did not include any numerical requirements, only that "adequate space and vents to ensure proper ventilation for the protection of the floor from damp and decay" (Government of New Zealand, 1947). This lack of a numerical requirement presumably allowed the sanitary or health inspector to make their own judgement as to the effectiveness of the sub-floor ventilation.

7. 1960s: Shift to Current Code Requirements

The Building Research Bureau, established in 1959, dealt quickly with issues of sub-floor ventilation with a 1960 bulletin on 'Dampness in Buildings' which included the first New Zealand recommendation for the use of polythene film as a vapour barrier (Building Research Bureau of New Zealand, 1960). However, the by-law requirements remained unchanged at "$\frac{1}{2}$ sq.in. of unobstructed air space per square foot of ground floor area" (0.35%) with the issuing of NZSS 1900:1964 Chapter 6.1 'Construction Requirements for Timber Buildings Not Requiring Specific Design.' (New Zealand Standards Institute, 1964). NZS3604:1978 continued the same approach, but converted to metric as 3,500 mm$^2$ per m$^2$ (0.35%) (Standards Association of New Zealand, 1978).

A higher ventilation level was required by the Ministry of Works, Housing Division’s 1964 ‘Standard Specification for Timber-framed Units Up to Two Storeys’ which required 12” x 4” (300 mm x 100 mm) vermin proof precast ventilators 2 ft (0.6 m) from the end of each wall, spaced “at 4ft (1.2 m) centres maximum” or 0.83% of the ground floor area (Ministry of Works, Housing Division, 1964).

With the development of the New Zealand Building Code in 1992, there was an opportunity to develop fully performance based sub-floor ventilation requirements. NZBC Clause E2 'External Moisture" included the Performance statement:
"E2.3.4 Building elements susceptible to damage shall be protected from the adverse effects of moisture entering the space below suspended floors." (Building Industry Authority, 1992, p. 136)

However, the 1992 Acceptable Solution (E2/AS1) first edition continued with the same requirements of 3500 mm² of net open area per m² of floor area, by use of either continuous gaps between the baseboards or perimeter wall ventilators no greater than 250 mm x 150 mm (Department of Building and Housing, 1992). The 1998 second edition allowed the ventilation openings to be reduced to at least 700 mm² per m² of floor area if used in conjunction with a vapour barrier (Department of Building and Housing, 1998).

The requirement continues unchanged in the 2017 current E2/AS1, although the details have been shifted to NZ 3604:2011. This provides four alternative acceptable ventilation methods (removing the ventiler size restrictions and adding gaps between boundary joists and the wall plates, and “other regularly spaced openings”). Clause 6.14 requires a crawl space of 450 mm to permit visual inspection of all subfloor framing. (Standards New Zealand, 2011), as was the case in NZS 3604:1999 (Standards Association of New Zealand, 1999)

8. Improved Understanding of Sub-floor Moisture Load

It was not until the 1980s that the sub-floor moisture levels and the effect of ground covers were the subject to research. While it is relatively simple to measure timber moisture contact, measurement of ground evaporation requires a longer time period and somewhat more intrusive equipment.

New Zealand sub-floor moisture data largely comes from a 1982 to 1984 survey of the sub-floor spaces in 60 suspended floor houses which found average ground evaporation of 400 g.m⁻²/day (Trethowen, 1994), averaging about 300 g.m⁻²/day in Auckland and Christchurch, and 550 g.m⁻²/day in Wellington (Trethowen, 1987). These compare with ground evaporation of 495 g.m⁻²/day reported in 1948 in an American basement (Harris, 1995; Rose, 1994). A 1982 NZ pilot study of 10 Invercargill houses found the use of polyethylene film over the ground in the sub-floor was from 70% to 95% effective at reducing moisture levels (Trethowen, 1988, 1994).

A multi-year project examining subfloor moisture, corrosion and insulation performance was completed in 2016 (McNeil et al., 2016). In addition to detailed monitoring in two test houses on the BRANZ site at Judgeford, approximately 30 km from Wellington, subfloor environments were measured in eight houses (Auckland 3 houses; Wellington 3; Invercargill 2). It was found that the existing ventilation requirements of 3500 mm² per m² floor provided a reasonable safety margin to manage the accumulation of moisture in the subfloor structural framing members. It was also found that polythene ground covers were an effective means for the control of ground-sourced moisture, although they must be detailed to avoid providing a space for rainwater accumulation (McNeil et al., 2016). The results of this work, coupled with other subfloor ventilation investigations hold promise for the development of science-based subfloor ventilation requirements in order to ensure long term moisture management

9. Summary and Conclusion

Table 1 provides a summary of the changes and their origins in house subfloor ventilation requirements from the first numerical requirement in 1912. Prior to this there were no limits on the space to be left open above the ground, with the “crawl” space often being too low for even the smallest child to crawl
through. The earliest requirement for 4 inches (100 mm) was included in a 1912 set of recommended by-laws prepared and distributed by the Department of Public Health. It would appear this was the basis for the requirement in the by-laws adopted by eighteen Maori districts.

The 1924 “Building Conference Relating to the Use of Timber in Building-Construction” not only increased the crawl space distance to 12 inches (300 mm) but also included possibly the first numerical code requirement for sub-floor ventilation in any country – that 0.7% of the floor area should be provided sub-floor vents. This code requirement was based on a corrected value from the guidance provided in the 1922 USA Bureau of Standards publication “Recommended Minimum Requirements for Small Dwelling Construction: Report of Building Code Committee.” Perhaps surprisingly, this would appear to remain the underlying basis for the modern requirements for suspended timber floors, although divided by 2 (0.7% became 0.35% in 1978).

Table 1 shows the vertical dimensions required for the subfloor crawl space varied over time, there was a trend to greater mandatory requirements (from 4 in (100 mm) in 1912 to the current 450 mm in 1999). It is worth noting that while the mandatory sub-floor distances have increased over time, experience suggests that many (if not most) pre-1900 houses would have been built with at least the current requirement.

The development the performance based New Zealand Building Code in 1992 saw the development and implementation of alternative approaches to sub-floor ventilation, including the use of a ground-cover-vapour barrier. In more recent years, there has been a shift of the requirements from the building code documents into separate standard. Thus, the floor requirements in NZS 3604: 2011 “Timber Framed Buildings” are used as an Acceptable Solution for the New Zealand Building Code Clause E2 External Moisture (NZBC E2/AS1).
Table 1: Summary of sub-floir ventilation requirements 1912 - 2017

<table>
<thead>
<tr>
<th>Year</th>
<th>Summary of Requirements (distances are above ground)</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1912</td>
<td>Every part &gt; 4 in (100 mm), adequate ventilation</td>
<td>Dept. of Public Health</td>
</tr>
<tr>
<td>1920</td>
<td>Joist &gt; 6 in (150 mm); sufficient and proper ... ventilation</td>
<td>One Tree Hill Roads Board</td>
</tr>
<tr>
<td>1922</td>
<td>Joist &gt; 4 in (100 mm); adequate ventilation</td>
<td>Eighteen Maori Districts</td>
</tr>
<tr>
<td>1922</td>
<td>Adequate underfloor ventilation</td>
<td>Portobello Road Board</td>
</tr>
<tr>
<td>1924</td>
<td>Minimum 12 in (300 mm); ventilators 1 in² per ft² (0.7%)</td>
<td>Building Conference</td>
</tr>
<tr>
<td>1925</td>
<td>Clear space 9 in (225 mm); thoroughly ventilated</td>
<td>Auckland City By-laws</td>
</tr>
<tr>
<td>1934</td>
<td>&gt; 9 in (225 mm); thoroughly ventilated</td>
<td>Nelson Counties Joint Bylaws</td>
</tr>
<tr>
<td>1939</td>
<td>Joist &gt; 4 in (100 mm); thoroughly ventilated</td>
<td>Taumarunui Maori District</td>
</tr>
<tr>
<td>1940</td>
<td>Joist &gt; 6 in (150 mm); thoroughly ventilated</td>
<td>Ngarawawahia Pa Maori District</td>
</tr>
<tr>
<td>1941</td>
<td>Joist &gt; 9 in (225 mm); thoroughly ventilated</td>
<td>Five Maori districts</td>
</tr>
<tr>
<td>1942</td>
<td>Joists &gt; 12 in (300 mm), ventilators ½in² per ft² (0.35%)</td>
<td>AEWS Carpentry Part 1 Study Course</td>
</tr>
<tr>
<td>1944</td>
<td>Joists &gt; 12 in (300 mm), ventilators ½in² per ft² (0.35%)</td>
<td>NZSS 95 Part IX</td>
</tr>
<tr>
<td>1947</td>
<td>Adequate space and ventilation</td>
<td>Housing Improvement Regulations</td>
</tr>
<tr>
<td>1964</td>
<td>Joists &gt; 12 in (300 mm), ventilators ½in² per ft² (0.35%)</td>
<td>NZSS 1900 Chap 6.1</td>
</tr>
<tr>
<td>1964</td>
<td>12 in x 4 in (300 x 100 mm) at 4 ft (1.2 m) centres (0.83%)</td>
<td>MWD Standard Specifications</td>
</tr>
<tr>
<td>1978</td>
<td>3500 mm²/m² (0.35%)</td>
<td>NZS 3604:1978</td>
</tr>
<tr>
<td>1992</td>
<td>3500 mm²/m² (0.35%)</td>
<td>NZBC Clause E2/AS1 1st ed.</td>
</tr>
<tr>
<td>1998</td>
<td>3500 mm²/m² (0.35%); ground cover 700 mm²/m² (0.07%)</td>
<td>NZBC Clause E2/AS1 2nd ed.</td>
</tr>
<tr>
<td>1999</td>
<td>As for 1998 plus 450 mm crawl space</td>
<td>NZS 3604:1999</td>
</tr>
</tbody>
</table>

This paper has reviewed the development of New Zealand sub-floor ventilation requirements from the earliest days of European settlement to the current year, 2017. It has shown that it was not until the 1912 that formal, numerical requirements were considered and not until the 1920s that they come into use in building codes.

The requirement for subfloor ventilation was initially proposed in 1924 as 0.7% of the floor area, but when incorporated in the Model Building Bylaw NZSS 95 it was halved to 0.35% - a value which remains current in today’s NZBC Acceptable Solution. Although recent BRANZ research has confirmed these ventilation requirements as being reasonable, the results may also contribute to a more science based set of requirements. The question for the future is how to create a suitable numerical value based not on merely continuing history but on actual measurements and scientific knowledge. That will be the challenge of the coming decade.

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Looking Back To A Job Well Done?

Measuring Success in the Integration of Teaching and Learning across Multiple Modes of Delivery

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Abstract: Thirty years ago, in 2017 we embraced a strategy to integrate all modes of teaching delivery in the School of Built Environment at Curtin University. We knew there would be significant challenges to teaching and learning practices. Back then, face-to-face and online teaching were considered discrete and separate practices; however, this was not reflected in the learning experience of students, predominantly the original digital natives, for whom new technologies had become a necessary part of their lives. The purpose behind integrating learning modes, in addition to embracing improved digital technologies, was to improve the teaching and learning experiences by recognising successes in both face-to-face and online practices, and adapting to suit all modes. All stakeholders had to participate, engage and commit to adapting teaching and learning practices to the new digital environments. This paper addresses what was a complex problem from the point of view of the different stakeholders— institutions, staff and students. The similarities and gaps in the support provided are discussed with the aim to identify alternative ways of supporting success in teaching and learning. This paper discusses the support offered in transitioning into the digital age and implementing an integrated strategy of delivery. In 2017 when this project was initiated, it had already become clear that the stage was set for further research on this topic. Since 2017 the work discussed in this paper was used to build the limited data available to develop tools that could be employed to measure the success of this strategy.

Keywords: Pedagogical practice; education experience; digital environments.

1. Introduction and Background

During 2017, the School of Built Environment at Curtin University offered a broad range of disciplines including Architecture, Interior Architecture, Urban Planning, Geography, Construction Management and Project Management; each delivered in multiple modes. The School had been transitioning their programs into online delivery for a few years and the first graduates of programs delivered solely online were completing their degrees. The online Architecture course was the first of its kind in Australia, and much had been learned in developing and integrating its online version with what was taught face-to-face. As we prepare to start the 2050 academic year, we reflect on the environmental changes imposed by new technologies. The reality that physical presence on campus was no longer required was only one of the
facts that higher education institutions were trying to reconcile early in the 21st century. It was challenging for the organisations to adapt to this new world of tertiary education and, for lack of a better strategy, trial and error had been the dominant paradigm (East et al., 2014). The only certainty at that time was that digital technology was “here to stay”; there was no going back to chalkboards and “the sage on the stage” model of education that had prevailed for centuries.

Now, as then, institutional engagement into the digital enterprise through leadership at every level is paramount. While the strategy developed by Curtin University defined the roles, responsibilities and lines of communication for all stakeholders (Curtin University, 2017) the impact of the implementation on university staff was influenced by how enabling environments for digital development were created more widely. It prompted accreditation bodies to join universities in accepting that digital education was the “new normal”. Transformation required a combination of institutional support and resources, leadership from program administrators, pedagogical alignment and staff engagement. Balancing the needs of an increasing diverse student body saw staff learning to teach across multiple modes with improved efficiency. It was increasingly obvious that providing engaging and personalised learning experiences with resources easily accessed and shared in different modes required consideration of timing of delivery, a range of levels of preparation and different unit or course structures. For many staff, this required a new way of thinking about learning as well as the development of new teaching practices that extended beyond the content of the learning (Bair and Bair, 2011). Improving student experience through this successful integration of digital and pedagogical changes meant identifying how students learnt in the early 2000s and how they would learn in the future; for student needs to be met, it was necessary to identify and understand multiple aspects of student diversity (Stone, 2017).

The aim of this paper is to identify the critical components of teaching and learning that are used to identify success and direct improvement and growth in Tertiary Education. It is argued that indicators of success that existed at the time were not sufficient or adequate because they did not address the complex issues arising from multiple stakeholders and multiple modes of delivery. Typically, the indicators of success of online learning were similar to those in face-to-face or traditional learning, and did not take into account the differences that technology has made to everyday life and attitudes, nor the way in which technology was used in face-to-face practices.

Curtin’s School of Built Environment now offers a broader view of this issue as teaching and learning within the School evidences an integration of disciplines, technical and non-technical skills and knowledge, and the multiple modes of delivery in teaching and learning practices. However, prior to commencing this discussion, it is important to recognise that while our current approaches are globally discussed, back in 2017 different countries and institutions referred to key components of tertiary education differently. Within Australia we refer to academics as staff, US references will refer to them as faculty; likewise Australian institutions refer to units within courses that are otherwise known as courses within programs in others parts of the world.

Curtin University’s measures of Learning and the Student Experience were developed as part of the Strategic Plan 2017-2020, in which the aim to become a leading global university is clearly articulated (Curtin University, 2016). The Learning and Student Experience was identified as one of the three pillars representing the University’s core business. Some of the strategic objectives within this pillar offered distinctive student experiences through new teaching and learning approaches, and an innovative digital environment for a diverse range of students. On-campus, digital and blended delivery modes were critical to providing students with the experiences they expected, regardless of locations (Curtin University, 2016,
p. 6), however this strategic plan made no distinction between these modes, and this was reflected in the indicators and measures of the resulting activities.

To frame our discussion on measuring success in the integration of teaching and learning across multiple modes of delivery at the time, we looked at indicators from the Online Learning Consortium, the Australasian Council on Open, Distance and e-Learning, and the Standards of Online Education. While the three frameworks addressed online learning specifically, many of the issues presented were applicable to face-to-face learning, and there seemed to be little difference in desired outcomes regardless of the mode of delivery. This is important to acknowledge because in 2017, the focus was on the distinction between online and face-to-face, which we now know is no longer significant.

The Online Learning Consortium identified the five pillars of quality online learning—learning effectiveness, cost effectiveness, access, student satisfaction, and faculty satisfaction (Lorenzo and Moore, 2002). These pillars came together in a framework, designed to guide institutions in the development of online learning programs, and to assist with the development, implementation and evaluation of online learning strategies. The five pillars were also applicable, and may have had their beginnings, in traditional face-to-face learning; in 2017, they were still considered the primary concerns for both traditional and online modes of teaching and learning.

Similarly, the Australasian Council on Open, Distance and e-learning (ACODE) Benchmarks for Technology Enhanced Learning (TEL) were developed in 2007 for use by institutions in their technology enhanced (online) learning strategies and programs. A major review in 2014 brought the benchmarks up to date. The benchmarks took an “enterprise perspective” and integrated the primary focus of pedagogy with institution specific concerns such as planning, student and staff development and the provision of infrastructure (Australasian Council on Open Distance and e-learning, 2014, p. 4).

The Standards of Online Education (Parsell, 2014) discussed how online teaching and learning was supported from three different points of view - the students, the staff and the organisation. For students, the quality of the curriculum; the opportunities for interaction; and appropriate support, such as resources, technology and feedback, were identified as critical. Staff required relevant and accessible professional development; sufficient technical support; and suitable recognition of the time required in providing (online) education. Organisations supported (online) education through clear strategy and leadership; appropriate resourcing; and systematic process for evaluation and development. The Standards of Online Education Framework recognised that, as required by the Tertiary Education Quality and Standards Agency (TEQSA), student outcomes must be equivalent regardless of modes (Tertiary Education Quality and Standards Agency, 2016). Therefore, the standards addressed were considered relevant for online and traditional modes of learning.

The different perspectives of various stakeholders needed to be considered as change from a single mode of delivery to multiple modes, for example, can influence learning experience and outcomes. Therefore, the focus of this paper is not the measure of success of the integration of multiple modes of delivery, but the way in which change was supported and how successful that support was.

1.1 The stakeholders’ perspective: why support is needed

While each of the frameworks reviewed addressed teaching and learning in different ways, all looked at the issue from the student, staff or institutional point of view, with some offering comments from all three perspectives. The catalyst for each framework was “technological disruption”, and the need for a change in teaching practices. The careful management required prompted different ways in which support is
provided to stakeholders. Here we discuss why each stakeholder needs support, and the outcomes that were anticipated or expected from the various actions and strategies offered.

1.2 Institutional point of view

The context in which tertiary institutions were operating in 2017 was complex and required rapid responses due to several changes to federal policies that had significant financial impact. This prompted change in organisational structures and strategies, as funding support became more competitive, and the emerging globalised market more widely sought after. Online delivery of courses was one of the strategies that could mitigate the pressure on scant institutional resources. Reported obstacles to a smooth transition and wide adoption of online technology were extra demands on staff (faculty), lack of compensation for unit (course) development, low staff (faculty) interest, incompatibility with unit (course) content, and inadequate technical support (Godschalk and Lacey, 2001).

The merging of physical and digital environments necessitated significant investment in infrastructure and services to meet the needs of staff and students. While these changes resulted in new ways of attracting students and sourcing funding, the expectations and recruitment of staff remained static. New policies had to be put in place to establish the pedagogical alignment of the different modes of delivery and to address workloads and properly compensate and recognise staff. No one could argue with the fact that online learning was making higher education more affordable and accessible.

1.3 Staff point of view

In 2017 not only was discipline and content knowledge required for teaching, but also improved levels of technological skills along with an understanding of pedagogical theory that was becoming increasingly complex. At the time, the TPACK Model best demonstrated the integration of Technological, Pedagogical and Content Knowledge required (Koehler, 2012). For many staff, the selection process relied on discipline knowledge and expertise, evidenced through either industry experience or research. However ongoing performance and expectations relied on pedagogical and technical knowledge. As technical knowledge was dynamic institutions needed to provide adequate professional development as new technologies and systems were introduced. Changes in technology impacted both traditional and online learning as many of the systems were required for both. It is also worth noting that in 2017, while many of the students were highly conversant with the digital technologies relied upon for online learning, many staff were not, and significant skill development and training was needed.

In their discussion of paradoxes of online teaching, Bair and Bair (2011) examined their own experiences. The descriptors used—number of online offerings, percentage of teachers teaching online and dropout rate—assumed that the focus of teaching remained in the traditional, face-to-face mode; that the structure of programs (courses) was relatively controlled and progression was carefully scaffolded; and that the measures of success in teaching and learning developed for the traditional mode, could be applied to online. This brought an old school approach to online learning that assumes that all teaching and learning happens in the same way, at the same pace, for everyone.

1.4 Student point of view

As Bates (2015, p. 29) highlighted some 35 years ago, since the mid-20th century the biggest change in higher education had been the students themselves. It was also widely recognised that online students were demographically very different from traditional campus students (Stone, 2017, p. 6). As online
student numbers increased, students’ profiles indicated they were older and fewer pursued full-time study because they were juggling study with increased living expenses and tuition fees (Bates, 2015, p. 30). The differences from ‘students of old’, as well as the demographical differentiation between online and traditional face-to-face students, were recognised and this assisted in developing social, cognitive and teaching support for students.

Around the same time, Stone (2017) focused on improving opportunities through online learning; acknowledging the changing student cohort, and recognising the diverse range of students, particularly those traditionally underrepresented at University. From this timely research Stone developed a set of National Guidelines around improving student outcomes through retention and completion rates (Stone, 2017, p. 6). While these guidelines were designed to be addressed by institutions and teaching staff, in doing so they highlighted important criteria for students. These guidelines were offered to institutions to inform strategies and support the development of emerging online learning experiences, and the technologies associated with this.

A common theme for all stakeholders was that there was constant change and the environments in which teaching and learning took place were becoming very different. This meant that the necessary support was also constantly changing. However, the question remained how do the stakeholders know if this support is effective in meeting these changing needs? Different strategies used to support success in providing learning and student experiences are outlined in the next section.

2. Supporting Success: How Benefits of Support were measured

Most of the indicators outlined below were applied to learning experiences, regardless of mode of delivery. They emerged from the analysis of the frameworks reviewed and while some were specific to the nature of the programs within Curtin’s School of Built Environment, it is evident that the indicators were also used to identify success in teaching and learning in tertiary education generally.

2.1 Learning Materials, Activities and Assessment

The quality and effectiveness of curricula was routinely evaluated by accreditation bodies, which had the responsibility to ascertain that courses offered students the knowledge necessary to be effective in their chosen profession. Accredited courses were trusted to provide students the skills they needed to acquire to perform. As such, accreditation was a significant desirable factor for courses, regardless of mode, and was granted to those courses that provided adequate learning materials and activities, and that had sensible means to assess students. Criteria for accreditation and professional recognition typically focused on course content and assessment, together with alignment to professional requirements and expectations. As such, they were often considered a way of determining the quality of curricula. Technology was used to embed some of the accreditation requirements and professional needs into curricula. Additionally, course design, pedagogical practices and staff development was also employed to support learning effectiveness. Since 2017 many of the accrediting bodies, and even profession, have changed, and the need for such tight regulation has relaxed in a workplace that values cross disciplinary collaboration as well as discipline recognition.

2.2 Student Demand and Experience

Typically, course demand was measured by student enrolments, expressed in EFTSL (Equivalent Full-Time Student Load) and/or headcount; however, completion rates and satisfactory student experience offered
a better gauge of success and better reflected the quality of education being provided by an institution. For years student experience was measured by student satisfaction; the Australian Government Department of Education and Training administered an annual Student Experience Survey (SES) nationally across all higher education students in Australia. Known as Quality Indicators of Learning and Teaching (QILT), the SES had six key indicators—overall quality of educational experience, teaching quality, learner engagement, learning resources, student support, skills development (Quality Indicators for Learning and Teaching, 2017a). The technology that allowed the measurement of student experience based on cognitive data compiled in all modes of delivery was being developed. However, now, as then, feedback mechanisms were important in measuring the quality of learning resources and course design as well as access to programs and student satisfaction and perception of the learning experience (Curtin University, 2016). This difference now, in 2050, is that this feedback is in real-time, across all modes, and is used to adapt practices as they happen. The lag that often occurred has become a thing of the past.

2.3 Graduate Outcomes

Student retention rates, along with pass rates, were considered indicators of the learning experience supporting and enabling students to achieve the expected outcomes. Retention rates reflected the individual learning experience and were seen as a good measure of the overall quality of courses. Comparing across the different modes provided valuable insights, not only about the course overall, but also reasoning about why students start, and why initial startup support mechanisms are not followed through. This data exists in the system, but in 2017 failed to be included in any statistical analysis. The same could apply to learning analytics tools that were becoming increasingly more available at all levels but analysis protocols were still being established and use of these tools was limited.

Graduate Careers Australia (GCA) used to undertake annual surveys such as Graduate Destinations (GDS), Graduate Outlook Survey (GOS) and Graduate Course Experience (GCE) among others (GCA 2016). A combination of these surveys were summarised by QILT and combined with considerations of graduates in terms of employment (full/part time or looking), continuation of study, and associated salaries (Quality Indicators for Learning and Teaching, 2017b).

Employer satisfaction data is still funded by the Australian Government Department of Training and Education through an Employer Satisfaction Survey (ESS) (Quality Indicators for Learning and Teaching, 2017b). Used in conjunction with the GDS and GOS, employers of graduates who completed these surveys are asked to provide feedback pertaining to indicators of overall satisfaction, foundation skills—general literacy, numeracy and communication skills and the ability to investigate and integrate knowledge, adaptive skills, collaborative skills, technical skills and employability skills (Quality Indicators for Learning and Teaching, 2017b).

2.4 Staff Support and Engagement

At Curtin, for decades staff engagement was measured through surveys such as the Your Voice survey. These surveys gathered data from staff on a number of issues ranging from satisfaction with infrastructure and resources, to leadership and governance (Curtin University, 2017b). Commitment of staff, and satisfaction and engagement with colleagues in teaching and research were considered as valid an indicator as they are now. The strategies to support staff included mandatory and optional professional development through technical support, equipment and software, and relevant training to keep staff up-to-date.
2.5 Financial Revenue and Costs of Resources and Infrastructure

The costs of providing teaching and learning opportunities were significantly growing in 2017, and around that time institutions were increasingly adopting commercial models or frameworks. In doing so, a consistent underlying operating margin was needed to sustain growth in revenue and increased efficiencies in expenditure. As revenue was gained primarily through teaching activities, new markets and sources were pursued to maintain growth. As staff and infrastructure costs were a large portion of expenditure, efficiencies and reduction in costs were often looked for in salaries and within the optimisation of facilities.

The fees associated with higher education were becoming an increasingly important consideration by prospective students and as the market became increasingly competitive, students were seeking value for money. However, there was very little evidence of how this was considered and how, if at all, this was offset by potential future employment.

2.6 Leadership and Management

The leadership and management of an institution has always had a direct effect on the success of teaching and learning experiences. As then, the nature of the leadership, and the direction provided is critical to the development of courses offered and the improvement of teaching and learning practices. Decisions made by those in leadership roles at all levels regarding resource allocation and workload, and the nature of feedback offered, can positively or negatively influence success. Today we have better means to support, recognise and reward progress and success.

An analysis of the frameworks discussed in this paper, the Online Learning Consortium, the ACODE benchmarks, the Standards of Online Education, and the Learning and Student Experience framework, looked for indicators of success in the actions and strategies that have been implemented. The performance criteria used to evaluate the effectiveness of these strategies were mapped, and the anticipated outcomes, in which this effectiveness is likely to be visible, were identified. Mapping these strategies, indicators, criteria and outcomes for each of the stakeholders identified similarities across the frameworks as well as gaps. To understand the significance of these similarities and gaps, a model was needed to clarify the different elements of teaching and learning experiences that occur.

3. Finding the Gap: What is missing from the Support Provided?

In their discussion of online teaching, Bair and Bair (2011) described a conceptual model for teaching and learning developed by Garrison and Vaughn (2008) that comprises three elements: social, cognitive and teaching. Although now forty years old, this model remains relevant and has been used in this paper to identify these elements of teaching and learning within each of the four frameworks discussed above. The model has been updated to include the governed element, as many of the situations and outcomes within tertiary learning experiences in 2017 were influenced by, and influenced, the ways in which decision making occurs, ultimately impacting on the outcomes and successes. It is also recognised that the different perspectives of the three stakeholders of these learning experiences - the institutions, the staff and the students – prioritised these elements differently. Strategies employed within a framework may not have focused on all the elements as each of the four frameworks recognised different ways in which the students and staff were supported, and the support that the institutions offered, in order to achieve the desired outcomes. The support outlined in these frameworks has been analysed to determine the types of actions or strategies that were implemented; the indicators that accounted for and measured
success; the performance criteria that were used to assess outcomes; and the nature of the outcomes themselves. When considering the integration of the modes of delivery, what is of interest in this paper are the types of actions and strategies that were implemented and the indicators that were used to identify where each of these frameworks addressed the four elements of teaching and learning experiences—the social, the cognitive, the teaching and the governed. While the occurrence of the outcomes is also important, the criteria and the nature of these outcomes is not considered critical here, as they were well documented and often discussed at the time. This focus on implementation strategies rather than outcome may, in 2050, seem rather obvious as it is now common practice, but at the time, in 2017, it was not.

3.1 Similarities

A number of similarities became evident despite the different backgrounds, age and intent of the four frameworks. Typically, when outlining the support provided to students, learning activities and aspects of student experience, such as feedback, technology and equipment, were commonly used strategies. These mostly fell within the cognitive element of the framework. Staff were typically supported by professional development and training, technological and educational systems and health and safety strategies. These fell within the cognitive and pedagogical elements mostly. The institutions supported both staff and students through leadership and management strategies, and by providing resources and infrastructure. These mostly fell within the pedagogical and governance elements.

3.2 Gaps

From a student point of view, staff support, leadership and management, financial revenue and resources and infrastructure did not feature in the strategies. While student experience was addressed, student demand and graduate outcomes featured only slightly, and the governance element was not addressed at all. For staff, learning activities, and student demand and experience were not covered, along with graduate outcomes and financial revenue. Again, it was governance that was not addressed. When viewed from an institution point of view, learning activities were the only strategy not addressed, though student demand and experience, staff support, graduate outcomes and financial revenue were minor. It is clear the social element was the least acknowledged, with the cognitive a close second. For institutions, the outcomes were still difficult to define, especially when considering support for staff and students. For some of the strategies in the frameworks, the performance criteria were subjective. The assumption that goals were common for all stakeholders, that there was only one way of doing something, or that situations were often typical were often made. This assumed causal relationship was not always the case, and often the relationship between action and outcome was more situational in that it relied on action being taken that responded to the situation.

The most significant finding when reviewing these frameworks was that, other than the institutions, the governance element was not often considered for contributors. Within the frameworks, certain actions and strategies were recommended, but it is difficult to identify which of the contributors is responsible. A consequence of this was that no one took responsibility for an action, and as a result that action may not have taken place.
3.3 Alternative ways of supporting success

In 2017, digital learning strategies were seen as a way of reconsidering the social context of learning, as many students lived and socialised online through social media. However, for many staff and those within management at institutions, this seamless integration of the physical and virtual interactions was new and difficult to comprehend. Therefore, a distinction was often made that in reality, for many students, did not exist. The strategy implemented in 2017 by Curtin’s School of Built Environment was done with the intent to remedy this, and to transition staff into these integrated learning modes.

An early outcome of this strategy was that it became clear that offering courses and teaching units across the different modes prompted cross-pollination and critical reflection. This resulted in positive change not only for the students, as they shared experiences and learnt from each other, but also in staff, as the unknown digital learning space opened up, and became more familiar. This had the added benefit of increased levels of satisfaction for the various contributors.

When implementing the digital learning strategy some difficulties emerged that indicated a need to reconsider the governance element of the experiences. Online students are typically older and study part time (Bates, 2015). As cohorts shifted to comprise more part-time students, regardless of the mode, the more organised and structured format required for online learning conflicted with the reflexive and responsive approach suggested for face-to-face experiences. This required a shift in teaching practices and additional support to assist with developing the cognitive element—the curricula.

4. Conclusion

This paper focused on the way in which change is supported and how successful this support was as a means to measure success in the integration of teaching and learning across multiple modes of delivery. After looking at several frameworks and analysing strategies, some of which have been in place for decades, we believe there is still room for improvement. Appropriate indicators of success are key to the improvement of Tertiary Education. While the indicators outlined in this paper—learning materials, activities and assessment; student demand and experience; graduate outcomes; staff support and engagement; financial revenue and costs of support and infrastructure; and leadership and management—were a reliable starting point, they are not the indicators used today, in 2050. The job well done has been in developing these indicators, adapting them to the fast paced digital learning environment, and anticipating the changes to come.

Institutions of higher education all over the world followed different paths in trying to reconcile the changes imposed by new technologies on university environments. There were several iterations of distance learning, e-learning, on-line education, web-based learning, technology-based teaching, MOOCs, and other monikers given to modes of delivery that completely changed the traditional environment of classrooms. Regardless of name or technology or medium, physical presence on a campus has not been a requirement for those pursuing a degree for more than three decades.

The adaptations of the organisational environment required to transform this new world of Tertiary Education were challenging, but after much trial and error, in 2050, we now have seamless systems that are reliable, accessible, and inclusive. Leadership at every institutional level was paramount in establishing the digital enterprise, with adequate resources provided so universities could make the transition into the digital age. Universities that created an enabling environment for digital development were more successful sooner. Some had to be creative and add new courses to their portfolio to continue pursuing innovation despite accreditation bodies, which were sluggish about accepting the fact that digital
education was the new normal. Of course, the transformation of education is far from over. The same nimbleness that was required to take universities through the digital revolution of education will continue to be necessary as our institutions evolve. Pedagogical alignment, adequate resources for staff and students, staff engagement, and leadership from institutional administrators will provide the foundation for the next phase as we continue into the future.

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Embodied Energy of the Common Wood Fired Brick

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Abstract: With calls for environmentally conscious building design and construction on the increase across East Africa, the need to better appreciate the environmental credentials of commonly used materials has become a priority. Lack of in-depth studies of Embodied Energy (EE) and Green House Gas (GHG) emissions related to the construction industry can be attributed to a variety of factors, most notably, the ad hoc nature of the industry in the region. Of interest for this study is the EE of the most commonly used material for domestic construction, the wood fired brick. Manufactured close to sources of heavy clays or laterite soils, these bricks are fired on site in traditional scove kilns, making use of wood fuel to bake the bricks. Regarded as a cheap material and used in virtually all construction, little is known of their structural integrity, embodied energy values or the emissions stemming from the manufacturing process. Through an investigation of a selection of kilns in the central region of Uganda, the manufacturing process of the bricks was tracked and documented, making use of the inputs-outputs method to determine the EE of the final brick product. The findings of this study suggest relatively high Embodied Energy value for these bricks with a value of 4.26MJ/kg. While burning wood in this case could be considered carbon neutral, the broader impact from Green House Gas emissions as a result of this method of brick manufacture still needs to be explored. This also raises concerns for the potential growth in materials to support the growing demand for housing over the next few decades.

Keywords: East Africa; embodied energy; scove kilns; wood fired brick

1. Introduction

The analysis of embodied energy in buildings has been investigated in different parts of the world over the past three decades, acknowledging that use of low energy inputs in building construction is a key strategy in energy efficiency (Iurah and Holm, 1999). Embodied energy has been revealed as a major element in life-cycle energy demand, with literature suggesting that energy associated with building construction may constitute a significant proportion of life time energy, and in some cases, may be greater than use energy, where energy use for space heating and cooling is negligible (Hashemi et al., 2015). Little is known of how life-cycle energy is proportioned in the context of buildings across sub-Saharan Africa (Mpakati-Gama et al., 2011), more so as much of the material used comes from informal artisans, as is the case across Uganda. While progress has been made to gain an appreciation of operational or use energy, largely related to the shortfall between energy generation and exiting demand (See Drazu et al.,...
2015 and Kazoora, et al., 2015), only limited efforts have been made to investigate embodied energy and its contribution to the energy footprint of buildings, with a few studies in South Africa, such as Irurah (1997) and in Ghana (Eshun et al., 2010). Consequently, more needs to be done to ascertain the embodied energy of buildings across the continent, in a push to lower energy consumption in the construction industry, where substantial growth in demand for housing is expected, to accommodate rapidly growing populations across the region.

In Uganda, wood fired bricks are the dominant material for new domestic construction, despite only being introduced to the region early in the twentieth century by Christian missionaries seeking to build in the style of their home countries. Lacking building stone, they found a solution in the firing of bricks; with early kilns built to provide bricks for the construction of the grand cathedrals that grace the skyline of Kampala; St Paul's Cathedral, Namirembe (1919) and St. Mary’s Cathedral, Lubaga (1925). While these buildings have weathered the decades, the quality and value provided by wood fired bricks has recently been brought into question, more so bricks produced in the numerous informal scove kilns that have cropped up over the years to meet the growing demand for housing. The quality of these bricks have only recently come to light, with a study of the structural properties of these bricks revealing they were largely sub-standard (Okello, 2010), confirming anecdotal evidence that already showed this to be the case, thus increased use of concrete frame construction for even simple building projects. Regardless, the availability and low monetary cost of these bricks have made them a dominant feature in the landscape (literally), but with increasing interest in environmentally conscious design and construction, attention to their environmental credentials have been thrust into the spot light in the context of life cycle energy assessment. A key task of the project Energy and Low Income Tropical Housing (ELITH) was to investigate embodied energy for building materials in sub-Saharan Africa, where only limited information is available, hampering investigations into life cycle energy related to construction, more so with much of the material and labour linked to the informal economy. This investigation would be a small step to map out embodied energy values for different materials across the region.

Studies by Hashemi et al. (2015) and Niwamara et al. (2016) had been directed at ascertaining the embodied energy of the whole building, and made extensive use of The ICE Database (Circular Ecology Ltd.: 2017). While attempts had been made to quantify embodied energy of wood fired bricks, this had excluded some aspects such as transport and labour. The current study seeks to rectify this shortfall, through a detailed monitoring process, undertaken in conjunction with the artisans who worked the kilns. This paper presents the initial findings of the study, which assessed embodied energy of wood fired bricks, looking at the manufacturing process of scove fired bricks within Mpigi District in Central Uganda, based around the township of Nkozi, situated 84km southwest of Uganda’s capital Kampala.

2. Embodied Energy and Wood Fired Bricks

Life cycle assessment is a key part of energy related research, seeking to evaluate the total environmental impact of a building across its life. This process takes in the four key stages of a building: Material production; Construction; Occupation and Use, and End of Life. Embodied energy taken as “… the quantity of energy required to process, and supply to the construction site, the material under consideration” (Hammond and Jones, 2008). It includes three components: Extraction and raw material supply, processing, and transportation. The importance of Embodied Energy studies in the context of East Africa, lies in the fact that virtually no energy is expended on heating or cooling of buildings, making the contribution of embodied energy in the construction and maintenance of buildings proportionally larger in terms of energy expenditure. While there has been a move globally toward more centralised methods
for manufacturing building materials, this is not the case for sub-Saharan Africa, where material production; from concrete aggregate, to scaffolding and brick and block production is still part of the informal sector and highly labour intensive. Significant work on brick kilns has been undertaken in India over the years, tackling elements such as kiln performance, brick properties, emissions and embodied energy, including: Mishra and Usmani (2013) and Weyant et al. (2014). In contrast no studies of environmental performance of materials have been conducted in sub-Saharan Africa apart from a few general studies in South Africa, such as Irurah and Holm (1999) and Mpakati-Gama et al. (2011). Gathering data for embodied energy analysis is difficult and time consuming at the best of times, with many companies not having this information readily available, while some claim it is confidential (Hammond and Jones, 2008). This is more challenging in the context of East Africa, where there is little interest in research and organisations are reluctant to share information, fearing it would end up in the hands of competitors or used against them. A bigger concern is that brick producers in the informal sector may not keep accurate records of their activities.

Scove kilns are a common method of firing bricks across the globe, and still dominate brick production across sub-Saharan Africa and some parts of Asia. This method of brick production is responsible for a substantial proportion of bricks used in Uganda. Compared to traditional methods of building construction that made use of wattle and daub, grass thatch, or other materials, bricks are generally considered durable and this a big step in upward mobility. A downside of this form of brick manufacture has been its contribution to deforestation, desertification, air pollution and soil erosion (Deboucha and Hashim, 2011), with wood fuel for brick making accounting for more than 50% of commercial firewood use (Tabutia et al., 2003). More recently, there has been increased attention to the embodied energy of these bricks, as the firing process makes use of firewood as the main, if not only source of fuel to fire the bricks, adding to an ever increasing demand on the dwindling reserves of old growth forests, due to the preference for denser wood which burns longer and hotter (Tabutia et al., 2003). The size of kilns in Uganda, are relatively small, ranging in size from 2,000 to 20,000 bricks, compared to some of the larger scove kilns in South Africa, that accommodate well over seven million bricks. This method of firing bricks is known to be inefficient, with significant energy lost through the outer surface of the kilns, not to mention their contribution to air pollution and other severe negative environmental effects (Akinsipe and Kornelius, 2015). In much of sub-Saharan Africa, the brick making industry is largely uncontrolled and unregulated, with kilns found virtually anywhere there is the raw material, and labour to make the bricks. A challenge in this production environment, which largely congregate close to centre of construction – i.e. urban centres, is that the lack of pollution controls means these kilns contribute immensely to pollution and particulate in the urban environment (Weyant et al., 2014).

Across Uganda, the abundance of laterite soils and heavy clays mean that these kilns are found everywhere, largely close to the road for easy access for trucks to deliver the firing material, and to carry out the finished product. Scove kilns in the central region of Uganda are largely an informal enterprise carried out by landowners, or young entrepreneurial men making the most of the building boom in the country. The bricks which are all hand made, using wooden moulds, and do not benefit from any quality control or consistency criteria; varying considerably in size, shape and density. The kilns generally incorporate the firing chamber at the bottom, with one two or three chambers depending on the size of the kiln. Crucially, no allowance is made for heat transfer through the kiln, save for conduction, with bricks stacked adjacent to each other. The external surface of the kiln is plastered with a mud slurry, presumably to prevent external lateral heat loss.
3. Assessment Methodology

The study makes use of Life Cycle Assessment (LCA), defined by Menzies et al. (2007), as a means of investigating the environmental impact of products, buildings or other services throughout their lifetime. LCA encompasses: extraction, raw material processing, manufacturing, transportation and distribution, use, maintenance, recycling and final disposal; giving an idea of the expansive nature of this assessment approach. In this study, the focus was on the former stages: extraction, processing and manufacture of the bricks. Lack of available data would make the use of an Input-Output approach difficult, giving added weight to the use of Process Analysis to determine embodied energy values. Manufactures in this case are largely informal sector artisans, thus process analysis which accounts for both direct and indirect energy inputs was deemed most appropriate, and able to generate information to aid comparison with other materials in terms of energy per unit; in this case per kilogram (MJ/Kg), and per unit (MJ/Unit). This approach is regarded as the simplest, and most accurate when dealing with a single material, and based on primary data (Mpakati-Gama et al., 2011). This approach in itself is labour intensive, requiring significant commitment of time to track and document activities, which could only be achieved through mutual trust with the artisans, many of whom were working sites illegally, and therefore were suspicious of any outsiders asking questions. Assured of our intentions, activities could be monitored unimpeded, providing the first assessment of the embodied energy of fired clay bricks in the region. Each stage of the process was meticulously documented, tracking the process of brick manufacture through primary documentation, investigating the source of the raw materials, time taken to mould the bricks, source of wood fuel for the firing process, and the quality of the final product. A key factor was the need to engage the artisans in the local language as a means of building trust, and ensuring they were comfortable in discussing the nature of their activities. Gaining trust was critical in ensuring the validity of collected data. Reviewing the brick manufacturing process, we can break these down into six stages, as presented in Table 1 below for a kiln of about 13,000 bricks.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Required Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forming</td>
<td>26 cubic metres of Clay</td>
</tr>
<tr>
<td>Sun Drying</td>
<td>100 kilogrammes Elephant Grass</td>
</tr>
<tr>
<td>Stacking for Air Drying</td>
<td>20 kilogrammes Elephant Grass</td>
</tr>
<tr>
<td>Sourcing of Firewood</td>
<td>35 Litres of Diesel</td>
</tr>
<tr>
<td>Scove Kiln Assembly</td>
<td>0.5 Cubic Metres of Clay</td>
</tr>
<tr>
<td>Firing</td>
<td>6,100 kilogrammes of Wood</td>
</tr>
</tbody>
</table>

Data was collected from three sites and seven kilns in the area, monitoring brick manufacturing from small producers, with scove kiln sizes ranging from 7,000 to 20,000 bricks. Brick manufacturing is largely undertaken in wetlands, close to the source of the raw material, as virtually all the work is undertaken using human labour. Bricks are hand made, and sun dried before being stacked on a scove kiln to be fired, making use of wood off-cuts for fuel. Finished products are transported direct from the kilns to site by the buyer, and thus are not included in manufacturing embodied energy calculations.
4. Production Process

The following subsections describe the manufacturing process, and provide an evaluation of the associated embodied energy for each step of production. In this case labour is treated separately to make it easier to calculate. The assessment is made based on an average size scove kiln of 13,400 bricks, arrived at after a study of seven different kilns in the area.

4.1. BrickMaking

The process starts by identifying a good location with available raw materials; preferably clay based soils (found around wetlands) or in some cases heavy laterite soils, common across the region, and locally known as Murrum; use of the latter brings brick manufacturers into competition with farmers. Three types of clays (*alumina-silicates*) were identified within the study area: Grey clays; Yellow clays, and; Red clays (Laterite soils with high iron content). The colour variations depended on the location, and affected the pH levels of the soils (Mukasa-Tebandekeet *et al.*, 2015). For the current study, bricks made from Grey clays are the focus of this investigation. The location for brick production was always close to the source of materials, eliminating the need to transport raw materials, understandable as virtually all work is by hand. Material is excavated or dug out using a hoe, and mixed both by hand, and using hoes; water is added to the laterite soils to make them malleable. Each brick maker works with a single wooden mould, and is able to make approximately 250 - 300 bricks per day, working seven hours per day. The moulded bricks, which are fairly moist, are tipped out onto grass covered ground to dry in the sun, and left to dry for one or two weeks, depending on the season. Bricks are then stacking for further are assisted curing for another two to four weeks. Curing times were largely determined by experience, and not on any measurable moisture content value. The length of time taken depended on weather conditions (largely related to the rains), which can greatly prolong the drying process (Figures 1 and 2). Thus, for a kiln of approximately 13,400 bricks, approximately 630 hours would be needed just to make the bricks, going through over 26 cubic metres of clay. In terms of embodied energy, there is no direct contribution from the raw material, with the major energy input from labour, which is discussed separately.

![Figure 1: Brick making in a wetland (source: Author)](image1) ![Figure 2: Air drying of bricks (source: Author)](image2)
4.2. Transport

While there are no associated transportation inputs as part of the brick making process, with bricks made close to the source of raw materials, and workers walking to work, it becomes critical for the sourcing of fuel to fire the bricks. Wood used generally comes from old growth forests. On average, three trips are required to ferry wood for the kiln, making use of a two tonne truck. Wood came from a number of different sites, ranging from 6km, to 124km, largely depending on the availability of felled wood; on average wood was ferried from 56km from the kilns. Based on data obtained through the project Supporting African Municipalities in Sustainable energy Transitions (SAMSET), vehicle transport energy for western Uganda was calculated to be 1.9MJ/t/km for petrol, or 2.5MJ/t/km for diesel (McCall et al., 2017). Most trucks make use of diesel, and are often overloaded, however for the purpose of this study the standard haulage value of the trucks is used. Based on a need for 6.0 tonnes of fuel wood, and an average 56km, the contribution of transport was calculated to be 840MJ, adding an additional 0.079MJ per useable brick, or 0.025MJ/kg.

4.3. Firing Process

Unlike kilns in Asia that often make use of waste material such as old tyres, low quality coal, and used-oil, brick manufacturers in Uganda use wood fuel as the only fuel source; largely off-cuts from trees that had been felled for timber. Trees were predominantly hardwood, such as Milicia excelsa (Mvule), as brick makers believe they ‘burn longer’. Milicia excelsa has a density of 0.58g/cm³ (580kg/m³), with a measured heating value of 22.8MJ/Kg (Adekiigbe, 2012). Use of Mvule wood is contrary to what has been reported in the literature, which suggests scove kilns are fired with eucalyptus wood, with a density of 0.56g/cm³ (560kg/m³) and a heating value of 17.0MJ/Kg (Hashemi and Cruickshank, 2015). While Eucalyptus wood may be in use in Kenya and Tanzania, it is generally not used in Uganda, with a visual inspection of most kilns indicating no evidence of use of eucalyptus wood. Use of Mvule wood however puts brick makers in direct competition with charcoal producers, and those seeking firewood.

Figure 3: Kiln with unfired bricks (source: Authors) Figure 4: Kiln after firing (source: Authors)

Assembly of scove kilns is done by two to three people, who stack the kiln within a day, plastering the outer layer with a clay slurry in order to reduce conductive heat loss (Figures 3 and 4). The average kiln size was about 2.4 x 3.0 metres at the base, with a height of about three metres, and contained about
13,500 bricks. Bricks in the scove kilns investigated were stacked close together, with the heat source at the bottom of the kiln, making conductive heat transfer the only real means of heating the bricks. The firing process generally started in the evenings, with two people working to keep the fire blazing for 20 to 24 hours, depending on weather conditions and the nature of the clays used to make the bricks. Artisans reporting that bricks derived from grey clays require the most fuel wood, and red clay soils the least. Kilns are left to cool after the firing process, and disassembled when a buyer is found, with most kilns generally fired as and when bricks are needed (fired to order), and not as a speculative endeavour.

The amount of wood required to fire one tonne of bricks was found to be about 0.25m³, which gives an energy input of about 3.3MJ per tonne of bricks. Given an average brick weight of 3.1kg, on average 139GJ of energy are used to fire a scove kiln of 13,400 bricks (about 26 cubic metres), or 10.4MJ/Brick, or 3.37MJ/kg, before factoring brick losses. Brick makers reported manufacturing losses of about 20% of fired bricks; the high temperature near the source of the fire contributing to a substantial proportion of bricks fusing together, while bricks near the outer surfaces are not fired completely, remaining brittle and of dubious strength (Okello, 2010). Taking a 20% loss, a brick kiln of 13,400 bricks will yield about 10,700 useable bricks; this revised figure giving embodied energy values per useable brick as 13.1MJ/Brick, or 4.21MJ/kg.

4.4. Labour

Energy inputs from labour, or eco-energetics, has been a controversial area in embodied energy studies, as it is often unclear how to relate human energy to manufacturing processes, more so in the context of industrialised societies where labour forms a minor component of production (Mpakati-Gama et al., 2011). For sub-Saharan Africa, where human inputs form a substantial component of the construction process, as is the case for burnt bricks production, where no mechanical equipment is used, labour forms a major energy component, along with the sourcing of wood and the firing process; thus, marginalising human energy inputs would significantly skew the data. Calculating the value of energy from labour is based on the calorific value of food consumed, as derived from the FAO (2010), which estimates that the calorific value of food consumed each day by an average adult in Uganda to be 2020kcal., or 8,448kJ. For this project, the full value of energy was used, which we acknowledge does not take into account Net Metabolised Energy, or Basal metabolism, nevertheless, it does provide a good indication of the energy expended by workers, given this is their full time activity, and the values are calculated based on the combined work hours, rather than for individual workers. The workers generally worked full time, and thus all their energy went into the brick manufacturing, and engaged at all stages of the low-tech process, including; sourcing of the wood (loading onto the truck), digging up the clays, making of the bricks, stacking of the bricks for drying, building the scove kilns, and feeding the furnace. For this study, felling of trees is excluded, as this activity could be attributed to the timber industry, more so as the wood used were a by-product. Work hours for each of the respective stages are presented in Table 2 below. In total, for an average brick kiln of 13,400 bricks, a total of 645 hours of labour goes into the production process. Based on these labour inputs, an energy input of 778.42GJ of energy was expended for the manufacturing process, translating to an additional embodied energy value of approximately 0.073MJ per useable brick or 0.023MJ/kg.

Table 2: Labour Requirements for Stages of Brick Manufacture
5. Discussion

Taking the various components of the process and putting them together forms a composite picture of the embodied energy for scove-fired bricks, up to the completion of the firing process. The study found that the total embodied energy for the bricks was 13.25MJ/brick (per useable brick), or 4.26MJ/kg (See Table 3 below).

Table 3: Embodied Energy per Component

<table>
<thead>
<tr>
<th>Stage</th>
<th>MJ/Brick</th>
<th>MJ/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>0.079</td>
<td>0.025</td>
</tr>
<tr>
<td>Firing Process</td>
<td>13.1</td>
<td>4.21</td>
</tr>
<tr>
<td>Labour Process</td>
<td>0.073</td>
<td>0.023</td>
</tr>
<tr>
<td>Total</td>
<td>13.252</td>
<td>4.258</td>
</tr>
</tbody>
</table>

Menzies et al. (2007) provided a range for clay products, from 0MJ/kg to 30MJ/kg, a range that reflects the range of clay products available, and the different levels of processing put into the different products. Hammond and Jones (2008) give a value of 3.0MJ/kg for bricks, likely made through industrial processes. More specific for burnt clay bricks, Esteban and Buccellato (2012) give an embodied energy value of 4.25MJ/brick (Although this seems an error, and should be per kg); they however do not provide the basis for this value, nor do they give the weight or density of the bricks in question. Hashemi and Cruickshank (2015) give a value of 4.76MJ/kg, slightly above that cited by Esteban and Buccellato, largely based on the firing process. A study by Mishra and Usmani (2013) suggests that the embodied energy of Burnt Clay bricks to be about 5.0MJ/brick with average size 100mm x 50mm x 50mm, typically used in India, while Mithra et al. (2015), give a value of 0.8MJ/kg, which is at the lower end of the values, although as with Esteban and Buccellato (2012), they do not specify what product was investigated, or how they were manufactured. By comparison, the embodied energy of fired clay bricks as presented in the current study, through Process Analysis could be seen to provide a fairly accurate picture of the embodied energy of wood fired scove kiln bricks. The established figure of 4.26MJ/kg is close to what Mishra and Usmani (2013) and Hashemi and Cruickshank (2015) suggested as the embodied energy value. The difference largely relates to the fuel used to fire the bricks, given that the firing process accounts for over 99% of the embodied energy of wood fired scove kiln bricks. Incorporation of energy from labour is certainly not mainstream (Dixit, 2017), thus incorporating this element into the current study, while useful still needs to be further refined, and build a case for comparison with different processes in the industry. Clay fired bricks thus emerge as having an embodied energy value substantially higher that that of the benchmark of 3.0MJ/kg, making them a significant contributor to energy use in the building construction industry in Uganda, albeit an unseen cost, which makes it that much more difficult to effect change in an industry.
which is largely unregulated, and where designers rarely specify the type of material to be used for construction.

6. Conclusion

The findings of this study are part of a process to unpack the embodied energy values of construction materials available in Uganda. It is however the case that such energy analysis is not embedded in the design and construction practices of the industry, where capital cost is still the basis for decisions. Transmitting such information to manufacturers, builders and designers becomes a key challenge, more so as there currently are no rules and regulations that are directed at materials used in the building construction industry, beyond basic strength and integrity. Nevertheless, seeking to quantify the environmental impact of various materials may provide the impetus for the change, and a catalyst for responsible materials management as the most viable means of reducing environmental impact of existing practices. There is a need to widen the study, looking at different regions, and clay types in order to build a more accurate picture of the embodied energy of wood fired brick produced in scove kilns. An added interest would be to assess emissions from the scove kilns, given anecdotal evidence that suggests they are also a large contributor to airborne pollution, in addition to the other environmental impacts already associated with this method of brick production. By placing a value on activities related to the manufacture of these products, it may be possible to influence the process, leading to more efficient firing practices.

Acknowledgements

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Design and Build an Organisation to Deliver

Learning from a Project Management Studio

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Abstract: Successful inter-professional collaboration in a built environment project takes personal leadership and interpersonal capacity, professional competencies that are not explicitly addressed in the current architectural curriculum. This paper presents an action research exploring the pathway of educating these traits through a project management studio. Students were challenged by a large group size from which to design and live out an organisational structure to deliver a debate. The results highlight two themes: perceived ambiguity and workload, and intragroup conflict as trigger of double-loop learning.

Keywords: Project management studio, ambiguity, organisational structure, collaboration.

1. Introduction

How architectural education should respond to the changing practice has been a focus of academic debate since the 1970s (Nicol and Pilling, 2000). New domains such as sustainability, BIM and integrated project delivery are taking more central roles in the building process, which confronts architects with a choice of either shrinking their service as a mere designer of styles or taking up the responsibility of project managers to work with stakeholders on the whole building process. For the latter, personal leadership and management skills become indispensible competences to be integrated into the existing architectural curriculum and studio system.

Architectural schools have been taking pride in their tradition of design studio since Schön’s (1985) exemplification of it as an ideal model of educating professional artistry in contrast to the model practised by modern universities that structures teaching into a dichotomy between theory and application (problem-solving techniques) (Schön, 1987). Traditionally, the model of architectural design studio consists regular one-on-one tutoring (desk critics) and one or two group juries. Students, before formulating an idea of what is architectural design, are coached through a design process by an expert (the studio master). Through the coached action of designing, students learn to ‘think like an architect’ (Schön, 1985). While group juries are set to test and develop the robustness of individual design decisions.

Seeing through Schön’s perspective, the studio-based pedagogy has the potential of educating professional artstries beyond architectural design. Practically, a learning journey well crafted to stimulate
reflection-in-action over a process of managing and leading will develop the artistry of management and leadership among students. The learning of interpersonal skills to be able to manage a design/build project is analogical to the mastery of skills of painting and drawing prior to design in the École des Beaux-Arts system or the mastery of computing skills prior to parametric design in the digital era. The common rationale is that one needs to master the media/tools to be able to achieve the goals. However, the individual based process of traditional design studio cannot provide training on the competence of interpersonal collaboration and teamwork, the indispensable tools for managing projects in real life projects in the future. This paper addresses such a gap and presents an action research that tests out the possibility of developing leadership and interpersonal skills through a project management studio.

2. Theoretical Base

2.1 The Generalizability of Design Studio

Design studio hosts a learning journey starting from acknowledging complexity in real life situations characterised by ambiguity, uncertainty and uniqueness (Schön, 1983), out of which problems need to be proactively framed and defined before progressing to formulation of solutions (Kvan and Gao, 2004; Schön, 1984). A studio project holds novices accountable for decision-making while the educator’s role is to facilitate to clarify and evolve their goals and decisions through inquiries, critiques and challenges. The outcomes of such a learning journey are robust decisions and decision-making capacities of the students, capable to be responsive to the unique and changing situations in their future workplaces. Based on a general experiential learning theory (Argyris and Schön, 1974; Kolb, 1984) and a specific model of reflection-in-action (Schön, 1987), the studio approach can be a vehicle to cultivate skills and abilities of design decision-making in a more general scope, such as the design of a human organisation (Boland Jr. and Collopy, 2004).

What Schön calls reflection-in-action requires a double-loop learning (Argyris, 1976; Argyris, 2002) in which the practitioner questions and challenges the assumptions of actions, which include to make sense of the new knowledge, to explore new options, and to test out the hypotheses (Schön, 1985: 25). The learning is not generated by an expert practitioner’s coaching of action, but by the learners’ reflective conversation with the situation of which the expert’s coaching is one of the conditions. The reflective conversation processed in the learner’s mind involves dismissal and reconstruction of his or her personal theory-in-use and which is not solvable without reframing that theory-in-use. In this sense, the process is methodologically a process of constructing a grounded theory (Glaser, 1978; Glaser, 1992; Glaser and Strauss, 1967). The essential process is to make sense of the real-life situation and formulate it into well-defined problems to develop an integrated solution that fits. This process is not necessarily articulated in language, but built into students’ personal habits and routines of reflective actions (Polanyi, 1967), an important competence in their future professional career. In this light, Schön suggests the studio pedagogy is generalisable to non-architecture disciplines:

“It would be studio-like in the sense that it would ask students to plunge into these before they know what they need to be doing or learning. It would expose students to the demonstrations, advice, and criticism of master practitioners. It would focus on the messiness of problematic situations which need to be converted to well-formed problems before they can be solved by the application of established techniques. It would pay attention to the strangeness of unique cases that escape the categories of established
theories. And it would engage the appreciative, value-laden questions as well as technical ones. ...” (Schön, 1985: 89).

2.2 Learning as co-construction of experience

In Schön’s description, the learning in architectural studio starts from a ‘leap of faith’ from which the student plunges into an experience before he can justify or explain or understand it, simply by trusting the instruction of the studio master. In this process, the master plays a role of giving experience, which the student is to go through in order to make sense of it. The actual learning outcome is the meaning of the experience constructed by the student him/herself. The latitude of decision given to individual students over their own work and the diverse ‘senses’ made by individual students out of the seemingly same experience signify the freedom of learning inherent in this mode of education.

A key issue with Schön’s (1985) widely cited case study of a design conversation between a tutor and a student is that Schön did not extend his examination to what happened to the development of the design idea after the desk crit. In the reality of architectural design studio, students often find it impossible to take on board the Master’s idea or make sense of it, although s/he is apt to accept it in full during the desk crit. Instead, students reframe the problem in their own way. The design idea imposed by the tutor and the demonstration of ‘designing’ feed into students’ subconscious as a habitus learned from the master’s demonstration and the theories and information picked up from other courses relevant courses outside of studio. In a university context, architectural students pick up a significant amount of background knowledge from the relevant courses outside of studio; this knowledge works as the students’ ‘theoretical sensitivity’ (Glaser, 1978) that determines what makes a meaningful problem to the student. The theories and knowledge also works as students’ personal repertoire of coping where they can draw from while constructing and revising their personal theory-in-use.

Here, Schön overlooked a fact that the novice has his own experience prior to and outside of his studio experience. The actual outcome of studio learning is a co-construction of experiences between the student’s existing experience and the design experience coached by the studio master. This is more apparent in a flexible education system like Australia where the majority of the student population is engaged in part-time jobs. If the student is of an older age, learning is even more explicit a co-construction of experience.

Seeing learning as co-construction of experience, students cannot be treated as a blank piece of paper but practitioners of their own knowledge and experience varied across their social backgrounds. They have their theories-in-use, may or may not be in their awareness, prior to and outside of their studio experience. The theory-application dichotomy in the ‘normal’ university teaching often feeds into students’ espoused theory that gives an explanation to their existing pattern of actions and tends to enhance their existing theory-in-use, rather than transforming it. Therefore the effect of such education is limited to ‘accumulative learning’ that keeps students in a self-enhancement cycle (Argyris, 1982).

2.3. The ‘Risks’ of Ambiguity and Uncertainty

Ambiguity is an intrinsic and essential feature of the studio setting. The tutor’s instructions drive students into a wonderment of discovery. Students are expected to make decisions before they know what they are doing. “The discovered ambiguity is a problem to be solved” (Schön, 1985: 68). The reflection-in-action draws reference from the old mode of learning as trial-and-error. The student needs to take a ‘leap of faith’ to plunge himself into a situation that he cannot fully make sense of and without a determined route
of getting the correct answer. They must “take a plunge into doing before they know what to do” (Schön, 1985: 88) in order to make the learning happen. As s/he makes sense of the situation, formulates problems and make decisions on an appropriate solution to address the current problem, he takes action to alter the situation of which he is part of, of which he is shaping and being shaped by. This process throws students into uncertainty and exposed them to the ‘risk’ of making mistakes and losing control, which is particularly worrying for engineering students who are programmed to get straight to the ‘correct’ answer and for Australian students who live in a culture of high uncertainty avoidance (Hofstede, 2001). The student must learn to be comfortable with uncertainty and ambiguity to be able to work with the ever-changing situation wherever he finds himself, thus embarks on the journey of co-constructing a new experience, through which to develop the artistry of management and leadership.

3. Rationale of the Project Management Studio

The generalised studio model has the strength of teaching the formulation of problems from a problematic situation “in such a way as to create a springboard for design inquiry” (Schön, 1985: 6). The student needs to consider all the perceivable constraints and make an intervention to the situation, then evaluate the consequences of his intervention and the possibilites and constraints in the new situation, based on which to make his next decision. Students take action to change the situation without a fixed theoretical framework to apply. He learns the consequences of his intervention to the situation after his action to it; he reflects on these consequences to determine his next action to the altered situation. Here design decision is not separable from the action of altering the situation.

![Double-loop learning cycle in a studio setting](image)

Figure 1. The double-loop learning cycle in a studio setting

In a traditional architectural studio, all these experiments and evaluation of decisions happen on paper instead of the real life situation. In the project management studio, the situation involves people - the goal of educating interpersonal skills has to involve human-based situation. Double-loop learning is made possible through the educator’s intervention/involvement into students’ learning cycle to trigger a knowledge co-construction process. The educator is to push the student practitioners out of their self-
enhanced cycle into a cycle of reflection-in-action through coaching, demonstration and more importantly challenging situations that takes development of measures outside their existing repertoire of coping (Figure 1).

Such a switch of cycle cannot be achieved by the student without developing the cognitive pattern of reflection in practice (Argyris, 2003; Schön, 1987). Expert involvement in the circle is to help novice practitioners to be aware of their theory-in-use and take them into the shift of cycle. The learning progresses by the generation of actionable knowledge within the learners (Argyris, 2003).

4. The Action Research

An action research was undertaken in 2014 and 2015 through developing, teaching and redeveloping a studio-based unit of Project Safety Management in a construction management undergraduate programme in Australia. The content and leaning process were reviewed and redesigned after the 2014 studio. The revised studio reduced the level of ambiguity in tasks and processes to adapt to the characteristics of construction management students.

3.1. Departing from the ‘Normal’ Model

The study unit was situated in a Bachelor of Applied Science (construction management) programme, the courses of which constitute a typical ‘normal education’ model set to teach technical expertise through lecturing and exam. Before the redevelopment, the unit was designed to consist twelve lectures, two assignments and one exam. One of the assignments was group work in which students were normally expected to work in a group of four or five. The best teaching practice recognised in the department expected the lecturer to set up well-defined tasks for the group assignment, give clear specifications of each role in a group (e.g. analyst, etc.) and provide detailed instructions on what they are expected to do and how to get there. This practice ensures students a secure path to follow to be able to deliver the specified ‘product’ (assignment) to get their desired mark.

The problem with this pedagogy is that students are not really given the experience of framing problems from complex situation, as they would encounter in their future job, nor the experience of building a team. Noting this issue, the design of the assignment (as analogical to the design brief in architectural studio) aimed to specify a set of values (e.g. caring, engaging, proactive, resilient), setting up deliverables (a debate, group report on the debate, individual reflection on the organizing process) and a broad pathway to get there.

3.2. The Project Management Studio

The aim of this unit is for students to be able to use systems thinking to make sense of safety management in the authenticity of specific stakeholders’ role such as client and contractor. The ultimate goal is to understand the importance and the complex context of making a learning organisation that can effectively respond to unexpected conditions. Compared to the studio tradition used in architecture programme as described by Schön, this class had two additional challenges which are representative to the normal disciplines in universities: it had a large class size of 120; the skills to be developed through the learning are about dealing with people rather than with materials.

A class of 120 construction management students was divided into six studios. Each of the studios assume a stakeholder’s organization related to a construction project. The brief assigned to students’ groups was to design and build an organization that represent the role of a specific collective stakeholder
over the supply chain of a construction project to deliver a debate on safety management that are
interruptive to their daily. Some constraints were set up in analogue to site conditions and requirements
in a design brief, including the focus of topic, the size of the group, the time frame of delivery and the
exam. Students were initially challenged by an unusual large group size, unto which they need to design
and live out an effective organisational structure, defining and dividing tasks, assigning roles and
responsibilities to identify a worthwhile argument for the debate, conduct research to inform the sub-
arguments of the debate and finally, to perform the required debate. Key features of the learning process
included the following:

- Develop personal leadership through the collaboration experience
- To make a large group of people to work effectively, the organization has to develop a mechanism
  of performing collaboratively. This can be a hierarchy, including dividing roles, assign tasks,
  assume authority and do one’s own role
- Students need to deliver the debate, through a process of engaging their teammates and assume
  leadership over their peers
- What does organisational resilience mean personally to the students: leverage the organization
  to respond to unexpected issues

Broadly, the studio work process can be described in these steps: (1) set up group of approximately
20 students; (2) provided the group with the task – design and build an organisation to deliver a debate,
with a suggested organisational structure; (3) each student group divide themselves into two to work out
the key points at stake and a pro and anti views worth debate; (4) the pro and anti views were further
researched to prepare evidences for the arguments; (5) students divided roles into ‘leaders’, ‘speakers’
and ‘researchers’ in order to work effectively; (6) a survey was administered in around the fourth session
to facilitate students to review their roles and tasks division; (7) in the last session, six debates were
performed, each given 20 minutes; (8) students were required to submit a report on the evidence base of
their debates, as well as a reflective journal on the process of the development and change of their
organisation. In practice, the process was loosely structured and spontaneously managed by the tutor.

4. Results

4.1 Ambiguity as a Breeding Ground of Self-initiative

Initially, students were troubled by the large group size and the ambiguity of the situation. But the
ambiguity was exactly a breeding ground for understanding the need of an organisational structure.

“Initially I had concerns about working in such a large group (19 members) with people I did
not know. I was concerned about the natural shyness and anxiety people have around new
people, let alone a large group of new people, and the impact that would have on
productivity and leadership capabilities. My initial trepidations were proven correct as it
took a few sessions before any real progress was made. I feel this can also be attributed to
the lack of ownership and responsibility from individuals, and absence of role definition.
The biggest contributor in enabling progression was the organisational structuring into
separate negative and affirmative teams, and allocation of roles.” (Student 099)

Leadership was developed from self-initiative after sitting around having nothing to do:
“I felt we were just standing around doing nothing so I opted to start organising the group by writing down team member’s full names and student numbers. The group then appointed myself as chairman, from here I managed to split the group into two sides; one being those who live north of the river and the second those who live south (For and Against teams).” (Student 011)

Naturally, students developed their team structures by physical locations.

“We have 20 people in the group, half of us live in the south of the river and half in the north of the river. We organized exactly in that way.” (Student 012)

“We sorted the groups into living locations. The members who lived north of the river were one group and the other members who lived south of the river formed the other. This was to make it easier to form meetings and discuss issues. The group decided to form a Facebook page to communicate to each group. We then decided together to base our debate based on the workers perspective towards heat stress management plans. Over the weeks we used Facebook to communicate throughout the group. At the beginning I believed a group of 17 people was a bad idea, because of miss communication issues and people not pulling their weight. In all honesty I haven’t worked in such a great group. Everyone performed well and did what was needed. Communication was clear and concise. All-round great group preparation lead to a great debate.”(Student 022)

As the city spread wide and traffic was a significant cost in terms of both money and time, students supplemented face-to-face meetings with social media communication, mostly using Facebook. The highly controlled Blackboard online forum was largely abandoned by students and was not used unless it was made compulsory.

“Having been appointed chairman it was my responsibility to ensure that the group had a clear form of communication and this was best achieved by creating a Facebook group between all members. Instantly information and ideas were posted by multiple group members and the debate topics started to form.” (Student 023)

4.2 Perceived Ambiguity under the Mask of ‘Workload’

Typical issues arised in Week 4 during the course where students started to complain about ‘workload’. Such crisis was facilitated with a survey including questions on workload, time and task complexity. The result of the survey was fed back to students. Surprisingly, only 9% of them felt 'overloaded', 59% felt the workload was "just about right" and 32% reported they were 'under-loaded'. It was found that leaders were normally overloaded while researchers at the bottom of the organisations felt under-loaded. The organisations were asked to review their task allocation within group, adjust organisational structure and make effective delegation of work.

In the second year, when the same scenario was repeated, it was surprising to find that students learned from their seniors to manipulate the survey! They organized themselves to exaggerate workload in the survey, and used it as evidence to demand to “cancel the exam!”

This crisis was resolved with a lecture bringing to explicit the meaning and vision of their university education to prepare them to be leaders of the future industry rather than simply job seekers. The key lecture helped students to reframe their problem from “how to reduce my workload on this unit?” into “How can I improve?” They never mentioned workload again.
4.3 Intra-group Conflict as an Opportunity of Double-loop Learning

Whilst ‘organizational’ decisions were largely left for students’ independent decision-making, intra-group conflicts were carefully attended, taken as opportunities to guide reflective thinking toward new knowledge construction and personal leadership development. A major intra-group conflict broke out when a student accused his team members for ‘bullying’ him by not engaging him in the work. He posted his complaint on the online public forum, which was seen by his teammates who were greatly troubled and worried. As an immediate defensive response, the leader wanted to kick him out of the organisation. Discussion with the group found that the complaining students was a latecomer to the team and was six years older than his peers. Further discussion with this student found that he had deeper thought and personal experience of family business related to the topic of debate, which was not engaged in the teamwork. This experience however also made him difficult to integrate into a team of young members. When assigned to do a part of the group report, he either tried to correct everybody else’s work, or tried to do the work all over again by himself.

After exploration, a “no divorce” policy was set up to the class. The tutor then personally coached the two conflicting parties to guide them to see the opportunities of personal development over this issue. The group eventually worked out. In the second reflection, the once-dropped-out student reported that he learned to be ‘diplomatic’ in dealing with people. Although he did not change his view that his younger peers were doing a shallow work, he accepted them, “But I don’t mind if they want to be superfluous.” He added.

5. Discussion

Architectural schools have been making effort to increase students’ exposure to real life situation by taking real projects into studio, inviting practitioners to design juries, and integrating a certain period of internship into the curriculum. A close examination of these measures would find that students have never worked beyond a designer’s role in any of these experiences, which highlight their inadequacy to educate the kind of artistry of framing and achieving project goals through designing, building, leading and managing an organisation of certain structure. This action research on a project management studio provides a prototype for architectural design studio to replicate and test out for a broadened architectural design studio that produces future architects capable of leading complex project teams.

In his classical work Culture’s Consequences (Hofstede, 1980), it took Hofstede an Appendix to acknowledge his personal values in order to be transparent to the readers on the possible bias of his culture theory. No research activity is value-free. Teaching/learning, too, is a cultural activity.

“If schools of architecture bid for wider legitimization of their alternative role as providers of general higher education, they must take on a commitment to explore and develop their connections to other forms of intelligent activity, and therefore, to other branches of learning. ... if architecture is the prototypical design activity, its more generic role in higher education would be enhanced by examination of its relationships to other modes of designing ... (Architects) may find it profitable to explore their family resemblance to, and differences from, kinds of designing undertaken in different media and with different ends in view.” (Schön, 1985: 97).

In spite of this vision, Schön’s specific case study of the studio model is a process of constructing new experience coached by an expert, who not only instructs, but also demonstrates and describes how to do the design. This project management studio addresses a large class size where students were directed
into a journey of trial-and-error to work on situations of uncertainty and ambiguity, by which they developed personal leadership and management artistry through adapting to and handling the changing situations. The students were not given demonstration of how others (neither an expert nor a peer) did it, although the second year’s students learned from their seniors to manipulate the survey to justify their reservation from going into the experience signalling uncertainty and anxiety.

6. Conclusion

This paper reports an action research exploring the pathway of educating inter-personal leadership and management skills through a project management studio. In contrast to the studio pedagogy described by Schön, i.e., the novice learns to see things through an expert’s eye through a learning-by-doing journey coached by the studio master, this project management studio designed a number of challenges to drive students to a self-discovery journey where they reconstruct their interpersonal set of skills in the formation of organisational structure and assuming specific roles in the organisational context. Initially challenged by an unusual large group, a chaotic situation to define and address, students ventured through a journey to design and live out a human organisation. In defining a chaotic situation and delivering a debate through a temporary organisation that is responsive to the changing constraints, students construct their own unique experiences, different from one another, as they struggling out their own roles and going through intra-group conflicts. The approach tested out in this project management studio is transferrable to architectural studios, as a protocol of training future architects on interpersonal skills in the complex project context.

References


Space Syntax in Design Curriculum

Opportunities and Challenges

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Abstract: Space syntax is a prominent theory for understanding some key aspects of the built environment and people’s behaviour within it. Hence, familiarity with the theory would be an advantage for the designers to analyse, learn from and improve the exiting design as well as to create a more responsible built environment in future. However, the theory of space syntax has not yet been adequately integrated into the curriculum of many design schools. This paper presents an analysis of opportunities and challenges of the application of space syntax in the undergraduate architectural design curriculum. The goal of this paper is to anticipate these challenges and support a curriculum planning strategy for the matter. For this purpose, this paper first provides a brief review of previous studies and efforts to integrate space syntax into the design pedagogy. Then, it pursues a qualitative approach to identify different aspects of the relevance of space syntax within the design pedagogy. At the end, the paper presents our approach to address the considerations arisen in the literature review and introduces some of the steps planned for familiarising architectural design students at the University of South Australia.

Keywords: Space syntax; design pedagogy; design curriculum.

1. Introduction

Space syntax is a prominent theory of understanding some key aspects of the built environment and people’s behaviour within. The theory is based on the abstract formulisation of human’s visual and mobile behaviour by geographic and geometric information from the surroundings (Ostwald, 2011). Space syntax theory provides robust and reasonably objective arguments, methods and techniques to model and predict effects of architectural and urban design on important social issues related to privacy, safety, crime rates, prosperity, traffic control, etc. Familiarity with the theory and its implementation would be a significant advantage for the designers in analysing, learning from, and improving the exiting design as well as in creating evidence-based, responsible and, sustainable built environment in future.

However, the theory of space syntax, its findings and tools have not yet been adequately integrated into the curriculum of many design schools, especially at the undergraduate stage (Griffith, 2014). Familiarity with space syntax, especially its theoretical framework, may improve the students’ skill set when they enter the profession. This is particularly important for Australia as the county plans for important measure to boost construction of new housing and development of cities.
The present paper aims to provide suggestions to improve the role of space syntax in design pedagogy. This paper tries to address this goal in three further sections. First, it provides a brief history and description of space syntax. Then, it reviews the existing studies on the teaching or using of space syntax in design schools. Third, it identifies potentials and challenges towards incorporation of the space syntax in design pedagogy. Finally, it proposes a preliminary step taken to address some of the issues.

2. Space Syntax

Space syntax was initiated at University College London (UCL) in 1970s by Bill Hillier and colleagues (Hillier et al., 1976). Their studies culminated in Hillier and Hanson’s book, The Social Logic of Space (1984). In summary, the theory tries to translate the complex and concrete fabric of space into discrete and syntactic components whose relations are explicable by mathematical mechanisms. The mathematical context in discussion is the Graph Theory that processes the topology of things with graphs – a set of nodes which are interconnected with edges. In space syntax, the space (usually in the form of floor/street plan) was abstracted into nodes based on their geometrical properties. Initially, there were two basic ways of abstraction which can be roughly expressed as 1D straight lines (e.g., streets and paths, called axial lines) and 2D convex areas (e.g., rooms and plazas, called convex spaces). The edges of the graphs are usually defined as when the nodes have direct access to each other (e.g., openings between adjacent rooms or intersection between streets). Later, in 1990s, a third related geometric abstraction of space called isovists was merged into space syntax corpus (Turner and Penn, 1999). Isovists were first proposed by Benedikt (1979) as a polygon representing the area visible from a point. In the space syntax approach, the points, as defined by a grid articulation of the floor plan, are represented by the nodes of the graph and their mutual visibility determines their connection. The outcome of the abstraction is called a map (i.e., axial map, convex map and isovist map for the respective mappings, though the last one is also called a visibility grid). Each of the mappings have been furthered by variants such as social boundaries (Peponis and Wineman, 2002) instead of strictly convex areas, and segments (Turner, 2007) or intersections (Batty, 2004) of lines instead of whole axial lines. The focus of the mathematical calculations is on either the likelihood of components being accessed and visited or that of being passed through (Hillier and Hanson, 1984). The former type of measures is termed with words such as integration while the latter implies choice.

3. Existing Approaches to Applying Space Syntax in Design Curriculum

Space syntax has more than thirty years of being seriously approached in academia. However, the available publications on this subject are scarce. Of course, this does not mean that similarly few pedagogical approaches to space syntax. For example, Dalton and Vaughan (2008) report that space syntax was taught to master students at UCL for decades; however, their report is the only publication discussing that course. Griffith (2014) also considered “many” design schools implement space syntax in their courses. However, he also argues that the relationship between space syntax – as a theory and research area – and design is not well defined and explored. Hence, in this subsection, we present published records of incorporating space syntax within design courses:

- UCL Bartlett School of Architecture has probably the most comprehensive approach to teaching space syntax with a master’s degree dedicated to the theory (UCL, 2017). Presumably, this degree is similar to what Dalton and Vaughan (2008) reported (their report discussed a one-year postgraduate degree titled “Advanced Architectural Studies”. However, the current course with this title at UCL does not match the description in that report). The 2008 programme contained...
three teaching approaches (called “practicum”) including, firstly, a technical workshop to study the
techniques and tools by a case study (a house); secondly, a formal and theoretical lecture on
theories directly related to the techniques; and finally, readings of different theories about space.
The current programme at UCL is titled “MSc Space Syntax: Architecture and Cities” containing 180
credits of which 60 are the final dissertation. Regarding the courses in the programme, the three
approaches in the 2008 report are traceable.

• Schneider et al. (2013) report a studio at Bauhaus University of Weimar, titled “Research-based
design”. The studio was held during one semester in winter 2013 and only involved masters’
students. The goal of the studio was to understand “how far designs can be derived from evidence”
(p. 3). Space syntax was selected as the main method to fulfil this goal. The first task of the studio
was to make students familiar with the concept of orientation in the buildings (with Bauhaus
building as the case where students were asked to personally navigate). Then, the students were
introduced to theory and techniques of space syntax and asked to perform some measures on
existing or algorithmically generated buildings. In the third step, design task was given to students
and they were asked to use space syntax to evaluate and select their design alternatives. Further
steps were taken to evaluate the designs (by also using VR), and a secondary task given to the
students. To evaluate the success of the studio, the students were asked to fill out two
questionnaires about both the studio and their current architecture education. While the students
found some difficulties with the tasks, they were mostly clear about that the studio provided more
scientific input to the design than their usual courses.

• Unlike the previous examples, Reveron (2009) focused on first-year undergraduate architecture
students, at Universidad de los Andes in Merida, Venezuela. The students were divided between a
control group and an experiment group while only the latter was taught about space syntax theory
and techniques. Both groups were given a same design task to be articulated on a grid network.
For assessing the results, the same task was given to a group of practicing architects. The study
found that the experiment group designed more integrated buildings and performed closer to that
of experienced architects.

• Griffith (2014) outlines some issues regarding teaching space syntax. First, he reiterates an earlier
cautions by Hillier that design courses should not focus only (or mainly) on the technical features of
space syntax (techniques and tools) but firstly on the theoretical background of space syntax. This
cautions is regarding the overemphasis on the crude quantification which may negatively influence
creativity of the design. Further in the article, Griffith answers two questions of what map and
which measure should be used (or learned) by the designers. He prioritises axial maps with
measures of integration and choice. Nevertheless, it is possible that the choice of axial maps is
related to the implied urban focus of his book chapter.

The above reviews do not draw a complete picture of the inclusion of space syntax in design curricula.
However, they provide us with a few noteworthy insights. First, while the theory and its techniques may
be considered advance within the mainstream architectural pedagogy, even first-year students were able
to understand the basics and successfully adopt it in their design. However, students may struggle with
combining different aspects of the theory in more complex design tasks. In the next section, we try to
identify some of these potential challenges.
4. Pedagogical Issues and Challenges

In this section, we discuss different aspects of space syntax which may affect the pedagogical application. We have identified four aspects of space syntax which may create challenges in its incorporation within design curricula. These aspects include those related to the general theory, techniques, tools and research findings. These aspects are discussed hereafter.

4.1 The General Theory

By the general theory, we mean the theoretical background behind the space syntax interpretation and abstraction of the human behaviour and built environment. It also includes basics of the measurements (such as a generic implication of the integration value, as noted in Section 2). In summary, the general theory is simple and would not possibly be difficult or time-consuming to teach to students even in a larger course on spatial theories. Reveron’s experiment (2009) has showed that even first-year students would grasp the basics of the theory. The more complicated side of the general theory is the critical debate around it and its limitation and implication. However, even in space syntax research, this side is not usually approached unless the research focuses on the philosophy of the theory. In addition, a basic understanding of graphs is required to have an acceptable grasp of that model.

4.2. The Techniques

The techniques of space syntax are probably the most difficult to cope with from a designer perspective. On the one hand, they are very abstract and mathematical in both what they represent and what they present. Indeed, Griffith (2014) considered questions about the techniques and measurements as frequently asked by designers. On the other hand, they have also numerous types and approaches. Currently, there are three types of maps (convex, axial, isovist or VGA) and several different approaches to utilising these maps (i.e. social and geometric boundaries in convex maps; primal, dual and segment axial maps; isovists, visibility grid and agent-based approaches to isovist maps). The analysis of each map would may include various possible measures (e.g., choice, integration and control value for convex maps). In addition, some purposeful analyses may require multiple approaches in the same analysis (e.g., convex maps with and without exterior, or axial maps with different radii).

Further difficulty may arise during and after the measurements. For example, some of the techniques require a number of parameters to be set beforehand. These parameters have certain nomenclature which may not be understood without a deeper knowledge of mathematics behind the measure (e.g., radius in axial map and VGA measures or interval in agent-based modelling). After the measurement, there are different ways by which the results are presented for each mapping type.

Clearly, learning all of the techniques and mastering their analysis will take an excessive time within a three- to four-year design program. We may argue that some design students may never need to master all of the techniques. For example, segment maps are only used in street maps for urban planning and design, not building interiors. In contrast, convex maps or VGA (except agent-based modelling) are not as common as axial maps in urban design analysis. However, even after such exclusions, the number of remaining techniques may still be too complex to be manageable in an undergraduate programme.
4.3. The Tools

Currently, depthMapX (Varoudis, 2015) is the only mainstream non-commercial software for space syntax analysis. DepthMapX (originally, DepthMap) provides an interface for drawing and measuring space syntax maps based on design documentation (mainly floor plans) which are imported as CAD drawings. The results are visualised by coloured maps on the plans or exported in spreadsheet files.

However, depthMapX was originally designed early 2000s and so does not feature a high level of interactivity expected by designers. Neither has it provided integration with CAD tools used by professional designers such as architects, without further scripting. It seems that the software was intended mainly for research not specifically for design purposes.

Another issue with depthMap which further reduces its integration or interactivity is its relatively slow speed. For example, for each small change in the design, the whole graph (axial or isovist maps) should be redrawn and recalculated from scratch. Particularly for VGA, each recalculation may take tens of minutes to hours. In convex maps, while the calculation is very quick, the manual redrawing of the map may take a considerable amount of time. There is also the possibility of losing the redrawn data because depthMap occasionally becomes unresponsive after minor changes to the convex or axial maps (based on the authors’ experiences).

4.4. Research Findings

There have been numerous research outlets regarding space syntax since its emergence in 1980s. The studies have usually approached space syntax in one of the following two directions (Amini Behbahani, 2016):

- to seek for empirical support for space syntax measures or to investigate how a space syntax measure correlates with a real-world issue;
- to analyse a design – proposed or constructed – by space syntax techniques to understand its spatial configurations.

Often, these studies focus on a single issue with a single technique. For example, a study compares the level of attention paid by nurses to wards in a hospital with the integration value of wards and the triage station for the hospitals convex map (Haq and Luo, 2012). Once a correlation is found, subsequent studies will try to evaluate the performance of hospitals on this particular issue based on the correlations. Presumably, there will eventually be designers who use the first research findings or the guidelines coming from the latter studies to improve their hospital design.

In this regard, the main pedagogical issue is the efficient use of the specific context and findings of these research. To apply such findings in their design and learning, students and architects need to find the relevant publications, study them, contextualise the findings and extract guidelines. For each task, the students may need more than a rudimentary knowledge of the theory to go through the articles and understand numbers, keywords and limitations in the studies. Of course, this is only when there are specific studies available for the students’ design context.

5. Proposed Solutions

In this section, we try to identify or propose some solutions for the challenges mentioned in the last section. The solutions are discussed within two levels. First, we discuss general solutions addressing the
identified challenges, which may help with future implementation. Then, we introduce some practical steps which we have taken to address the issues in a recent architectural studio for third year students.

5.1. General Solutions

In the last section, major challenges were identified in three of the four discussed aspects of space syntax for design students. In summary, the major issues were that the space syntax techniques are numerous and may be confusing; the tools are mainly suitable for research not design; and the findings can be very specifics and scattered in the literature. In this subsection, we propose some general solutions to address these challenges.

The findings of space syntax studies often inform designers and policy makers to take necessary actions to improve design. In this sense, they resemble guidelines and standards although such findings are limited to certain scopes and contexts and are subject to further critical limitations. Once designers decide to apply such findings they may treat them similar to other standards and guidelines. Designers are usually familiar with documentations of standards and guidelines. Documentation approach may be useful to facilitate designers’ access to the space syntax findings. This documentation can be in the form of an open web database containing the relevant and regularly updated information. This database can be collectively contributed and maintained by space syntax researchers and practitioners.

Another issue with many space syntax tools is that they are not integrated properly into design process because of the lack of interactivity in the tools and the potentially long duration when performing measurements. There are already studies that aim to address this issue. There are simpler, faster and more user-friendly tools emerged such as Agraph(Manum et al., 2005) and Viraph(Amini Behbahani et al., 2016). However, none of them has the inclusiveness of depthMap regarding the techniques. There are also studies with focuses on using space syntax within CAD programs like using convex maps in Rhino(Herthogs et al., 2013).

The above solutions may reduce the effort for students to understand and apply space syntax. Hence, they may have more time to them to focus on learning the analytical techniques. Furthermore, to avoid overwhelming the students by the complexity of the techniques, it is possible to only include simplified but fundamental techniques in relevant foundation courses beforehand. For example, convex maps are similar to bubble diagrams which are often used by designers to represent programmatic features of the design. Hence, by asking the students to redraw the diagrams with different focuses relevant to space syntax, the students are made familiar with the core concept of graph justification in convex maps. With such foundation courses, the main features of the techniques will be more efficiently mastered by the students because the conceptual understanding is established in advance.

In summary, there are three propositions in our approach listed below. Figure 1 shows a schematic diagram of these propositions within design program:

- an open web database containing the research findings and details design applications;
- more interactivity and faster analysis in tools to be better integrated into design process;
- foundation courses to teach conceptual bases of some space syntax techniques in advance.
5.2. Practical Steps planned for a third-year Architectural Studio

The previous subsection outlined three propositions to address the teaching of space syntax to design students. However, to implement them, a comprehensive plan is necessary which will also require some advancements in CAD tools. Until such a plan is mature and becomes practical, design students may still find it challenging to apply space syntax in design and learning. We have tried to devise a plan with practical steps with architecture students. This plan was implemented for the third-year architecture students at the University of South Australia.

The first step was to optimally use the available material. For example, we used the latest depthMap tutorial (Pinelo & Turner, 2010) and a few basic and concise summaries articles about space syntax as the core learning resources. These included a Brief introduction by Bafna (2003), Spatial structure of environment and behaviour (Peponis and Wineman, 2002) and a chapter from the first author’s thesis (Amini Behbahani, 2016). To facilitate the learning of the students, further explanations and examples were added to the depthMap tutorial to show the implications of the techniques explained in that tutorial. In addition, a concise set of slides were prepared to highlight the use of these techniques for design by existing examples. Together, they would help to contextualise these resources for the students learning.

The course only focused on using depthMapX software because it is important to learn this mainstream tool. The students were then instructed how to maximise the efficiency of working back and forth between depthMapX and CAD tools such as Autodesk Revit (the students were allowed to choose different CAD tools).

Similar to the previous studies, a design task was assigned to the students including the redesign of a number of historic hotels (pubs) in Adelaide including the Austral, Botanic, Black Bull and Stag hotels. The students were instructed to redesign these hotels to meet present standards and lifestyles with the help of space syntax analysis. A small database of selected research findings of space syntax was also prepared in the light of the first proposition. A list of space syntax findings was made available to the students as a
reference for various space syntax techniques and their usage. However, it was expected that students would only use generic space syntax findings because there is almost no space syntax study specifically on the topic of hotel buildings. Figure 2 shows a sample (redesign of New Market Hotel, Adelaide) given to the students on how to use the space syntax measures in their project. A set of slides explained for them how the measures justify the proposed changes in the plan.

![Figure 2](image)

Figure 2. A guide for using space syntax in the design task given to the students. Rows: existing ground floor plan of New Market pub (top) and a proposed modified plan (bottom). Columns, from left to right: raw floor plan, convex-map integration, angular mean depth, and connectivity (VGA).

While a thorough analysis of the plan and its outcome is outside this paper’s scope, some observations are provided here. Regarding results and responses from the third-year students of Bachelor of Architectural Studies. The main observations from the students’ analysis included how fascinated they were that this method we were proposing would give them design insight. The student cohort seemed a little reticent to embrace it at first as they had been working at the beginning of the semester with analogue methods of measured drawings. They were initially confused as to the value of working between the digital and analogue. We explained that this was an evidence gathering exercise where spatial syntax offered a computational analysis for them to first interrogate the existing spaces of the historic pubs. The students engaged with the software to ascertain visibility and connection of the plan forms.

Students’ reported that spatial syntax prompted decisions about “where to start the design process,” “areas of the plan to focus on for greater visibility” and “points to intervene with their new extension.” They felt it was a “valuable” and “interesting tool” with which they would have preferred more time to experiment during the studio.
Some of the students represented the spatial syntax diagrams using a three-dimensional layering on clear Perspex. This was very effective in understanding the results across the volume of the building. They also expressed how they were able to understand the two-dimensional analysis and effects beyond each floor. Other students presented the “as existing” analysis adjacent to their “design concept floors” and talked to the method which informed their design decision-making. “Visibility and connection” for the new extension was vital to the way they organised their new spaces irrespective of the diverse programs which were selected across the four pubs under study. The adoption of the two quite distinct methods for this studio, without presenting the students with a preference for either, meant they became skilled in two approaches. It also gave them the confidence to compare each approach through a data collection, evidence gathering process which offered a unique set of parameters and experiences from which the students could expand their thinking around design processes.

6. Conclusion

This paper has outlined a number of challenges against the inclusion of space syntax in the design courses. The challenges include the complexity of the techniques, lack of interactivity of the tools and sparsity of the research findings. The paper has proposed respective solutions for these challenges although these solutions may vary depending on the context of the course and the intended purpose of the instructions.

The paper further discussed a plan for teaching space syntax in an architectural design studio to third-year students. The outcome of the studio is yet to be fully analysed, however, the interaction with the students and our observation of the outcomes suggest a satisfactory interest and familiarisation of the students with the topic, and their ability to introduce space syntax analysis in their design decision making. The future research will include a thorough evaluation of the studio and further development and verification of the propositions.

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Regenerative Development

What is it, How does it Support Innovation in the Built Environment and how can it Lead to a Sustainable and Thriving Future

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Abstract: There has been a call from many areas of research and practice for a different approach to sustainable development in the built environment. This has occurred because of the evidence that the social and ecological indicators that underpin our civilisation are being eroded; that is, we are failing at our current approach to sustainability. Led by thinkers in the built environment the call has gone out for approaches that facilitate built environment outcomes that move beyond marginal improvements and shift our focus towards creating vitality and net benefit. That is, projects that begin to heal the damage done in the past and create vital relationships that lead to resilience, as well as adaptive and thriving outcomes. It is argued that regenerative development is a process that can facilitate this type of approach to contributive development. This paper will present the frameworks used to support the application of regenerative development thinking to three projects in Victoria, Australia. While these are long-term projects that will be in development over 15 years, what is presented here is their initial conceptual design processes which aim to increase the potential for regenerative outcomes. The projects were informed by the LENSES framework, the Living Building Challenge, the Regenesis frameworks and Biophilic design principles. Each project has an ecological baseline that was collected as part of the project so as to measure the benefits post construction and occupation.

Keywords: Regenerative development; built environment innovation; eco-city; ecological worldview.

1. Introduction

Regenerative development has been referred to by the Secretary-General of the Commonwealth as the ‘Radical new approach to development’ that will provide the innovation catalyst to solve our current ecological challenges. Here we will outline what regenerative development is and what it could mean for the built environment. It starts by outlining how regenerative development is different from sustainable development and how it is based on a fundamentally different worldview. This is followed by the description of three case studies and how regenerative development processes have been applied using different frameworks for operationalising it. Where possible a comparison is made between the outcomes achieved and “business as usual” sustainability.
1.1. Why a fundamentally different worldview?

As Einstein is reported to have said, “a new type of thinking is essential if mankind is to survive and move to higher levels” and in 1955, he was part of a group of 15 leading scientists that signed a manifesto stating “We have to learn to think in a new way”. We interpret this as: it is impossible to create sustainable outcomes that improve social and ecological well-being within the same thinking, worldview or framework that created the degradation. We can see evidence of this in our increasingly negative social and ecological impacts. After decades of working towards sustainability, findings from a number of recent international studies, such as the Millennium Assessment Reports (2005) and the 2014 Intergovernmental Panel on Climate Change (IPCC) assessment report, indicate that the situation is getting worse, not better. It has prompted the World Watch Institute (2013), to ask whether sustainability is still possible.

Our current approach to structuring sustainability practice is couched in the language of quantitative, performance-based indicators; reporting on performance in isolated categories; and compliance which is largely driven by individual interest: reputational, financial, or simply ‘compliance’. Much has been written about the flaws in this framework and its foundation in the so-called mechanistic worldview (Goldsmith, 1993; Rees, 1999; Capra, 2002; Sterling, 2003; and, Bourne, 2008), as well as the need to shift towards a more relational worldview that will help us develop frameworks suitable for working with living systems (Hes and du Plessis, 2015; and, Murray, 2011).

Many call this more relational worldview (in which the mechanistic is a part) the ecological worldview. As early as the 1960s, its needs were highlighted in built environment practice by Ian McHarg (1969). Since then, numerous authors have explored the characteristics of the emerging ecological worldview and its main narratives (see for example Goldsmith, 1988; Capra, 1987; and, Elgin and Le Drew, 1997). The consensus is that the ecological worldview represents a shift from looking at the behaviour, performance and interests of individual ‘parts’, to consider the well-being of the whole as expressed through interdependent relationships - a web of life of which humans are irreducibly part. The focus is oriented at designing solutions that work at the biophysical level, within inherently nested systems, and across scales including the human mind. The latter is critical because it is argued that the current approach to sustainable development has forgotten the mind and the heart of people (Mang and Haggard, 2016). It has forgotten that we need to create an irresistible narrative that will change behaviour not because we ‘have to’ but because ‘we want to’. Unfortunately, the current irresistible narrative is based on the values of the mechanistic worldview: competition (winning), imperialism (control over) and rationalism (we can explain and understand everything); and a narrative that rewards power, monetary wealth, and status.

Regenerative development is an approach that applies an ecological worldview. In essence, it is a process that aims to achieve an outcome that is a living environment as defined by Plaut et al. (2016,p2) as: “a setting that is thriving, healthy, and resilient because its ecological, social, and economic systems are continually nourished.” Plaut et al. (2016, p.2) using a regenerative development approach defined it as “the process of cultivating the capacity and capability in people, communities, and other natural systems to renew, sustain, and thrive”. Simplified, the authors’ approach to regenerative development is to:

1. Understand the flows through a system that bring it to life, that create a living system. Flows are the various resources, including ‘intangibles’ like culture and social cohesion, that interact with the place,
2. Design place-based solutions that create multiple, mutual benefits between these flows by focusing on the opportunities for creating relationships and
3. Operate within the context of the place to ensure its relevance, resilience, and ability to adapt.

Though in its infancy in application, Regenerative Development is based on the accumulation of millennia of human knowledge and provides us with an opportunity to positively change the often-negative future predicted. Critically, regenerative development is about working within a system to enable the potential of the system to emerge, to co-evolve the aspects of the system so that it can constructively adapt to change and evolve towards increasing states of health and abundance. There are examples of the application of regenerative development ideas internationally but these tend to be reflections on projects and their outcomes (Mang and Reed, 2012) and case studies found on practitioner pages such as Regenesis and the Institute for the Built Environment (IBE) at Colorado State University. While these provide insights into the outputs of regenerative development projects, there is a need to better understand the process that supports regenerative thinking and contrast it to ‘business as usual’. That is: how do we operationalise these abstract concepts of creating ecological, social, and economic benefit?

2. Introduction to the Three Frameworks and Approaches

2.1 The LENSES Framework

The Living Environments in Natural, Social and Economic Systems (LENSES) Framework aims ‘to facilitate tangible, actionable and contextually based solutions that support and create healthy, natural, social and economic systems’ (Plaut et al., 2010). It provides an overarching process and specific activities that guide teams through identifying and realising the regenerative potential in each place or community. As depicted in Figure 1, the framework is represented by a circular disk with three overlaid lenses, each representing a level 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. In the centre of the framework is the Vitality Lens which contains the two spheres of degeneration and regeneration and prompts the team to consider strategies to create opportunities for interaction between flows, create benefit for a flow and to think about that in context of the key guiding principles.

Figure 1. Visual representation of the LENSES framework. (Source: Institute for the Built Environment (IBE) at Colorado State University2017)
2.2. The Regenesis Frameworks

The Regenesis approach is a process that guides regenerative practitioners as they design for the place, its surrounding community and environment. It draws upon a wide range of disciplines (e.g. permaculture, psychology, ecological architecture) and applies different methodologies to help the practitioners develop three essential capabilities: seeing potential, manifesting this potential in a contributive way and creating a vitalising energy field that will allow the system to continue evolving without losing momentum (Mang & Haggard, 2016). These methodologies serve different purposes and are adaptable to a wide range of scales and roles within a single project.

2.2.1 Three Lines of Work

This tool is used for ongoing reflection and as a reminder to work across three levels: the motivations to do a project, growing the capacity and capability of the community, and improving the value and health of the systems where we design (Mang & Haggard, 2016). Simultaneously, it reminds the designers to work across three nested systems: the project itself, its immediate context (or proximate whole) and a larger context (greater whole). The context can be understood in physical and ecological terms (a site, within a forest, within a bioregion) or social terms (e.g. a governance or leadership system). The proximate and greater wholes are then considered the spheres of influence of the project: the areas, themes, or relationships where this project can contribute and catalyse change towards a healthier system.

2.2.2 The Regenerative Development Tetrad Framework

This tool is used to understand the dynamics working on a project. It was designed to allow us to see the value that is being added to an area because of the project (Figure 2). The tetrad has four dimensions used to understand the system and trigger creative solutions that respond to what the place, ecosystem and communities are trying to become. Figure 2 indicates the four dimensions of the framework using two alternative names: Place-sourced Potential (Ground), Regenerative Capability (Goal), Co-evolving Mutualism (Instruments) and Vocation of Place (Direction).

Figure 2: Left: The tetrad framework. Right: The Regenerative Tetrad Framework superimposed on three levels of nested systems (Source: Regenesis 2017)
2.3. The Living Building Challenge Framework and Biophilia

Living Building Challenge is a certification tool for buildings and communities, which aims to result in buildings that ‘make the world better’. The aim is to be energy, water and waste positive, contribute positively to ecological services and social capital and to challenge the industry to build as if the building was a flower or tree, the community a forest. It is made up of seven petals (place/site, water, energy, materials, beauty, equity and health) which have 20 imperatives that need to be met, including water positive, energy positive and so forth. The certification is only achieved once the building or community has been operating for 12 months. One of the imperatives is biophilia and requires the design team to have a workshop integrating biophilic concepts in the development. Biophilia is "the urge to affiliate with other forms of life" (Kellert & Wilson 1995, p. 416). Its integration into a building project is called biophilic design. For the project, both Kellert’s 70 Biophilic design attributes (Kellert, Heerwagen and Mador, 2008) and Terrapin Green’s 14 Biophilic patterns (Browning, Ryan and Clancy, 2014) were used.

2.4. Combining the Approaches

Each project described here focused on the use of one of the approaches, but each approach is complementary. That is, each of the frameworks and approaches can support a project in different ways. The Regenesis approach provides a greater conceptual and contributive foundation and will lead to great ability to develop the foundations and flows of LENSES and facilitate a greater level of creativity in the design process. The Living Building Challenge, using biophilic design, supports the detail design and delivery of the design.

3. Case Studies

3.1. Introduction

This paper focuses on three development projects of various scales:

1. Seacombe West, a proposed off-grid eco-resort situated within 80ha of coastal saltmarsh at Gippsland Lakes, Victoria. It will use shallow geothermal opportunities to produce hot water for the resort, intensive greenhouse agriculture and aquaculture.

2. The Paddock, a proposed intentional housing development of 26 homes on a 13,500 m² site. It is located in Castlemaine, a small city located 1.5 hours north-west from Melbourne, Australia where it incorporates a series of private and shared spaces including wicking beds, greenhouses, native greenery, garden sheds, guest rooms, a community centre and washing facilities.

3. BioSciences, an Environmental Sustainable Development (ESD) Blueprint for the new Biosciences Precinct at the University of Melbourne, Parkville Campus. It presents a vision for the university and provides guidance to the project teams working on the design and construction of the new buildings.

The three projects are all real, ongoing and at different stages of design. Each presents a complicated agenda and has consulted diverse stakeholders. This paper specifically reflects on the outcomes of applying regenerative thinking to these three projects, as reflected upon by the authors who actively participated in the project and recorded our observations. As these are long-term projects, the monitoring and reporting of their eventual contribution to the socioecological systems is beyond the scope of this paper. Having said that, it is important to note that an ecological survey of the site and the development
of clear evaluation guidelines was completed for each project to capture the shift before and after development.

3.2. The Three Projects Approach to Understanding the Flows

Responding to the challenges and opportunities present within each project, the approach utilised to apply regenerative development varied with each project applying at least two of the frameworks described in the introduction. For instance, Seacombe West and the Biosciences project applied the LENSES Framework to document the flows for this project and design opportunities for flows to interact and relate. Subsequently, an interactive artefact was made for participants to use as a prompt for their creativity while documenting the guiding principles of the project and the flows which are most relevant for the ongoing viability and vitality of the system. Meanwhile, for The Paddock, the regenerative development approach evolved more organically and was driven by the passion and values of everyone involved in the project. In the latter, the Living Building Challenge was used to guide the design process and enabled the team to identify gaps in their knowledge and reach out to a broader set of consultants who ultimately enhanced the regenerative development approach. Table 1 summarises the specific approach used by each project.

Table 1: Regenerative Development Approaches within each of the three case studies.

<table>
<thead>
<tr>
<th>Seacombe West Eco-resort</th>
<th>The Paddock</th>
<th>Biosciences</th>
</tr>
</thead>
<tbody>
<tr>
<td>LENSES Framework, Regenesis Frameworks</td>
<td>Living Building Challenge (LBC), Biophilia, and Regenesis frameworks</td>
<td>LENSES Framework</td>
</tr>
<tr>
<td>The project began through a series of four workshops utilising the LENSES framework to understand the social and environmental flows of Lake Wellington, Gippsland Lakes, Victoria.</td>
<td>The Living Building Challenge acted as a gateway to engaging with the local community and a broader set of experts who participated in developing an irresistible narrative and strove to contribute beyond the standard scope to enhance the potential of the project.</td>
<td>The LENSES Framework was used as a guide to the creation of the blueprint, benchmarks, and targets for the future Biosciences Precinct within the University of Melbourne.</td>
</tr>
</tbody>
</table>

3.3. The Three Projects Approach to Design Place-based Solutions and Operate within the Context of the Place

The key difference between traditional practices and these three case studies is the fact that the design team took a collaborative approach to understand the physical and intangible flows interacting within a site. This resulted in a unique set of values and commitments for each project. These values became the guiding principles of each project and a source of inspiration and guidance on decision making through the ongoing design and construction process. The guiding principles closely related to those principles present in the original LENSES Framework. In this section, we provide a brief description of the outcomes achieved by each project and how it reflects regenerative development.

3.3.1 The potential for Seacombe West

The process of understanding a place through the flows that bring it to life, or degrade it, meant that the development of the master plan could focus on designing for the potential of beneficial relationships. This
resulted in a master plan which differed significantly from an earlier one done in 2003. The outcome, described in detail in a previous paper (see Hes, Stephan and Moosavi, 2016), showed that instead of the project aiming to be a canal development driven by holiday accommodation for boat owners where ecological restoration and social capacity building played a minor role, it shifted to one driven by the potential to create thriving social and ecological systems. The project now includes the potential to link ecologically responsible tourism, increasing the capacity of the land to adapt and thrive through the salination changes happening and the ability to contribute to the economy through tourism, food production and job creation.

Bringing together community, government, industry, indigenous elders and specialists in soil, geomorphology, water, fish, ecology, agriculture, architecture, construction, engineering, planning, and many others meant being able to co-design the development with an understanding of the flows that bring vitality and viability to the site. The resulting masterplan not only had a vision for the look of the place, but a governance, finance and legal model, detailed architecture, services infrastructure, water formation, and an educational and ecological strategy. Further, the phasing of the masterplan was so that each phase learnt from the lessons of the previous, ensuring continual research and input into the site’s evolution. One particularly fascinating challenge came out of the two-day workshop relating to how the project would have an essence of its indigenous roots: how could people by living and visiting the place ‘know’ they were part of a 70,000-year story?

3.3.1 The potential for ‘The Paddock’

From the beginning, the project was guided a strong desire to challenge conventional development practices while enhancing social connection and increasing the biodiversity of the area. The landowners engaged a design team with a long-standing relationship with the local community and a history of creating good socio-ecological outcomes. The outcome of their design is not just a set of homes and a nice landscaped productive garden, but it also addresses the need for the ongoing operation of the site to facilitate the project’s vision. This required the design team to shift from just the delivery of a physical design to the delivery of systems and strategies for the implementation, management, and evaluation of the site, the homes, and the community. For example:

1. **Food system:** Placed physically at the centre of the development, the food system will provide organic and local food resources to the residents and the surrounding community. The residents will manage part of the garden beds while other sections will be leased to a local producer. There is also a section for bush food highlighting the natural resources of the area. The full food cycle will be incorporated from seedling greenhouses to compost facilities.

2. **Intentional housing system:** in physical terms, the development incorporates a series of shared spaces where the residents and neighbours can come together. However, they considered critical to the ongoing success of the project a need to develop strategies to support the individual and collective wellbeing of their residents and surrounding community. As the design continues to be finalized, the future residents are participating in a series of workshops where they will co-create their governance system, value system and operation strategies for the ongoing management of the site.

3. **Biodiversity design system:** Connecting to the ironbark forest system of the region, the project is maintaining most of the native trees already on the site and incorporating a native landscape strategy where the intention is to enhance the biodiversity system by 50%. Native vegetation
surrounds the homes and permeable paths conserve water. The landscape proposal emulates permaculture principles and understands the project site as part of a broader landscape.

3.3.1 The potential for the Biosciences Precinct, University of Melbourne

The report resulting from this process identified twelve key flows which have been identified as being most relevant to the zone (e.g. Energy, Health and wellbeing, Food) and developed benchmarks for each of the flows as well as specific targets for energy, water, and waste. The benchmarks and targets were intentionally outcome focussed, giving design teams full remit to apply innovative technologies and design solutions to achieve them. Elements of these work now appear on three key university documents: (1) The Sustainability Charter; (2) Our Campus in the 21st-century report; and (3) The Succeeding sustainability report.

Table 2 – Example of targets set for the flows for the precinct (Source: Aurecon)

<table>
<thead>
<tr>
<th>Flow</th>
<th>Metric</th>
<th>Business as Usual</th>
<th>Best Practice</th>
<th>World Leadership / Regenerative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>Operational Carbon Emissions kgCO₂e/m²/year</td>
<td>Operational carbon emissions (excluding green power purchased from the grid) less than 230 kgCO₂e/m²/year.</td>
<td>Operational carbon emissions (excluding green power purchased from the grid) less than 116 kgCO₂e/m²/year. (50% reduction from BAU).</td>
<td>More energy is generated on the site than is used in the lifecycle of the zone (operational and embodied energy).</td>
</tr>
<tr>
<td></td>
<td>Embodied Energy GJ/m²</td>
<td>Embodied energy of the building less than 10 GJ/m².</td>
<td>Embodied energy of the building less than 7.6 GJ/m².</td>
<td></td>
</tr>
</tbody>
</table>

This case study highlights the potential to pragmatically quantify a trajectory toward a more regenerative campus through a 15-year journey. The regenerative development potential of this project stems not only from the benchmarks and processes undergone to map out said trajectory, but through the creation of an application guide and a training session encouraging designers to become regenerative practitioners. This guide can potentially engage all teams bidding for the university project to think regeneratively, identifying the potential of the project and enabling it to be a catalyst shifting towards livings systems or ecological engagement in development in the campus and surrounding city.

Unfortunately, since being written, the document has not been actioned nor the workshops implemented. The outcome of this project is an example of the intentions of future ecologically-based living systems thinking being too big a leap for an embedded mechanistic approach to development. Developing a campus is a complicated multi-actor process, which is already fraught with issues. The introduction of the blueprint did not resonate sufficiently to be taken up.

4. Discussion and Conclusions

Regenerative Development aims to support humans to design and interact with the environment in such a way that it enables both to thrive. These case studies showcase an array of methodologies through which the potential of regenerative development could be achieved. The LENSES framework has the ability to understand the flows through the location of a development and then to look for how to invest impact to achieve mutual benefit can lead to innovative ideas. Beyond that, it can provide a strategy to assess the project’s outcome to track the alignment of the project to the place and community values. For ‘the Paddock’ the Living Building Challenge already creates a specific set of parameters for assessment but does not provide the methodologies to measure those parameters. To enhance the rigour of
evaluation, different design teams also engaged with private consultants to develop evaluation methodologies to measure their success. This included conducting an ecological survey, and a series of workshops with surveys and interviews to track their success.

In each case, the regenerative approach led to the potential of a stronger social and ecological value of the site and developing strategies to support positive interactions within the system. What is more remarkable, is that every project resulted in more than a design master plan: they designed systems. For instance, *the Paddock* has engaged in a process with the future residents to co-create their governance system while the *Biosciences* project resulted in the creation of a process to simultaneously communicate the design brief and up-skill industry practitioners in regenerative thinking and design. Lastly, *Seacombe West* developed a partnership with various universities and collaborated on a research agenda that aims to trial and evaluate regenerative development strategies. Across these three cases, there is an understanding of the project site as a small part of larger interacting systems and that the design can exert an influence in the proximate and greater wholes.

In conclusion, undertaking a regenerative development process engaged the hearts and minds of the participants, community, and consultants. This can be demonstrated by the fact that each project resulted in three key elements: 1) the design team engaged in system design, not physical designs, 2) the process resulted in the development of evaluation methodologies to measure the projects’ contribution or influence, and 3) educational strategies were integrated to highlight regenerative development and to communicate processes and outcomes of their design.

These levels of investment by everyone involved in the process requires long-term engagement and highlight the basic differences between the ecological worldview and the mechanistic. An ecological worldview simultaneously works on various ‘levels’ and places with as much effort in the ongoing expectations of the project as it does in the physical design. By increasing our opportunities to interact with nature, incorporating food security into the design, implementing self-governance strategies, pioneering biodiversity design guidelines, or planning long-term development for a world-leading university, the three case studies above have enormous potential to influence and change the way we develop and grow our cities. However, they also hint at the importance of encouraging continued investment from the people involved in each project. If the momentum is lost, amazing projects can degenerate into business as usual.

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Whither Design Theory and Methods?

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Abstract: This position paper briefly introduces design theory and design methods, presents changes that have occurred on the last 50 years prior to examining the changes that are likely to take place over the next 50 years in designing and in building. It examines potential changes in our knowledge about the cognitive behaviour of designers, users, users’ social behaviour, user-building interactions, user emotions, design tools that learn and adapt, buildings that learn and adapt, buildings as part of a social ecology, and three new types of interfaces: brain-computer interfaces, user-building interfaces and brain-building interfaces. Each of these is assessed for their potential effect on design theories and design methods. The conclusion is that very few, if any, of these will require modifications to design theories but that new design methods will need to be developed.

Keywords: Design theory; design methods

1. Introduction

Design methods date back at least 4,000 years to the instructions for a flood-proof ark given in the Epic of Gilgamesh and the rules for urban design given in the Instructions of Shuruppak. Some 500 years later design and building are given a unique mention in the Code of Hammurabi. The history of architecture gives special attention to the design rules in Vitruvius’ De architectura: Ten Books of Architecture, which dates from 50 BC. Vitruvius gave both prescriptive and performance design methods in the form of rules. However, it was not until 1452 that Leon Battista Alberti in his De re aedificatoria: Ten Books of Architecture, introduced the concept of design process as an intellectual activity that involved a designer and which laid the foundation for design theory. Alberti also laid the foundation for two separate streams of enquiry: design as a process and design as an object. Modern scientific-based design research leading to more formal design theories and design methods commenced in Germany in the 1850s with Ferdinand Redtenbacher, who in 1841 became the Professor in Mechanics and Mechanical Engineering at the Polytechnikum Karlsruhe. He propounded the view that design could become a science. Franz Reuleaux, who studied under Redtenbacher and became a Professor of Engineering at the Swiss Federal Institute in Zurich took that view further with the formalization of the kinematics of machines. At the same time, also in Germany, there was the view that not all of designing could scientized and that some aspects of designing were humanist in nature and hence beyond the purview of formalized methods.
Research in design as a process in the second half of the 20th century began in the 1950s with one of the first conferences on design methods being held in 1962 resulting in the influential Conference on Design Methods: Papers presented at the conference on systematic and intuitive methods in engineering, industrial design, architecture and communications (Jones and Thornley, 1963). One of the early and seminal books in architecture was Christopher Alexander’s Notes on the Synthesis of Form (Alexander, 1964) although similar research in engineering design appeared before Alexander (Asimov, 1962). However, the more widely read and more influential book was the result of Herbert Simon’s Karl Compton Lectures at MIT in 1967 that he turned into the book The Sciences of the Artificial (Simon, 1969) which lead to a noticeable increase in both research and research funding in Australia, the USA and the UK for design methods and design theory.

We can place research in design as a process over the past 50 years into the following categories: design using simulation, design using optimization, design using artificial intelligence and design using cognitive science. Research in design as an object in the second half of the 20th century began in architecture (and engineering) with the development of formal models of representation of objects, primarily in PhD theses produced at Cambridge and Stanford Universities in the 1960s and 1970s. This has resulted in CAD systems with varying degrees of modeling capabilities. Most recently there has been a confluence of these two streams through the use of visual programming languages such as Grasshopper that not only parameterize object modeling but also allow for the inclusion of simulation and optimization during modeling (Tedeschi, 2011; Woodbury, 2010).

In line with the theme of the conference this paper discusses two questions:

- What has happened to design theories and methods over the last 50 years?
- Will design theories and methods change over the next 50 years?

The next section of the paper briefly describes the development and changes to design theories and presents an example of one that is presented in the form of an ontology that is used as a frame of reference for later discussions in the paper. This is followed by a section that briefly describes umbrella design methods in use today. We then turn to the areas that are harbingers of change and are likely to play an increasing role in designs and designing and examine whether they require changes to design theories and design methods.

2. What has happened to design theories over the last 50 years?

Design research has largely adopted the scientific paradigm in which it is assumed that there are regularities that underlie phenomena and it is the role of research to discover and represent those regularities in designs and designing. When the representation of those regularities has the capacity not only to describe the past and to account for the present but also to predict we claim that it is a theory. Goel and Helms (2014) state that “a scientific theory is (i) based on testable hypotheses and makes falsifiable predictions, (ii) internally consistent, (iii) supported by evidence, and (iv) modifiable as new evidence is collected”. Any general design theory commences with or can be based on the following qualitative axiom:

*The foundations of designing are independent of the designer, their situation and what is beingdesigned* (Gero and Kannengiesser, 2014).

A model of designing is “a representation of some phenomena and relationships among phenomena ... [whilst] a theory is an abstract generalisation of phenomena, which can be modelled in multiple ways.”
Whither Design Theory and Methods? (Chakrabarti and Blessing, 2014, p. 29). Designing, including designing in architecture, for the last 50 years has until recently been a manual act carried out by individuals and teams. The design theories were based on experience (Pahl and Beitz, 1983), induction over cases (Altshuller, 1984; Gero, 1990), or formal derivations from axioms, logic or mathematics (Braha and Maimon 1998; Hatchuel and Weil, 2003; Suh, 2001). Many models of designing can be traced to Asimov (1962).

The environment of designing has changed with the introduction of novel technologies for both designing and for what is being designed. An examination of design theories (Chakrabarti and Blessing, 2014) does not show that there has been a consequential change due to what is being designed. Empirical studies have shown that the same theoretical framework could be applied to novel areas such as software design as to traditional areas such as architecture and engineering. One such theory is based on using the Function-Behaviour-Structure (FBS) ontology as a theory (Gero, 1990; Gero and Kannengiesser, 2014).

We will use this as an exemplary design theory in this paper and base our examination of the need for change in a design theories on the capacity of this design theory to cover potential future changes in the what is to be designed. Hence, we present it in sufficient detail for later use. The FBS ontology is a design ontology that describes all designed things, or artefacts, irrespective of the specific discipline of designing. Its three fundamental constructs – function (F), behaviour (B) and structure (S) – are defined as follows: Function is the teleology of the artefact (“what the artefact is for”). It is ascribed to the artefact by establishing a connection between one’s goals and the artefact’s measurable effects. Behaviour is defined as the artefact’s attributes that can be derived from its structure (“what the artefact does”). Behaviour provides measurable performance criteria for comparing different artefacts. Structure is defined as its components and their relationships (“what the artefact consists of”).

Humans construct connections between function, behaviour and structure through experience and through the development of causal models based on interactions with the artefact. Specifically, function is ascribed to behaviour by establishing a teleological connection between the human’s goals and the observable or measurable performance of the artefact. Behaviour is causally connected to structure, i.e. it can be derived from structure using physical laws or heuristics. There is no direct connection between function and structure except through experience. For a more detailed exposition of the FBS ontology consult Gero and Kannengiesser (2014).

The most basic view of designing consists of transformations from function to behaviour, \( F \rightarrow B \), and from behaviour to structure, \( B \rightarrow S \). view, behaviour is interpreted as the performance expected to achieve desired function. Yet, once a structure is produced, it must be checked whether the artefact’s “actual” performance, based on the structure produced and the operating environment, matches the “expected” behaviour. Therefore, the theory based on FBS distinguishes two classes of behaviour: expected behaviour (Be) and behaviour derived from structure (Bs). This extends the set of transformations with which we can describe designing to include: \( F \rightarrow Be \), \( Be \rightarrow S \), \( S \rightarrow Bs \), and \( Be \leftrightarrow Bs \) (comparison of the two types of behaviour). The observable input and output of any design activity is a set of requirements (R) that come from outside the designer and a description (D) of the artefact, respectively. The FBS framework subsumes R in the notion of function and defines D as the external representation of a design solution, \( S \rightarrow D \).

Based on the common observation that designing is not only a process of iterative, incremental development but frequently involves focus shifts, lateral thinking and emergent ideas, the theory defines the following additional transformations, \( S \rightarrow S' \), \( S \rightarrow Be' \), and \( S \rightarrow F \) (via Be). These three transformations assume an existing structure as the driver for generating changes in structure, behaviour or function.
The eight fundamental transformations or processes in the theory are shown and labelled in Figure 1:
1. Formulation (R → F, and F → Be); 2. Synthesis (Be → S); 3. Analysis (S → Bs); 4. Evaluation (Be ↔ Bs);
5. Documentation (S → D); 6. Reformulation type 1 (S → S’); 7. Reformulation type 2 (S → Be); 8. Reformulation type 3 (S → F).

Figure 1: A theory of designing based on the FBS ontology. (Source: Gero and Kannengiesser, 2014)

New areas of knowledge have developed over the last 50 years. Of particular interest to design researchers is cognitive science, which studies the processes of the mind. The knowledge produced by cognitive science has had an effect on design theories in that some have been extended to include cognitive behaviour without changing the underlying concepts such that the cognitive design theory maps onto the earlier theory when removing cognitive behaviour.

Using the exemplary design theory shown in Figure 1, cognitive science distinguishes between the mind (inside the designer’s head) and what is external to the designer’s mind. The FBS theory needed to be extended to include this distinction and as a consequence new cognitive processes that were not in the original formulation were added. The resulting ontology on which the design theory was now based is labeled the situated FBS ontology. It is founded on idea that situated designing involves interactions between three worlds: the external world, the interpreted world (inside the designer’s mind) and the expected world (also inside the designer’s mind) (Gero and Kannengiesser, 2004). However, the foundational ontology is unchanged.

3. What has happened to design methods over the last 50 years?

Design methods, the techniques and tools used to design, have changed with the introduction of new designing technologies although the fundamental processes of designing have not. Here we will give some examples demonstrating this. Optimization as a design method is a formal process that requires a set of design variables, a set of equations that describe the constraints on the values those variables can take and a relationship between the design variables that needs to maximised or minimised. (Papalambros and Wilde, 1988; Radford and Gero, 1988). This fits within the theoretical design process of “synthesis” and therefore does not require any modification of the theory. However, it does require that the designer change the way they design by defining all the design variables at the outset of the optimisation process. As a second example of a novel design method consider design using evolution. Here the design method
is a form of search that is based on a simplified genetic model of Darwin’s Theory of Evolution (Bentley, 1999). Again all the design variables need to be defined at the outset as does the search criterion. The design variables are represented as genes, along with a mapping from the genes to the design and a derivation of the performance from the design. The genetic operators of crossover and mutation are used to move around the design space and are applied in parallel to a population of designs. The performance of the individual designs generated are used to rank the designs in that generation for selection to be used as the basis for the next generation. This fits within the theoretical design process of “synthesis” and therefore does not require any modification of the theory. However, it does require that the designer change the way they design by defining all the design variables at the outset when applying this method. As the third example consider parametric design exemplified by Grasshopper used with Rhino (McNeel, undated). Grasshopper is a visual scripting language that works with parameterised variables (Tedeschi, 2011; Woodbury, 2010). Yu et al (2015) have shown that existing design theories can be used to elucidate explanations of empirically observed design methods as well as describe cognitive behaviour (Yu et al, 2013).

4. What is likely to happen in the future and its effects on design theories and design methods?

Here we list and some of the changes that are likely to happen in the future and the effects they may have on design theories and methods.

4.1. Cognitive behaviour of designer

Currently only a small number of design theories take account of the designer’s cognitive behaviour, while no account is taken of their behaviour in almost all design methods. The situated FBS theory is an example of a design theory that has changed with the change in available knowledge about designers (Gero and Kannengiesser, 2004). New knowledge about human thinking is likely to have an impact on both theories and methods (Haselton et al, 2015; Kahneman, 2011; Lawson, 1990). Kahneman’s System 1 and System 2 Thinking has the potential to describe a range of observed design behaviours including fixation, design patterns, and divergence and convergence. This is likely to result in novel cognitively-based design methods. We can already see “cognitive computing” becoming a new research and application area (IBM, 2017) with potential to be used in novel design methods. We can expect that the design process may include how the designer is progressing towards a design and provide feedback to the designer using concepts from information theory in meta-models of the designer’s cognitive space of potential designs (Shannon, 1948). This fits into some existing design theories such C-K theory (Hatchuel and Weil, 2003) and FBS (Gero, 1990) but not axiomatic design theory (Suh, 2001).

4.2. Users

Currently modelling of the building’s behaviour rarely includes modelling the behaviour of people in the building, although there is a rich field modelling user-device behaviours (Preece et al, 2015). This is generally left to post-occupancy evaluation and is not part of the design process (Preiser et al, 1990). We can expect to see design simulation methods that include occupants’ and visitors’ use of the building as part of the design process (Bona and Salotti, 2014; Preiser et al, 2015; Tsai and Gero, 2006). Since the modelling of user behaviour is a form of analysis it fits well into current theories of design and therefore
does not require any modifications to existing design theories. It may require new methods to carry out the modelling (Schaumann et al, 2015).

4.3. Users’ Social Behaviour

Increasingly we live in a world that uses social media as the connective tissue between people and their environments (Lenhart et al, 2010; Stefanidis et al, 2013). The social behaviour of building occupants needs to be accounted for in any method. Users’ social behaviour is different to users’ behaviour as an individual’s behaviour is modified by the behaviour of other users through social media. This is an underexplored area in design research although it has become a major research area in other domains (Qualman, 2010; Scott, 2017)). User behaviour, whether individual or social, can be seen as a form of building analysis, ie, how does the building produce the expected behaviours of its occupants. Viewed this way the users’ social behaviour fits well into existing design theories as instances of analysis to produce behaviour, with the user becoming part of the structure (in FBS terminology) from which behaviour is derived. The modeling of user behaviour will require methods that are novel in design research, methods from social analytics (Pentland, 2015; Sarkar and Gero, 2017)

4.4. User-building interactions

Currently buildings are designed without taking any or only a minimal account of the interactions of the user with the building and the building with the user, although there are unique exceptions. This used to mean intelligent buildings, whose services respond to user behaviour and changes in the environment (Nguyen and Aiello, 2013). More recently the facades of some buildings change shape based on their interactions with their environments. Today interactions cover both the building and the Building Internet of Things (BIoT), where both the building fabric and fitments are all capable of interacting and responding by being connected to the internet (Atzori et al, 2014; Li and Yu, 2011). Designing for such interactions will require new knowledge about component capabilities and interaction processes but these fit well into structure and behaviour in design theories. Current design methods can encapsulate these interactions within the methods used for determining behaviour of a building using different knowledge to produce the behaviour, so no new design methods would be required.

4.5. User emotions

Currently there is little if any account taken formally of the emotional response of building users in the design process. This is surprising given that architecture distinguishes itself from building by being concerned with the emotional response to space and form (delight) as well as utility (commodity and firmness), whilst building is only concerned with utility. We can expect, in the near future, that methods for the determination of emotional responses will be better developed. Predictive methods for emotional response to space and form such as Kansei (Nagamachi, 1989) and others based on perception, psychometric and physiometric studies of people and designers are likely to be included in the design process (Weber et al, 2002). Emotional response is a behaviour derived from the building and fits directly into current design theories. It will require new tools and knowledge to incorporate emotional responses into design processes but does not change the process itself.
4.6. Design tools that learn and adapt

Currently design tools are unaffected by their use, we can expect design tools to learn through their use and to customize themselves to their individual users. Many tools are expected to remain unchanged by their use: for example a spreadsheet should always provide the same answer for the same input. However, for example, it would be useful for a CAD interface to become easier to use the more you use it, ie, it should learn and adapt itself based on the way an individual designer uses it (Gero, 1996; Peng and Gero, 2009). Tools that learn and adapt would have no impact on design theories or design methods as they would improve the efficiency of the tool but not change the fundamentals of the tool itself.

4.7. Buildings that learn and adapt

Currently buildings do not learn about their behavior and use in ways that the knowledge gained can be transferred to designers and other designs. This is because buildings have very few sensors in them and where there are sensors the data is not made available. Elsewhere, vast quantities of data are generated about human behaviour and learning from mining that data. For example, this is the basis of Amazon’s recommender system. As the cost of sensors drops it becomes economically feasible to embed a large array of sensors in buildings and to collect data that becomes the foundation of new knowledge which is made available to designers (Chong and Kumar, 2003). The new knowledge is about building behaviour and no changes will be needed to either design theories or design methods, as the new knowledge sits outside both. Currently only a few building adapt to their environment and even fewer if any adapt to the way they are used, we can expect buildings to be designed to adapt, expanding the definition and meaning of “intelligent buildings”. There are exemplars of advertising in buildings adapting to the viewer in the movie Minority Report (Spielberg, 2002) and of virtual buildings adapting to their use in ActiveWorlds (Maher et al, 2003). Learning and adapting changes the behaviour of the design by possibly changing its structure, although no change in structure may be required. This is likely to require new design methods that can include the new knowledge supporting the processes for encoding learning and adaptation in the building but existing design theories cover this under synthesis.

4.8. Buildings as part of a social ecology

Currently, each building is an individual entity without any interaction with other buildings, we can expect buildings to interact with each other form an ecological network of sensors across buildings. This based on the way that trees turn out to be part of a social ecology by communicating with each other about activities such as insect infestation (Wohlleben, 2016), similarly buildings could communicate with each other about external conditions that affect them to give early warning to other buildings to make remedial responsive changes in time. This requires new design methods but in terms of design theories it fits well into behaviour, so no changes in design theory would be required to include this.

4.9. Brain-computer interface, user-building interface and brain-building interface

The concept of a brain-computer interface was introduced in 1973 (Vidal, 1973) and we can expect this to become available as a means of both designing and using a building (Liu et al, 2016; Nicolas-Alonso and Gomez-Gil, 2012). As the computer becomes more fully integrated into design, brain-computer interfaces will bypass many current interfaces. In 2010 commercial brain-computer interface systems demonstrated controlling virtual objects in a CAD-like environment by thoughts in the brain alone, Figure 2. It is unclear whether progress in this area will result in the externalization of the more intellectual activity that
designing entails (Alexiou et al, 2010). If it is does then we may have re-examine current design theories, certainly it will result in new design methods.

![Figure 2: Images from Le’s TED talk (Le, 2010). (a) EEG headset on user, (b) orange cube as object to be controlled by thought alone, (c) result of thinking of bringing cube closer, and (d) result of thinking of making cube disappear.](image)

The physiology of the user can now be measured using biometric technologies developed for the security industry (Jain et al, 2004) and this provides a new kind of user-building interface that would allow the building to respond directly to users. There is already mobile brain scanning equipment that could be used as the basis of a brain-building interface. These novel interfaces do not change designing, they introduce new behavioural responses in the building and may require new design methods.

5. Conclusion

This position paper has examined nine possible changes to designing and to buildings based on new knowledge or new technology within the framework of assessing whether design theories or design methods will need to be changed to cover them. It looked at potential changes in our knowledge about the cognitive behaviour of designers, users, users’ social behaviour, user-building interactions, user emotions, design tools that learn and adapt, buildings that learn and adapt, buildings as part of a social ecology, and three new types of interfaces: brain-computer interfaces, user-building interfaces and brain-building interfaces. It assessed whether each of these could be fitted into current design theories. In all but one case it found that these changes could fit within many of current design theories and as a consequence no modifications or extensions would be required to make use of the new knowledge or new technology to describe and model designing. However, new design methods would need to developed to make use of this new knowledge and new technology. This points to where design methods research should focus.

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References


Sensory Pleasure of Interiority

Finding Transdisciplinary Research Language for Complex Indoor Environment Quality

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Abstract: While indoor environment quality (IEQ) measurement is an established process, it omits the sensory pleasure of interior environments, possibly due to perceived subjectivity in the context of objective productivity. Given the significant commercial interior renovation industry, the developing evidence linking sensory pleasure to thermal comfort, the known complexity of indoor habitation, and the growth of large data set analysis, there exists an opportunity to expand the scope of IEQ appraisal. Drawing on the interior architecture discipline and its holistic ‘interiority’, this speculative paper presents a high-level content analysis of selected texts and identifies candidate sensory quality variables for future use in environment quality measurement. The intention of this process is to translate across the interior architecture and architectural science disciplines by quantising interior architecture perspectives into measurable variables. These broader candidate variables would likely be more inclusive of the lived experience and agency of occupants of interior spaces and offers extended complex indoor environment quality data collection for future use in advanced statistics.

Keywords: interior design; interior architecture; indoor environment quality; methodology.

1. Introduction

Designers make design decisions about interiors with many intentions. One intention is to create sensory pleasure of an enclosed built environment space, which we know is important if only from the commercial success of mass media telling us so. From ‘Grand Designs’ to ‘The Block’ we see the fetishization of our enclosed spaces demonstrated. In Australia, ignoring structural renovations, we spend nearly as much on furniture, floor coverings, and houseware goods as we do on clothing ($1.2bn vs. $1.4bn, December 2016, ABS report 8501.0). Our interiors are clearly more than shelter, yet pleasure in all building classes, not just residential, is seen as less important than more commercially honourable intentions like productivity.

At the previous Architectural Science Association Conference (Zuo et al., 2016), two keynote speakers spoke about the pleasure derived from thermal experiences. Lisa Heschong suggested that buildings are now our ‘natural habitat’ and that her ‘little ambassador’ of necessity, delight, affection and sacredness of lived thermal variation still applies (Heschong, 1979). Richard de Dear reflected on his personal
experience of using Heschong’s framework. Furthermore, he described his work using images of interiors, such as Gujarat step wells, to demonstrate the ‘emotional landscape’ and topophilia of the indoor. Both speakers discussed space with more nuance than, say, a Greenstar indoor environment quality (IEQ) measurement, demonstrating the implicit broad understanding of interior, creating an opportunity for the knowledge base of interior architecture to contribute to indoor environment quality appraisal.

1.1. (Re)introducing Interior Architecture / Interior Design / Spatial Design

Interior Architecture (IA) is ‘...the design of space through human occupation’ (Brooker and Weinthal, 2013, p. 8), such that,

Designers act upon interiors through multiple entry points that include atmospheric conditions like color and light, understanding the client’s needs, giving form and shape to materials, and unifying these elements into a captivating design. (Weinthal, 2011, p. 11)

Thus, it is taken for granted that occupants should feel something positive about the built design. Occupancy is seen as ‘familiarity’ with an interior due to ‘...the close proximity of people, objects, and space’(Brooker and Weinthal, 2013, p. 3). It is also concerned with the temporality of designed spaces, particularly the need to adjust infrastructure to occupants as their needs change (Vischer, 2008; Brooker and Stone, 2016), requiring shorter lifecycles of interior architecture than architecture.

Interior architecture emerged as a professional practices in the nineteenth century (Edwards, 2011, p. 15). Debate about the delineations of interior practice and origins is ongoing (Plunkett in Cys, 2009; Brooker and Weinthal, 2013, p. 93-104; Brooker and Stone, 2016). Currently, interior architecture is also known as interior design and spatial design, with practitioners known as interior designers.

The broadness of the practice of this discipline is seen as both opportunity and challenge (Cys, 2009). This paper is positioned in the broader definition of interior architecture, i.e., ‘...the design of structurally created interiors...’ (Edwards, 2011, p. 2), which includes interior design, decoration, understanding of structure and services. Its knowledge base needs a range of empirical and theoretical research methods and paradigms, covering science, social science, and phenomenology. This is seen as an opportunity to consider transdisciplinary thinking: ‘...that which is at once between the disciplines, across different disciplines, and beyond all disciplines’ (Repko, 2012, p. 21) to reconsider IEQ. The intention is to start to translate across the disciplines of interior architecture and architectural science. This will make explicit additional relevant aspects of sensory pleasure of the enclosed built environment for inclusion for future extended indoor environment quality, possibly as fine detail to post-occupancy investigations (e.g., Kim et al., 2016). As an inductive exercise, questions about transdisciplinary methodology are also raised.

This paper is in four sections. The first section revises the consequences of the subjective / objective split in knowledge claims for IEQ. The second section reviews emerging challenges to this dichotomy through the examples of thermal comfort and interior architecture. The third section provides a broad content analysis of selected theoretical writing from the interior architecture discipline to nominate candidate variables for future investigation. Finally, applications and further work is discussed.

2. Transdisciplinary Research Challenges

As a speculative exercise, this paper is interested in literature beyond the current scope of architectural science to what might be considered ‘subjective’ or ‘soft’ approaches as a source of new variables for future scientific research method. From the perspective of scientific knowledge, the environment is
independently knowable and measureable (Groat and Wang, 2013, p. 71). Epistemologically, this knowledge claim is post-positivist and knowledge quality is based around internal and external validity, reliability and objectivity (Groat and Wang, 2013, p. 80-83). From the perspective of architectural science, architecture is split, somewhat neatly, into art and science (Szokolay, 2008, p. ix), yet architecture, its art, production and use, is interrelated with its physics (Groat and Wang, 2013, p. 8-9). While the use of scientific method is appropriate for physics, pragmatist knowledge claims consider that knowledge is limited by its specific audience (Metcalfe, 2008), suggesting limits to useful knowledge from architectural science and the building science community.

Stepping outside of that community, the quality of this knowledge is different. Through a constructivist paradigm, it is asserted that this knowledge is actually constructed by the scientific community, i.e., objectivity originated in subjective thought, and, as such, contains bias (Teddlie and Tashakkori, 2009, p. 86). Others in science and technology studies (STS), argue that the separation of science from non-science, objectivity from subjectivity, never existed, and that this separation is a constructed political decision, which should be reversed (Latour, 1991, p. 144). Similarly, philosopher A.N. Whitehead argues that we should not ‘bifurcate’ nature because there is an interaction between cause of awareness and awareness:

... everything perceived is in nature. We may not pick and choose. For us the red glow of the sunset should be as much part of nature as are the molecules and electric waves by which men of science would explain the phenomenon...(Whitehead CN29 in Stengers, 2011, p. 33)

Thus, we naturally use different methods to understand our world. This does not mean that the methods are wrong (heat transfer physics is clearly useful), but stepping outside of a specific community opens up choices about research methodology.

Environmental psychology is an obvious gateway to user experience with built environment research (Vischer, 2008); however, ambiguous yet persistent experience of interior is not necessarily covered. There are research efficiencies and validities associated with psychology science methods; however, if variable selection is undertaken without designer input, this reductionist approach of parameterising indoors is limited. This means that the ephemerality may not be knowable beyond interior theorists and personal narrative, the latter clearly important as seen by the commercial success of renovations.

Extending architectural science beyond physics to include people in the system is not new. Last century, Hillier and Leaman raised limitations with scientific approaches. They proposed a ‘man-environment paradigm’ and positioned their ideas in structural sociology, where social structures, including artefacts, act on a population (Hillier and Leaman, 1973). The later theory of structuration justifies re-examination of positive approaches towards building appraisal. Structuration is:

... neither the experience of the individual actor, nor the existence of any form of societal totality, but social practices ordered across space and time. Human social activities, like some self-reproducing items in nature, are recursive. ... they are not brought into being by social actors but continually recreated by them via the very means whereby they express themselves as actors. (Giddens, 1984, p. 2)

We could consider interior architecture as a physical manifestation, and measure it accordingly; however, they are recursive artefacts of human social activities and, thus, contain expression of the people that both create them and occupy them, both of these being production of space (Lefebvre, 1974). Thus, positivist approaches to architectural science tell only part of the story of occupation and need to integrate the different systems for commercial, workplace, education and private spaces.
The metaphor of mechanical systems used to describe sustainability systems (Williamson 
*et al.*, 2003, p. 85), makes explicit the distinct social and individual sub-systems, suggesting an approach based on sociological structuration. Rich understanding of sub-systems requires mixed methods approaches (Teddlie and Tashakkori, 2009), which consider positivist and constructivist research methods as complementary and inter-related through abductive logic (Teddlie and Tashakkori, 2009, p. 89; Groat and Wang, 2013, p. 34-35). Abductive logic argues that knowledge starts with observing a surprising phenomenon, initiating a circular deduction and induction knowledge creation process (Figure 1).

Indoor environment quality parameters come from somewhere. Architectural science clearly uses surprising phenomena from professional practice and research to trigger new lines of inquiry (e.g., Cohen 
*et al.*, 2001). Someone observed an effect or a need and developed *useful* hypotheses and tools to quantify indoor environment quality. This is abduction in practice. The start of this process is coloured by the originator’s tacit knowledge. Any extension of professional praxis (Crouch and Pearce, 2012, p. 37-44) will influence the process. Current IEQ approaches are fit for (current, limited) purpose. This paper is interested in expanding the existing inductive origins of environment quality. The inclusion of interior architecture sources is just a continuum of the abduction process.

### 2.1. Methodology and Method

To overcome the dichotomy of objective and subjective, this work is positioned as a pragmatist, mixed methods inquiry. It is also positioned as one part of an abductive research process. Sensory pleasure is presented as one transdisciplinary topic to test this process. First, thermal comfort as sensory pleasure is reviewed and a logical argument (Groat and Wang, 2013, p. 379) is made that sensory pleasure rewards described in theoretical interior architecture are useful. Second, assuming the abductive process in Figure 1, a preliminary content analysis (Repko, 2012, p. 249-250) of selected interior architecture texts is presented to identify additional candidate concepts for future parameterisation in expanded indoor environment quality appraisal. The terms presented are those that either provide ‘surprising phenomena’ relative to current IEQ, or offer the possibility of more nuanced approaches to existing IEQ topics, and is the start of an interative process (Teddlie and Tashakkori, 2009, p. 251-254).
3. Sensory Pleasure

Biologically, alliesthesia, that property of stimuli which results in an affective response, is useful because, through sensory pleasure, it rewards and motivates behaviour (Cabanac, 1979). This section briefly reviews an exemplar of sensory pleasure, thermal comfort, and then argues that the sensory pleasure of interior architecture is worthy of further investigation.

3.1. Thermal Comfort as Exemplar

The alliesthesia of thermal comfort has been proposed as a ‘paradigm shift’ to understanding how people respond to indoor climate (e.g., de Dear, 2011, and beyond), suggesting that comfort is more than purely building physics and human physiology. This work is expanding the parameters associated with indoor environment quality, thus beginning to address the human lived experience of an environment as a complex and contingent experience requiring other sources of knowledge about spatial atmosphere.

With some exceptions (e.g., Erell et al., 2011), thermal comfort studies occur in an indoor environment, where the indoor is a volume fully enclosed by a container, sometimes porous (mixed mode), and occupants have specific normative activities. This positivistic approach, quite rightly, defines the challenge of thermal comfort for achievable scientific method; however, sensory pleasure of the indoors, of which thermal comfort is one aspect, is constructed through socialisation and structuation.

If alliesthesia is proving useful in extending the adaptive thermal model of comfort then it might also offer extension to other aspects of the indoors. It relies on a changed sensation and is ‘perceived as pleasant or unpleasant according to the inner state of the subject’, i.e., it is a temporal variable, changing throughout the day and relative to a previous steady state (Cabanac, 1979). Cabanac’s tridimensional hedonic continuum proposes three pleasure sensations: affective (pleasure – distress vs delight); quantitative (stimulus intensity); and qualitative (stimulus nature), noting that the qualitative and quantitative here are not those of social science methods. Cabanac’s quantitative stimulus, such as temperature or salty taste, are likely more controllable in positivistic research situations. In that, they are relatively simplistic in experience. The cumulative inter-sensory pleasure effect of a designed enclosed space requires more complex research approaches, particularly if occupant agency is included.

Reminding ourselves that Cabanac suggests a link between pleasure and reward, this provides incentive to investigate environmental sensory pleasure further. While interior architecture research demonstrated interested links between interior design and comfort voting patterns (Rohles and Wells, 1976), the discipline also offers theoretical and phenomenological writings that attempt to describe the complex and holistic sensation of occupancy of interiors, including sensory pleasure.

3.2. Sensational Interior Architecture

The IA knowledge base comes from a wide range of knowledge claims such as, but not limited to, theoretical approaches (Clemons and Eckman, 2011), environmental psychology (Gosling et al., 2013) and practiced-based research by design (Postiglione in Brooker and Weinthal, 2013, p. 59-69). Interior preferences are also highly complex and subjective, and is both individual and constructed through socialisation (Sparke in Brooker and Weinthal, 2013, p. 559-597), resulting in interiority:

Interiority is that abstract quality that enables the recognition and definition of an interior. It is atheoretical and immaterial set of coincidences and variables from which “interior” is made possible. (emphasis added, McCarthy, 2005, p. 112)
Interiority is development of enclosure and boundaries, originating in historical design (Attiwill, 2004), but also the pure sensory engagement of linking personal with spatial interiority (Taylor, 2013, p. ix). It is a developing concept, beginning as a social theory and moving to an activity of spatial construction (Popov, 2010), thus, becoming more explicit as a design concern.

It has been asserted that itemising these components is not particularly useful for interior architecture, and it is recommended to ‘...recognise that multiple paradigms operate simultaneously – the sensorial experience, the cognitive or thoughtful, evaluative experience, and the immediate confrontation or immersive experience – [so that] a more holistic understanding is facilitated’ (Verghese & Smith in Brooker and Weithal, 2013, p. 514–527). In contrast, the duality of environmental quality components is also noted: light can be measured scientifically and holistically as an ‘antediluvian affect’ (Cantwell in Brooker and Weithal, 2013, p. 544). Thus, measuring environment quality is not an either/or situation: both quantitative and qualitative, objective and subjective, methods have their individual validity and purpose, reinforcing each other, suggesting that interior architecture is not hostile to scientific methods.

A full literature review of integration of environmental and cognitive psychology models into the interior architecture discipline is beyond the scope of this paper. It is noted that these disciplines have their own significant body of knowledge, and some has made its way into the interior architecture and design discipline, such as preference lens (Brunswick model), affordances, and collative properties (Gosling et al., 2013). Outside of the interior disciplines, application of these models extend measurement beyond basic components, e.g., ‘friendliness’ of classrooms, as rated by users and independent assessors (Douglas and Gifford, 2001). This parallel appraisal unintentionally confirms that there is opportunity for component itemisation as well as holistic understanding, i.e., neither approach is useful alone.

The literature and practice of interior architecture offers a significant body of knowledge about holistic understanding, but in the form of phenomenology and interpretation. Interdisciplinary research involving interior designers as independent assessors is association with psychologists is one possible future direction, albeit a personnel intensive future. Acknowledging the research efficiencies of quantitative surveys, and as a speculative exercise, this paper is specifically interested in expanding the reductionist research strand by quantising holistic writing about interiors. While this will not measure the poetics of interior atmosphere – that is for narrative – it could extend our current IEQ approaches.

4. Mining Interior Architecture and Design

This section reviews selected contemporary interior architecture texts (Weithal, 2011; Brooker and Weithal, 2013) currently used in interior architecture university education at the author’s workplace. It presents a preliminary content analysis of these texts to identify additional topics and variables for future inclusions in IEQ evaluation (Table 1). Content here was selected based on obvious and interesting theoretical language about sensory pleasure and translated into preliminary candidate variables.

<table>
<thead>
<tr>
<th>IA topic</th>
<th>Source</th>
<th>Candidate variables</th>
<th>Test</th>
<th>New?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senses – acoustic intimacy</td>
<td>Pallasmaa (W)</td>
<td>Presence / absence / time marker</td>
<td>SC, MC</td>
<td>N</td>
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<tr>
<td></td>
<td>Cantwell (Ch 38, B+W)</td>
<td>Harshness / softness / tranquility</td>
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<td></td>
<td>von Drathen (W)</td>
<td>Directionality</td>
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<tr>
<td>IA topic</td>
<td>Source</td>
<td>Candidate variables</td>
<td>Test</td>
<td>New?</td>
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<tr>
<td>Sense body / bodily resonance space</td>
<td>Pallasmaa (W)</td>
<td>Scale / volume</td>
<td>SC, MC, PE, WT</td>
<td>N</td>
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<tr>
<td></td>
<td>Cantwell (Ch 38, B+W)</td>
<td>Interaction</td>
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<tr>
<td></td>
<td>von Drathen (W)</td>
<td>Gravity – apparent vs defying</td>
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<tr>
<td>Senses Vision extended (seen vs touched)</td>
<td>Pallasmaa (W)</td>
<td>Near vs far</td>
<td>SC, MC, PE, WT</td>
<td>N</td>
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<td></td>
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<td>Surfaces, contours, edges</td>
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<td>Agreeableness / unpleasantness</td>
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<td>Affection / indifference / stress</td>
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<tr>
<td>Senses - touch</td>
<td>Pallasmaa (W)</td>
<td>Texture and density</td>
<td>SC, MC</td>
<td>B</td>
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<tr>
<td></td>
<td>Cantwell (Ch 38, B+W)</td>
<td>Weight; Eye vs body</td>
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<td></td>
<td>von Drathen (W)</td>
<td>Temperature and light</td>
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<tr>
<td>Senses - olfactory</td>
<td>Pallasmaa (W)</td>
<td>Memory</td>
<td>SC, MC</td>
<td>N</td>
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<tr>
<td></td>
<td>Parkinson (Ch 22, B+W)</td>
<td>Association</td>
<td></td>
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<tr>
<td>Historical and Geographical design influence / Fashion trends</td>
<td>Massey (Ch1, B+W)</td>
<td>Design style / hybrid</td>
<td>SC, MC, PE, WT</td>
<td>N</td>
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<td></td>
<td>Scott (Ch 10, B+W)</td>
<td>Diffusion</td>
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<td>Shyder (Ch29, B+W)</td>
<td>Flexibility</td>
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<td>Sparke (Ch 39 B+W)</td>
<td>Fashion</td>
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<td>Threshold / connection public and private / views / relation to site</td>
<td>Griffith Winton (Ch 3, B+W)</td>
<td>Entrance openness</td>
<td>SC, MC, PE, WT</td>
<td>N</td>
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<tr>
<td></td>
<td>Parkinson (Ch 22, B+W)</td>
<td>Sense of privacy</td>
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<td></td>
<td>Moreno (Ch 26, B+W)</td>
<td>Permeability in and out</td>
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<tr>
<td>Desire and delight</td>
<td>Moreno (Ch 26, B+W)</td>
<td>Immersion</td>
<td>SC, MC, PE, WT</td>
<td>N</td>
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<tr>
<td></td>
<td>Parkinson (Ch 22, B+W)</td>
<td>Preference / Liked</td>
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<tr>
<td>Transience / change</td>
<td>Farrelly (Ch 11, B+W)</td>
<td>Preference</td>
<td>SC, MC, PE, WT</td>
<td>N</td>
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<td></td>
<td>Littlefield (Ch 17, B+W)</td>
<td>Liked</td>
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<td></td>
<td>Moreno (Ch 26, B+W)</td>
<td>Permanent vs temporary</td>
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<tr>
<td>Material culture (fixtures, fittings, decoration, furniture, that dress</td>
<td>Griffith Winton (Ch 3, B+W)</td>
<td>Functional / everyday objects</td>
<td>SC, MC, PE, FA</td>
<td>N</td>
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<td>an interior)</td>
<td>Massey (Ch 35, B+W)</td>
<td>Pleasure objects</td>
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<td></td>
<td>Blavuelt (W)</td>
<td>Exhibition / installation of objects</td>
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<td></td>
<td>Schouwenberg (W)</td>
<td>Participatory action of design/decoration</td>
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<td></td>
<td>Helguera (W)</td>
<td>Observed / reported / Preference</td>
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<td></td>
<td>Betsky (W)</td>
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<tr>
<td>Spirit of place / meaningful occupation</td>
<td>Farrelly (Ch 11, B+W)</td>
<td>Likely a combination of other variables, e.g., factor analysis</td>
<td>FA, WT</td>
<td>B</td>
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<tr>
<td></td>
<td>Vergheese &amp; Smith (Ch 36, B+W)</td>
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<td></td>
<td>Cantwell (Ch 38, B+W)</td>
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<tr>
<td>Health and wellbeing / design for operational rationality vs compassionate</td>
<td>Parkinson (Ch 22, B+W)</td>
<td>Natural light, noise reduction, layout, views</td>
<td>SC, MC, PE, FA</td>
<td>B</td>
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<tr>
<td>interior design</td>
<td></td>
<td>Engagement with spatial design</td>
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<td>Compassionate/welcoming space</td>
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<td>Emotional / physical stress</td>
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<td>Psychological / social support</td>
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<td>Overload / Peace / Stimulation</td>
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<td>Movement agency</td>
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<tr>
<td>Materials and colour and surfaces</td>
<td>Vergheese &amp; Smith (Ch 36, B+W)</td>
<td>Texture and Moulding, Light</td>
<td>SC, MC, PE, WT</td>
<td>B</td>
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<tr>
<td></td>
<td>Bachelor (W)</td>
<td>Cultural norms of colour</td>
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<td></td>
<td>Weinthal (W)</td>
<td>(national, commercial, fashion)</td>
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<td>Seigel (W)</td>
<td>Safety of materials</td>
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<td>IA topic</td>
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<td>Candidate variables</td>
<td>Test</td>
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<tr>
<td>Experience of environment /</td>
<td>Verghese &amp; Smith (Ch 36, B+W)</td>
<td>Time spent in environment</td>
<td>SC, MC, B</td>
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<td>familiarity with space</td>
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<td>Peripheral vs primacy</td>
<td>PE</td>
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<td>State of mind</td>
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<td></td>
<td>Associate physical / memory</td>
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<tr>
<td>Technology</td>
<td>Keeble (Ch 37, B+W)</td>
<td>Comfort (heat, light) control</td>
<td>SC, MC, B</td>
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<td></td>
<td>McQuire (H)</td>
<td>Surveillance / Linkage</td>
<td>PE</td>
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<td>Domestic vs industrial tech</td>
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<td>Work vs pleasure technology</td>
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<td>Ambivalence vs defined outcome</td>
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<td></td>
<td></td>
<td>Participation</td>
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</tbody>
</table>

Sources: B+W = Brooker and Weinthal (2013); W = Weinthal (2011)
Test instrument: SC=scale question, MC=multiple choice, PE=photo elicitation, FA=factor analysis, WT=walkthrough.
Identification of new variables: N = new, C = common to interior architecture and architectural science, B = both new and common

Further work is required to refine these candidate variables. This will include systematic searches of key peer-reviewed interior design journals for triangulation to confirm candidate variable categories and description. Table 1 also provides a range of quantitative and qualitative test instruments for testing the validity of variables. These candidates do not map neatly into Cabanac’s tridimensional hedonic continuum axes. Once the candidates are clarified, they should also be tested for contribution to the hedonic continuum, in conjunction with temporal changes and spatial types.

5. Complex Indoor Environment Quality: Holism vs Reductionism

Integrating architectural science and interior architecture knowledge paradigms is challenging, particularly when considering holistic phenomenological approaches. Environmental psychologists, themselves, acknowledge that checklists omit special features (Gosling et al., 2013). The process here is explicitly reductive, but this is deliberately part of the stated transdisciplinary intention of this paper. From a circular abductive perspective, the quantisation required to expand a set of variables is not mutual exclusive of more nuanced qualitative research. Taking an overall view, this is considered complementary operative research linking theory to practice (Postiglione in Brooker and Weinthal, 2013, p. 59-69).

In reading architectural science and interior architecture it must be observed that they use different words – indoor and interior. Where indoor environment quality is a set of physical parameters with some preference variables, interior literature is broader and explores the experience of body. Much of interior literature is about fully enclosed spaces, but the recent claiming of the urban interior opens up further transdisciplinariness (Hinkel, 2011). Urban Interiority covers any sense of enclosure thus including outdoor and liminal space. Thus, thermal comfort of urban spaces might also include interiority sensory pleasure. This intellectually frees up the reliance on building fabric, but it should not remove the building fabric from the research challenge: maintaining an exclusive position on either the scientific or humanist side does not progress interior architecture (or other building knowledge) and that, in practice, physics and interiority (phenomenological or other theory) are interconnected through human experience.

Thus, any measure of environment quality needs to be explicit in its starting point and scope. Indoor environment quality measurements are achievable, but potentially limited, although the limitations may be valid depending on the intended concerned audience. This paper suggests that this scope could be extended and, using the interior architecture theoretical knowledge presented here, a more accurate name might be interiority environment quality. The risk with this is twofold: first, the audience,
architectural science, may not be fully aware of the breadth of interiority theory, and, second, though accurate, the use of another discipline-specific term may restrict future inter- and trans-disciplinarity.

An alternative term is complex indoor environment quality. This is indoor environment quality that is expanded to include variables that capture more of the complexity and richness of lived experience, including the sensory pleasure of interior habitation, as described by interior architecture theory. It provides this experience in a quantitative form suitable for statistical analysis, such as inferential statistics, factor analysis, and structural equation modelling, in the context of emerging ‘big data’ methods. The next steps are to refine the candidate variables, develop empirical test instruments, and then test their sensitivity to selected quality dependent variables, either as correlative relationships or loadings on any factor analysis in various interior typologies, all as companion to other qualitative methods. It is anticipated that there is core group with additional clusters of variables based on interior spatial function, e.g., dependent variables such as productivity and satisfaction will vary from residential to work place.

6. Conclusion: Interior is the New Indoor

While architectural science and building science provide objective knowledge through physical built environment appraisal methods, this paper speculated that there are opportunities to extend our knowledge of habitable space through integrating subjective knowledge from interiors disciplines, known as interior architecture, interior design, and spatial design.

One exemplar of useful subjective knowledge is the alliesthesia of thermal comfort. In this, sensory pleasure has a biological purpose – it provides motivation for action – and is quantifiable. Thus, sensory pleasure is important and should be taken seriously in design; however, applying this presents challenges due to perceived mutual exclusivity of objective and subjective knowledge paradigms. From the perspective of pragmatism, using abductive logic, these paradigms are linked and complementary, and open up transdisciplinarity.

Interior architecture’s theoretical knowledge offers rich phenomenological and sociological interpretation of the experience of ‘interiority’, the nuanced sense of being within a defined space, as inadvertently described by keynote speakers in the 2016 ASA conference. This paper proposed that this abstract experience and language of interiority could provide additional variables for exploration. As an example, two interior architecture teaching texts were mined for sensory pleasure variables and presented here as a preliminary content analysis. These variables require further investigation and validation and are not a substitute for rich qualitative work. This process offer the means to integrate sensory pleasure into new complex indoor environment quality appraisal, through statistical and ‘big data’ quantitative methods, in conjunction with complementary and interconnected abductive research methods, so that interior is the new indoor.

References


Apartment Assessment Platform

A Model for Capturing and Comparing Apartment Designs

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Abstract: Since 2002, multi residential developments proposals are assessed under the State Environmental Policy No 65 (SEPP 65) which measures apartment design quality according to nine design principles. The introduction of the SEPP 65 has improved the quality of apartment designs, however, it has also introduced the challenge of collecting data and analysis for assessment. Current analysis tools predominantly assess environmental conditionals and provide analysis results without mechanisms to store the analytical data in a structured hierarchical format. This paper explores a framework for capturing apartment designs and associated analytical data in a structured format, allowing a method for documenting and presenting design analysis in an efficient manner. An initial case study demonstrates the capture of metrics across a range of spatial and environmental analytics which can be tailored to meet the SEPP 65 objectives. In addition, the framework allows comparative analysis between apartments, providing a methodology for Architects and developers to build an intelligence within their portfolio of designs. Through the structured storage of design plans and analytics, fundamental design questions about layout, room sizes, daylight, sunlight, natural ventilation and privacy can be assessed as historical data sets that can provide insights into the success of designs over time.

Keywords: Data, BIM, Analysis, Apartment Design, Parametric Design

1. Introduction

Since 2002, multi residential developments proposals are assessed under the State Environmental Policy No 65 (SEPP 65, 2017) which measures apartment design quality according to nine design principles. The introduction of the SEPP 65 has improved the quality of apartment designs, however, it has also introduced the challenge of collecting data and analysis for assessment. Current analysis tools predominantly assess environmental conditionals and provide analysis results without mechanisms to store the analytical data in a structured hierarchical format. This introduces issues around the consistency of analysis and reporting as well as difficulties in the assessment process.

This paper explores a framework for capturing apartment designs and associated analytical data in a structured format, allowing a method for documenting and presenting design analysis in an efficient and consistent manner. An initial case study demonstrates the capture of metrics across a range of spatial and environmental analytics which can be tailored to meet the SEPP 65 objectives.
In addition, the framework allows comparative analysis between apartments, providing a methodology for Architects and developers to build an intelligence within their portfolio of designs. Through the structured storage of design plans and analytics, fundamental design questions about layout, room sizes, daylight, sunlight, natural ventilation and privacy can be assessed as historical data sets that can provide insights into the success of designs over time.

2. Background

This research explores the limitations of current software in achieving the requirements for legislation around apartment design quality. This section will describe in brief the assessment criteria under the SEPP 65, followed by an outline of the current software available, highlighting the limitations and need for the framework proposed in this research.

The objective of the SEPP 65 is to improve the design quality of residential apartment development in New South Wales, Australia. There are nine design quality principles which include contextual response through to building amenity. A supplementary guide, the Apartment Design Guide (ADG, 2017), provides design criteria and guidance about how development proposals can achieve the nine design quality principles. The ADG consists of five parts. This research will focus on Part 4, designing the building, as this part directly relates to the design of the apartments with objectives and design criteria that can be calculated from a building model. Part 4 of the ADG has 23 requirements including Amenity, Configuration and Performance metrics that need to be described in a development application. A sample criteria is that Living rooms and private open spaces of at least 70% of apartments in a building receive a minimum of 2 hours direct sunlight between 9 am and 3 pm at mid-winter in the Sydney Metropolitan Area and in the Newcastle and Wollongong local government areas. To report on this criteria, an Architect must first be able to calculate the design criteria, i.e. number of hours of direct sunlight for living room and private open space at multiple times throughout the day, then calculate this for all apartments in a project, aggregate the results and provide evidence of the results for assessment. The next section will look at ways to address the first part of this challenge, the tools available for the calculation of the required design criteria.

There are a range of design analysis software available to Architects. The most commonly used software available for environmental analysis include RADIANCE, EnergyPlus, Sefaira and plugins to parametric design software such as Ladybug and HoneyBee. These tools allow the calculation of daylight, heat balance, illuminance, glare and other metrics. Radiance and EnergyPlus are console based programs that require an interface such as Sefaira, Ladybug and HoneyBee. RADIANCE is the primary tool used for daylighting calculations, which aims to “predict illumination, visual quality and appearance of innovative design spaces” (Reinhart et al. 2001 Pg. 686). It simulates illuminances under any sky condition using data extracted from weather files, the latitude, longitude and solar radiation and also the “optical properties of surfaces” (Ramos et al. 2010, pp 1949). The main advantage of RADIANCE over similar, simpler daylighting and lighting calculation tools is that the program has no limitations over the geometry or materials that can be assessed. Whilst RADIANCE predominantly works with the illuminance of a space, EnergyPlus offers “joint analysis of the heat exchanges and daylight gain through the window” (Ramos et al. 2010, pp 1949). Both programs measure reference points within a room and calculate data that contributes to solving the internal reflectance of a room.

There are also a range of spatial configuration analytics that are described as Space Syntax (Hillier & Hanson, 1984). A partial set of analytical techniques from Space Syntax called gamma analysis interprets
urban space syntax measures for permeability of interior spaces. Of importance here is the ability to represent a design as a series of connected spaces through a justified map, as this allows further analysis.

In addition to the analytical software, Building Information Modelling (BIM) software such as Autodesk Revit allows the creation of 3D building models with associated data. A combination of using BIM and analytical software can perform most of the calculations required for the SEPP 65 design criteria, however these programs are not structured to describe and analyze multi-unit developments and require advanced skills, custom scripting, workflows and time consuming data entry to extract out all the relevant criteria in the correct format. As there are no standard views / methods to report on the SEPP 65 design criteria in a consistent way, this also introduces the issue of quality control through a range of non-standard solutions to data collection and reporting. If different Architects are collecting data and producing reports using a mix of software and reporting styles, it is difficult to verify the results and methods used which can introduce difficulties and uncertainty in assessment, and inconsistent assessment depending on the extent and style of reporting.

Technological improvements have provided researchers with the tools to revolutionize the way that buildings are designed and assessed. The structured format of BIM coupled with the accessibility of cloud computing, analytical tools and the resources to analyze large datasets provides Architects with unprecedented computational power and obligation to integrate performance assessment in the design process. However this section has introduced issues around the complexity of design criteria calculations, the identification of non-standard solutions and the difficulty and uncertainty this brings to the assessment process. In addition, these analytical software packages have often been associated with various limitations including being “restricted to calculations on simple built-forms with limited capability to describe context” (Jones et al. 2004 Pg. 253). A key issue in using these off-the-shelf analysis tools to achieve the requirements of the SEPP 65 and Apartment Design Guide criteria is that they have not been developed to structure and perform the analysis on multi-unit developments. The next section will introduce a conceptual framework that aims to resolve the issues identified around the complexity of capturing apartment design data and having an integrated approach to analysis and reporting that provides a standard workflow and assessment basis in the future.

3. Conceptual Framework

This research adopts the approach by Nunamaker and Chen (1990) that describes system development as a research strategy. This strategy has five stages which include the construction of a conceptual framework through to the building of the prototype system, observing and evaluation the said system. This paper explores the construction of a conceptual framework for the apartment assessment platform, Figure 1, and an initial prototype to capture and compare apartment designs which demonstrates the key components of the conceptual framework.
The framework is composed of five components which are described below:

- The first stage is to construct a Building Information Model (BIM) of the multi-unit residential complex. This will allow the documentation of the key building elements including walls, floors, roofs, rooms and openings.
- The second stage involves parsing the BIM to extract all relevant elements that are required for analysis and reporting. These are stored into an Apartment Design Schema (ADS).
- Once the data has been processed into the ADS, the ADS is uploaded to a database on the cloud for processing. This is conducted using parallel processing to ensure the data is captured efficiently.
- Once the data has been received, an application on the cloud servers will read the ADS and perform a series of assessments and save the data to the database in the required format.
- Finally, a series of reports and interactive views can be constructed to meet different assessment purposes such as a SEPP 65 submission.

The next section will describe a case study that demonstrates an initial implementation of the conceptual framework.

4. Case Study

The following case study is a proof of concept to test the conceptual framework. For testing purposes, the case study for the multi-unit development will focus on the development of the analytics and show an assessment of two seemingly identical apartments in the project. This will demonstrate the stages of the conceptual framework including the modelling, type of design analysis and sample reporting styles.

A standard Building Information Model is constructed in Autodesk Revit for the apartment complex that includes the Walls, Floors, Roof, Doors, Windows and Rooms. The model can be seen in Figure 2.
Once the building has been modelled, a custom plugin has been developed to collect all the elements and relevant data from the model and submit to a custom design database and cloud application for design analysis. The following types of analysis are conducted on the design which relate to the key SEPP 65 design criteria.

Direct sunlight analysis determines which rooms out of a dwelling achieve adequate direct sunlight whilst storing the direct sunlight polygon, Figure 3, and the amount of hours of sunlight achieved per hour, Figure 4. The figures below also show the type of standard reporting style available for demonstration of compliance.

Figure 3: Calculation of direct sunlight polygons by hour of the day Mid-Winter.
Ventilation, cross ventilation and daylight calculations determine if adequate ventilation and daylight has been provided by comparing the openings to the room sizes in accordance with the SEPP 65 guidelines. The different rooms are highlighted if they comply, see Figures 5. The prototype is also able to output a table outlining which apartments comply across a project across any criteria.

Whilst we have highlighted these analytics, there are a series of other metrics that are calculated including spatial depth, connectivity, privacy, room sizes, balconies and storage size plus the percentage of open plan. The architecture of the system allows additional analytics and metrics to be added. With the data captured in a structured format, it also allows collecting additional information of historical designs through new analytical techniques.

Figure 4: Mapping of direct sunlight achieved by room, amount and hour of the day.

Figure 5: Calculation and reporting on natural and cross ventilation.
To demonstrate the benefit of the comparative tools that become available once the data is structured using the Apartment Design Schema, a multitude of designs can now be visually compared to start building design intelligence across a portfolio by having a visual comparison. Figure 6 shows a visual matrix identifying a single design metric across a range of apartments in a portfolio. Table 1 shows the same data in tabular format that can be accessed via API which is suitable for machine learning and predictive analytic applications.

![Figure 6: Comparison of a design metric across a portfolio of designs.]

![Table 1: Apartment design data in tabular format.]

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Finally, an Architect can now deep dive into the comparison between two seemingly identical apartments by visualizing side by side via any design criteria. Figures 7 highlights a comparison of direct sunlight across two plans which have are at the same scale. This can also be used throughout the design stage to compare different design options. Similar consistent reports can be shown against any criteria and can be tailored to the requirements of the SEPP 65 and ADG.

![Figure 7: Comparison of two apartment on direct sunlight.](image-url)
5. Conclusion

The SEPP 65 legislation and the Apartment Design Guide have provided Architects, planners and clients to bring design quality to the forefront when assessing development applications for multi-unit developments. However, due to the complexity of calculating, storing and representing the analysis, it has led to time consuming processes that do not provide consistent calculations and reporting across different design firms for objective assessment.

Technological improvements have provided researchers with the tools to revolutionize the way that buildings are designed and assessed. The structured format of BIM coupled with the accessibility of cloud computing, analytical tools and the resources to analyze large datasets provides Architects with unprecedented computational power and obligation to integrate performance assessment in the design process.

This paper introduces a conceptual framework for an Apartment Assessment Platform that allows the capture, storage and consistent analysis of apartments. The framework was demonstrated through a case study that showed the types of analytics and consistent reporting styles it makes available to the industry.

Through the adoption of the Apartment Assessment Platform for presenting multi-unit developments for assessment, the authors propose that there will be:

- Efficiencies in documentation,
- Access to real time assessment during design
- Consistency in calculations
- Consistency in reporting style
- Efficiencies in assessment

The same framework can also be used for developing a design intelligence over a portfolio of historical apartment designs. The insights available through collecting design data in a comparable format has implications for optimising and learning from historical design, as well as introducing the ability to integrate machine learning and predictive analytics into the designers workflow.

6. Future Work

Future work will involve both optimising and developing more design criteria based on industry feedback. The automated reporting functionality will be tailored to not only meet the SEPP 65 requirements, but producing other automated reports to meet national and international legislative requirements such as the National Construction Code. Once there are sufficient datasets, the next stage of research will explore the possibilities of machine learning and implementing predictive analytics in the design phase to pull insights from real estate, market preference and property valuation.

References


Always New Performance Based Design

Ise Shrines as a Model for Future Architecture

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Abstract: In Japan, a radical experiment has been going on for more than one thousand years: wooden structures are built and dismantled every twenty years in an ongoing renewal process without a known beginning or end. We will look into the Ise shrines not as buildings but as genetic sequences or generative lines of code. As living organisms that change through time, that... emerge, age, decay, emerge... living organisms that have an exact understanding of their importance and impact in a much wider system. A renewable system carefully planned for long term resilience. A large widespread system that expands through all Japan. A system that has a long term strategy that resists becoming part of other global systems. A system that trades short term benefits for long term security. A system that changes and adapts through the years sometimes trying to be forgotten, sometimes trying to be embraced by the population. Ise in its humble scale and lack of ornamentation is as relevant for our future as it was thirteen hundred years ago.

Keywords: Ephemeral architecture; system; generative architecture; permanence.

1. Introduction

I know not what is within. But I am in tears of gratitude. Sigyo XII Century

The Shinto Priests were told to build shrines that would last forever. They relied on wood based construction techniques and the available material was the Japanese cypress Hinoki. How can permanence be designed with such an ephemeral material? It is easy to understand processes from nature such as growth, de-growth, decay, renewal, generation, symbiosis, and so on. It is far more difficult to implement them as architecture. In the West, architecture is understood as permanent. Structures are built as solidly as possible. It is considered that the greater the mass of a building, the longer it will last. Today we can see the ruins of the Parthenon made of its original stones - even though it was rebuilt multiple times (Ford, 1997). In Ise, the wood’s natural lifespan and processes of growth and decay are not only accepted but are embraced as part of the design. A design that looks into processes from nature and integrates them into a renewable system.
A system that becomes a performance stage for characters, visitors, nature, architecture and absent entities to perform seamlessly together. A system designed as a veiling mechanism. A mechanism that enables us to see just enough, that lets us project our own expectations about what we cannot see. A system where the physically built presence is not the most important. A system designed above all to contain charged voids and important absences.

We live in a finite world with an overgrowing population. Architecture has a high influence on our quality of living. It consumes vast amounts of the earth’s limited resources. It is expensive, of slow execution and its execution requires a large number of people. Architecture has to be thought as something that lasts a long time. That ages, that has a surrounding that also ages and changes. Architecture is always part of a wider interconnected system. One should not produce a building without thinking about the wider consequences of the systems that all the parts of the building belong to. Systems that together allow for the existence of human beings in a delicate balance. Climate related long term catastrophes, over population, uncontrolled consumption, disregard for humans and non-human’s environments, food and water supply constraints, artificial intelligence, massive migrations, cultural tensions, raising inequalities, extremist groups and unannounced acts of random violence are unprecedented challenges that are all connected. Looking at Ise as an example, we can find lessons in careful design, extreme long term planning, management of a complex systems, and user centric strategies.
2. Architecture as a genetic sequence/generative line of code

There are two main shrines in Ise: Gekū and Naikū. Every twenty years new shrines are built next to them. For a brief moment in time the old and new shrines coexist. A ritual of passage where the resident gods together with sacred objects are moved from the old shrines to the new ones. After this ritual, the old shrines are dismantled leaving empty plots (Tange, 1965). The shrines have already been rebuilt 62 times and the next rebuilding will be completed in 2033. They cannot be compared to traditional western buildings. They are sets of instructions designed to achieve permanence through ephemerality. The shrines might look like exact copies of the old ones, but they are not (Isozaki, 2011). Minor changes are made, as in a family tree, a genetic code or a generative software that allows only minor variations. For instance, it is believed that there used to be only two fences around the shrines instead of four (Horiguchi, 1973). The new shrines are not exact copies of the original, they are also not replicas - understood as inferior copies. This process supposedly started around 4 BCE, but the first documented version of the shrines is from the late 7th century. Documentation of the origin cannot be found. This erasure of the origin is another reason to consider the last built as the only possible original. By not knowing exactly when the process has started we have to accept it as a continuum. A shrine that was new before our existence and will be new after our existence. The most recent built is simultaneously the original and new. The repetition of relocation and rebuilding preserves identity over time (Inagaki, 1976).
3. Embracing Ephemerality

The Shrines are based on the design of ancient rice granaries - Elevated platforms with thatched roofs that guarantee that the rice is kept dry. The wooden posts made of Hinoki are sunk directly into the ground. The construction is made without nails or glue. Only minimal waterproofing is applied to some exposed log ends but overall the wood is left untreated. It is known that already in the 7th century, this construction method was anachronic (Isozaki, 2011). In Japan, there were already palaces and Buddhist temples with stone foundations and ornamental brackets supporting heavy tiled roofs. By not having thatched roofs and avoiding contact between wood and the ground’s natural humidity, this building technique allowed more permanent structures. We can only assume that using this less permanent methods was a decision. Not only for a more archaic ethos but also an acceptance of the Hinoki’s limited lifespan, growth and decay. An embracement of impermanence.

4. Buildings as Living Structures

As in traditional rice granaries the shrines roofs are thatched. The shrines walls are made of piled logs that naturally have small gaps between them. In autumn when it starts raining the roofs become soaked and heavy. This weight forces the gaps in the walls to close leaving the interior sealed and dry. When spring arrives the roof becomes dry and light again. The heat reduces the humidity on the walls making wood contract and gaps appear again, allowing ventilation. The shrines not only change every twenty years, they also change every season.

On the way to the shrines, we can see Tamagushi - small branches from sakaki trees decorated with shide possibly made of white silk. These branches - still with green leaves - are hanging, sometimes from the living Hinoki - trees, sometimes in the new activated life of the Hinoki - fences. One cannot but associate the juvenile branch next to the full grown tree with the new and old shrines that will for a brief period in time be present next to each other. The shrines are not only wooden structures with no monumental scale or elaborate ornamentation. They are designed as living structures with a deep understanding of the seasonal changes of the Hinoki. The material’s limited lifespan is not only accepted; it is part of the design process that includes rituals to exaggerate its ephemerality.

5. A Renewable System

The shrines are not only designed as living organisms, they are part of a wider interconnected system. In Ise there are 125 Shinto shrines built around the two main shrines. Every twenty years Naikū and Gekū are dismantled and their parts distributed to a network of shrines all over Japan. 18000 shrines belong to this network (Motegi, 2006). From the 125 shrines in Ise, around 16 are rebuilt every twenty years together with the wooden bridge on the Isuzu river and Torii gates. Another 46 shrines are rebuilt every forty years. The Hinoki is present not only as building material for shrines, bridges and gates but also in the trees around shrines - sometimes supporting shrine fences - and other elements such as spoons for washing, food storage boxes, and so on. This process requires twelve thousand Hinoki logs, most of them cut from 200-year-old trees (Hvass, 1998). The shrine secretariat Jingu Shicho manages the 200-year time scales of the forest to guarantee enough available wood for future reconstructions. Hinoki logs are transported by floating them down adjacent rivers. Each main shrine has two main pillars - eleven meters tall from 400-year-old trees. After twenty years these pillars are relocated and reconstructed as the two
Torii gates on Uji bridge. After another twenty years, they are again reconstructed as Torii gates at Shichirino-Watashi and Seki-no-Oiwake. The population of the entire region participates in the reconstruction through rituals and ceremonies as for instance the Oshiraishi-mochi where people pick up, wash and pile up white pebbles to be put on the shrine’s ground. The carts that transport the pebbles and logs from the river to the shrines are pulled by the local population in lively festivities.

In the reconstruction of the shrines, only traditional tools are used. This way the technology for the reconstruction is already guaranteed - there is no need for experimenting new assembling tools, new materials or techniques. By avoiding experimentation, the risks normally associated with building construction or maintenance are reduced. The Ise shrines were used multiple times as an example to change the procedures for acceptance as UNESCO patrimony (Sand, 2015). Interestingly they were never proposed to be accepted as such. For survival, they strongly rely on their own network. If they were proposed as UNESCO patrimony, they would become “patrimony of all world citizens”. This would be a shift, a change. It is exactly by resisting change that Ise anchors its resilience. Ise changes but it only allows its own internally defined changes. By allowing dismantlement and reconstruction, small changes in design, small changes in rituals, by avoiding dependency on external networks of support, Ise remains alive and relevant. Let’s for a moment try to imagine that today the Parthenon’s appearance was as new, and lively festivals and rituals would happen around it as they happened when it was first built. To imagine this is an almost impossible exercise. But it is exactly what happens every day at Ise. Ise shrines, priests, rituals calendar, local population, forest, rivers, network of shrines throughout Japan, traditional tools, proven building technologies and sacred objects become one single renewable system that is managed as a whole. Without one item, the whole system would collapse and not be able to be replicated every twenty years.

6. Important Absences

At Ise absences are designed. The Torii gates that define the limits of the sacred territory are no more than a sign - no walls, no fences. The Tamagushi (fig.2) are not on display for us. They are offers for an unseen deity. It is in the physical presence of the Tamagushi that we think about the unseen, non-physical entities. During pilgrimage, people leave the middle of the paths empty for the deity to move through freely. There is no “main space” for visitors as in the navel of a gothic church. We stay between nature and fences. (fig.3). The main spaces inside the shrines are designed at the human scale but not visible - they are voids for absences (Koolhaas and Obrist, 2009). For the gods that reside on them, without windows or natural light. The relocation ritual from the old shrine to the new one is not announced. It is performed in secrecy and in darkness. This ritual Shikinen Sengu, (fig.4) most probably a real and tangible experience cannot be visually confirmed. This way, it is elevated to a non-confirmed existence - the same status that is attributed to the Shinto gods that reside in the shrines. By doing so they are not only elevating a physical experience to a spiritual one, they are also making the spiritual experiences more credible.
7. Charged Voids

When arriving closer to Gekū, first we see Kodenchi the adjacent site (fig.1). It is a vast void, a rectangle perfectly defined by its emptiness, the different material of its ground and the two lanterns that mark a possible future entrance. There is only a very small structure in the middle. This vast empty plot has a powerful effect on the viewer. Not only for its spatial qualities - the only opening among the dense forest - but also for its past - the shrine and sacred treasures used to be here - and its potential future - the shrine and its sacred treasures will be here again. Looking at the void, we are looking at an absence - nothing is there. We stare where we weren’t allowed to look when the old shrine was present and where we will not be allowed to look when the new shrine is built. A charged void of the utmost importance, an emptiness that carries the past and the future while sitting next to the present - the tangible built current shrine next to it.

Looking at the fence right next to the empty site, we can see part of the shrine roof where the sacred treasures are today. We can only suppose as we cannot see the sacred treasures or even the shrine in its whole. When we go through the fourth fence we cannot see anything again. We know that the shrine is behind it. We can almost sense its mass through the delicate white silk screen, but here we cannot see it. We stay in absolute silence waiting to see the contours of the shrine through the screen.
Nonetheless, it doesn’t happen. We can only sense its presence. By walking away from the screen, we can see again parts of the shrine roof over the third fence. Through nonlinear openings on the second and first fence it might - or it might not - be possible to see parts of the shrine walls - it is not clear what exactly we are seeing. It is precisely in these designed indefinities that the strength of the experience lies.

8. Performance Architecture

By looking to our left, we understand that the whole time we were in front of the white silk screen trying to glimpse the shrine, we were being observed by a priest that sits in the silent semi-obscurity of a small pavilion. The sound of our steps on the small loose stones announces all our movements. We are now behind the third fence. Here we are as close to the shrine as we will ever be. A woman dressed in black arrives. The priest has already changed position and is now waiting for her. She signs a book and a ritual starts. The priest closes the book and goes to the back side of the pavilion. Here he opens a fence door for the woman and lets her into an intermediate space between fences - not through the white silk screen. After a ritual where the priest lays white rice on the path, he lets the woman walk all the way between two fences until she arrives on the middle side of the plot. Here he opens another fence door and they walk, struggling to stand still, as the stones here are larger and loose. The priest leaves the woman in the void between the second and third fences. She is standing behind the second fence - seeing almost the same as us standing behind the third fence. But she is closer. She is closer and for her, that is enough.
Everything is designed to allow these performances to happen. There is no separation between stage and audience. Priests, visitors, nature, architecture are all integral parts of the performance.

9. Conclusion

Some architects say that they find inspiration in Nature for their designs. Some create nature inspired forms that are no more than a skin over traditional orthogonal structures. This designs create increasingly complex forms that are extremely difficult to build. Nature is understood as a fixed image, there is no understanding of any type of nature’s processes.

Another category of projects inspired by nature are the ones where ordinary buildings have a prominent green element, such as green facades, trees on balconies, green rooftops, and so on. This eventually can be an advantage for the project: living elements might relate to interior spaces and make them better, performance gains might be achieved by reducing thermal exchanges with more insulation - as in green rooftops - or solar exposure might be reduced in summer and increased in winter by the placement of trees that lose their leaves over the seasons. However, most of the time the green element is again no more than an image. For instance, there are multiple examples of green elevations made of living organisms where the environmental costs of watering make it less sustainable than if it was simply made of an inert material such as cork.

What can we learn with the Ise shrines and how can they be used as a model for future architecture?

• Vernacular architecture has provided solutions that have been tested and proved correct over long periods of time. It should be studied, embraced and adapted into contemporary solutions.
• Buildings should change and adapt, reacting to each season’s climatic conditions.
• Careful long term planning: Buildings, cities and landscapes should be designed considering timelines that span thousands of years - not decades.
• A decreased selection of building materials can lead to more knowledge about the building material sources. In today’s worldwide interconnected construction industry, materials come from an increasing variety of sources in different countries. By having a large quantity of different building materials, it is impossible to control or to be knowledgeable about the sources. Sometimes material sources can work in less ideal situations where workers are exploited, environmental impacts are ignored, and materials are contaminated with toxic or lower quality elements and so on. By reducing the variety of materials used, we are further reducing the number of material sources. If there is interest, this can make the process of obtaining information on the sources simpler.
• A reduced selection of building materials allows a more focused research and development strategy. This can potentially lead to advances in construction techniques, fabrication processes and materials performance.
• It is important to include people when planning for important buildings. By considering how people can be part of the building’s future life - through festivities, rituals, celebrations or other uses - the building has a higher chance of permanence through time. Multiple recent failed examples such as the Expo’ 92 Seville buildings, the Euro 2004 stadiums in Portugal or the Expo 98 Portuguese Pavilion have not been planned with a consideration of how the population would participate in the long term.
• The consideration of user-interaction within buildings can be more important than the design of form and materials.
• When designing a proposal, it is important to remember that the non-tangible can have the same importance as the tangible. Voids, absences and memory can play a significant role in a building design. Examples are the Ise shrines and also Wang Shu’s Ningbo Museum with its walls made of recovered tiles and bricks from the village that was destroyed for the museum to be built.

• Nature can be considered to be an integral part of the design. Defining spatial qualities of enclosure and openness, static and dynamic, voids and mass, veil and screen. Nature can be real, alive and healthy and still perform in designed architectural qualities. Not as mere decoration but performing as any other architectural material.

In Ise we have a radical experiment where a human creation is copying nature’s processes. Where a wider system needs to be carefully managed to guarantee Ise’s resilience through constant regeneration. Where one cannot define where nature ends and architecture starts. Ise in its humble scale gives us a lesson in long term planning. In a world with limited resources and an overgrowing population, Ise’s example is as relevant today as it was thirteen hundred years ago.

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Abstract: This study aims i) to characterize the ratios of bioaerosol levels in a meeting room to outdoor levels and ii) to investigate the impact of two factors, air-conditioning and mechanical ventilation (ACMV) operation status and human occupancy, on time-resolved relationship between indoor and outdoor bioaerosols. Using an ultraviolet-light induced fluorescence (UV-LIF) technique, we measured number concentrations of total aerosol particulate matter (tPM) and fluorescent biological aerosol particles (bioPM) (1.0-3.0 μm and 3.0-5.0 μm diameter) in an office and outdoors, sampling with 1-min resolution. The air-conditioning and mechanical ventilation (ACMV) system equipped with high-grade filters was effective in controlling both tPM and bioPM indoors. As expected, removal efficiencies were found to be size dependent. One human subject walking on the carpet was found to be a strong contributor to bioPM, resulting in 2-3 times higher concentration than that outdoors. Compared to the times when the room is vacant, the biological proportion of total airborne particles increased by an order of magnitude during the light walking period. Consequently, indoor-to-outdoor ratios depend on the ACMV operating conditions and on human activities. This pilot study provides preliminary data concerning the bioPM levels in an indoor environment equipped with an ACMV system. Ongoing investigations using this approach promise to improve our understanding of the processes that influence indoor bioaerosol levels and the effectiveness of control alternatives.

Keywords: Bioaerosol; real time; indoor-to-outdoor ratio; human occupancy.

1. Introduction

Bioaerosols are airborne particles that contain living organisms or were released from living organisms. They contain biologically active bacteria, spores, viruses, toxins, and other similar material. As summarized in a review work (Nazaroff, 2016), there are many reasons to be interested in indoor bioaerosols: (i) Humans spend most of their time indoors, and bioaerosols are abundant in the built environment, (ii) bioaerosols play important roles influencing public health, and (iii) the goal of improving bioaerosol management can influence building operation strategies. Quantification of bioaerosol
concentrations and the influencing processes is valuable for multiple applications within the indoor environmental sciences.

Several recent studies have employed DNA-based approaches to examine airborne biological particles in a variety of indoor spaces (Hewitt et al., 2012; Hospodsky et al., 2015; Yamamoto et al., 2015). These studies have revealed that human occupancy and activities increase the abundance of bioaerosols and also leave human-associated taxa in the built environment. However, this approach is not well suited for studying short-term dynamic processes that might influence the concentrations and fates of bioaerosols indoors. Compared to DNA-based method, new developments in ultraviolet-light induced fluorescence (UV-LIF) measurement technique provide the capability of real-time detection of biological aerosol particles. This UV-LIF technique provides opportunities in various applications, such as in laboratory studies (Healy et al., 2012; Toprak and Schnaiter, 2013) and in outdoor areas (Gabey et al., 2010; Huffman et al., 2010; Crawford et al., 2014). The studies that using UV-LIF measurement to investigate bioaerosols in indoor environments are limited. Two examples, Bhangar et al. (2014) and Handorean et al. (2015) characterized fluorescent biological aerosol particle levels in a mechanical ventilated classroom and a hospital, respectively. Office is an environment where working adults spend most of their days, yet its concentrations of biological aerosol particles are not well characterized. In addition, to date, there are no studies utilizing UV-LIF to investigate the time-resolved relationship between indoor and outdoor bioaerosols.

Previous research (Toprak and Schnaiter, 2013; Healy et al., 2014; Hernandez et al., 2016) has demonstrated that airborne spores, bacteria, pollen, and their fragments are detected by the UV-LIF technique. It is worthwhile to note that it possesses some inherent limitations. The fluorescent particle concentrations represent the lower-limit estimate of the abundance of primary biological aerosol particles (Huffman et al., 2010; Pöhlker et al., 2012; 2013). The UV-LIF technique may support discrimination between broad bioaerosol categories (spores, bacteria, pollen) (Healy et al., 2012; Hernandez et al., 2016); however, it cannot provide information at level of genus or species as can DNA-based analysis methods.

The design of the present study was motivated by the context summarised above. Specifically, i) efforts on quantifying bioaerosol concentrations in built environment is warranted owing to the increased concern on indoor bioaerosol and its associated health impacts; ii) the new development of UV-LIF technique offers the opportunity to capture the temporal pattern of bioaerosol dynamics; and iii) the factors influencing indoor bioaerosol concentrations are not well characterised. To contribute new knowledge and inform building operations, the specific aim of this investigation is i) to characterize the ratios of bioaerosol levels in a meeting room to outdoor levels and ii) to investigate the impact of two factors, air-conditioning and mechanical ventilation (ACMV) operation status and human occupancy, on time-resolved relationship between indoor and outdoor bioaerosols. The results of this work are of potential use to improve the prediction of bioaerosol concentrations in built environment. The work also contributes to a better understanding of the human activities and ACMV system as influential factors to indoor bioaerosols, which could improve the building design and operation.

2. Methods

A meeting room with carpeted flooring and a central air conditioning and mechanical ventilation (ACMV) system in a university building in western Singapore was selected as the study site. The room volume was ~150 m$^3$ based on physical dimensions (length × width × height = 7.52 m × 6.95 m × 2.75 m). It shared ACMV ducts with nearby offices and labs. The ACMV system was a central forced-air system with integration of outdoor air intake and indoor air recirculation. The ACMV system operated from 8:00 to
22:00 every day. The room air-exchange rate (AER) was 2.6±0.3 (mean ± sd) per hour when the mechanical ventilation system was on. The supply air to the room, which comprised about 90% recirculated air and 10% outdoor air (according to ACMV design), was filtered with MERV 13 filters that were replaced every 3-6 months. When the mechanical ventilation system was off, the infiltration and leakage caused the room AER to be 0.7±0.03 per hour. The AER was evaluated through sulphur hexafluoride (SF6) tracer decay tests. The mean value and standard deviation of AER was determined from analysing three SF6 decay tests (5 hours of data for each test when the ACMV system was on, 12 hours of data for each test when the ACMV system was off).

Observational monitoring was conducted for 6 days (labelled D1-D6). The room was unoccupied during the monitoring period except 13:00 to 16:00 on D3-D6. One human subject performed light walking during the occupied period. The human subject was doing typical office work in another indoor space before the scripted experiment. Biotrak (Model 9510-BD; TSI, Inc.) was used to measure time-resolved number concentrations of tPM and bioPM in two particle-size ranges (1.0-3.0 μm and 3.0-5.0 μm). The device was configured to sample air during 40 s out of every 1 min. The sampling flow rate was 28 L/min. We took measurements indoors and outdoors by using tubing and an auto-switch device. The frequency of switching between indoor and outdoor samples was once per four minutes. The indoor sampling inlet (S1) was placed at the centre of the study room, at a height of 1.2 m. Outdoor air (S2) was sampled via an inlet protruding from a window to the outdoor corridor.

Figure 1 illustrated the experimental design for the monitoring. The red arrows stand for the sampling point S1 and S2 through turbines. The black arrows illustrate the particle dynamics in indoor environment. They are i) particle gain due to air infiltration \((Q_L \times C_O \times \rho)\), contribution from mechanical ventilation system \([Q_M \times (1-\eta_M)]\) and emissions due to human activity \((E)\); and ii) particle loss due to filter removal \((Q_R \times \eta_R, \eta_R = 0 \text{ in this work})\), deposition \((C \times \beta)\), and air exfiltration \([(Q_L + Q_M) \times C]\). The descriptions of abbreviations were noted in Figure 1.

![Figure 1: Schematic diagram for experimental design. The C and C_O are indoor and outdoor particle concentrations, respectively. The Q stands for the air flow. Its subscripts L, M, and R correspond to infiltration, mechanical ventilation, and recirculation. The \(\eta_M \) and \(\eta_R \) are the particle removal rates of ventilation and recirculation filters, respectively. The \(\rho \) and \(\beta \) are particle size-dependent infiltration and deposition loss rates, respectively. The E is particle emission due to human activities.](image)

Calibration testing of aerosol losses in the tubing and auto-switch device was conducted before the monitoring period. For this purpose, the sampling inlets were collocated for 5 hours in an outdoor
environment at a height of 1.2 m. We added a third sampling inlet (S3), which didn’t connect with any tubing or switch device. Sample S3 was designated as the reference case. The objective was to adjust data from S1 and S2 to match as closely as possible the response of the S3, so as to offset the aerosol losses during transport from the point of sampling and the point of measurement. Table 1 summarized the calibration factors specific to S1 and S2.

Table 1: Calibration factor (mean ± sd) for sampling point S1 (indoor) and S2 (outdoor).

<table>
<thead>
<tr>
<th>Particle size</th>
<th>1.0-3.0 µm</th>
<th>3.0-5.0 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>tPM</td>
<td>bioPM</td>
</tr>
<tr>
<td>S1</td>
<td>0.95±0.07</td>
<td>0.80±0.15</td>
</tr>
<tr>
<td>S2</td>
<td>0.94±0.07</td>
<td>0.79±0.11</td>
</tr>
</tbody>
</table>

3. Results

Figure 2 showed the time series plots of the tPM$_{1.0-3.0}$ and bioPM$_{1.0-3.0}$ concentrations measured outdoors. Noting that the concentrations are plotted on different scales — a larger scale (million particles per m$^3$) is applied to tPM$_{1.0-3.0}$ compared to the scale (thousand particles per m$^3$) used for bioPM$_{1.0-3.0}$. We can observe high variation across monitoring days. The concentrations measured on D1 is about 2× the values recorded on D6. The significant variation is true for both tPM$_{1.0-3.0}$ and bioPM$_{1.0-3.0}$ concentrations.

Figure 2: Time series data for the number concentrations of total particles (tPM, top frames) and biological aerosol particles (bioPM, bottom frames) in the diameter range 1.0-3.0 µm measured outdoors on (a) day D1 and (b) day D2. The measurement date and sampling point were noted on the top left and top right of each frame, respectively.

Figure 3 presented the time-series concentrations measured in the selected office for total (top) and biological (bottom) aerosol particles. Similar to outdoor concentration plots, the scale for total aerosol
Relationship between Indoor and Outdoor Fluorescent Biological Aerosol Particles

particles is one magnitude larger than the scale used for bioaerosols. We can observe consistent pattern between tPM\(_{1.0-3.0}\) and bioPM\(_{1.0-3.0}\) for both occupied and unoccupied period. The concentration reduction and peak can be associated with the operation of ACMV system and human activity, respectively.

Figure 3: Time series data for the number concentrations of total particles (tPM, top frames) and biological aerosol particles (bioPM, bottom frames) in the diameter range 1.0-3.0 µm measured in (a) unoccupied office on D1 and (b) occupied office on D4. The measurement date and sampling point were noted on the top left and top right of each frame, respectively.

4. Discussion

Comparing outdoor tPM with outdoor bioPM in Figure 2, the concentration profile for bioPM didn’t always follow the broad trends of the tPM, implying that their sources were time dependent and the composition of tPM was changing at different times of the day. The biological proportion of total airborne particles (BPTP) of outdoor particles in the 1.0-3.0 µm and 3.0-5.0 µm diameter range were 0.14±0.12% (mean ± sd) and 0.82±0.68%, respectively, during the monitoring period.

The ACMV system served as an important indoor/outdoor air exchange pathway. The ACMV system equipped with high-grade filters effectively reduced the indoor aerosol concentrations. As shown in the concentrations plots for indoor environment (Figure 3), the concentrations for both tPM and bioPM dropped significantly as soon as the ACMV system was turned on at 8:00, indicating the effectiveness of this removal mechanism.

The presence of a human occupant is an important factor for both indoor tPM and bioPM. Figure 3(b) shows a significantly higher indoor concentration occurring at 13:00-16:00 on D4, which coincides with a designated light walking period. The probable causes of the observed peaks are resuspension of tPM and bioPM from the carpet and shedding from the clothing, hair or skin of the occupant. The indoor/outdoor (I/O) ratios for bioPM (2.1 for 1.0-3.0 µm particles, 3.3 for 3.0-5.0 µm particles) were significantly higher than the values for tPM (0.10 for 1.0-3.0 µm particles, 0.33 for 3.0-5.0 µm particles) (Table 2), which
indicates that walking on the carpet makes a stronger contribution to bioPM than to tPM. The time-averaged BPTP indoors was 1.9% and 5.6% for the particles in the size range 1.0-3.0 µm and 3.0-5.0 µm, respectively, higher than the BPTP estimated for unoccupied periods by one order of magnitude. This result further substantiates the important role of human activities contributing to bioaerosols indoors.

Table 2 and Table 3 summarized the results for 1.0-3.0 µm and 3.0-5.0 µm particles, respectively. Overall, across the six monitoring days, the time-averaged outdoor concentration of total airborne particles in the 1.0-3.0 µm (and 3.0-5.0 µm) diameter range was 4000k/m3 (150k/m³); the value for biological aerosol particles was 3.2k/m³ (1.1k/m³). The indoor concentrations were less than a quarter of the outdoor concentrations when the room was vacant. During occupied times, the average indoor-outdoor (I/O) ratios for bioPM were higher than the value for tPM by a factor of 20 for 1.0-3.0 µm particles and by a factor of 10 for 3.0-5.0 µm particles. These higher ratios indicate that the particles resuspended from carpet and/or shed from occupants were strong determinants of indoor bioPM levels.

Table 2: Time-averaged particle number concentrations (PNC) of total airborne particles (tPM, 1000 particles per m³), biological aerosol particles (bioPM, particles per m³), and indoor-to-outdoor concentration ratios (I/O) in the diameter range 1.0-3.0 µm.

<table>
<thead>
<tr>
<th>Condition</th>
<th>ACMV off, unoccupied</th>
<th>ACMV on, unoccupied</th>
<th>ACMV on, occupied</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>tPM (×1000) bioPM</td>
<td>tPM (×1000) bioPM</td>
<td>tPM (×1000) bioPM</td>
</tr>
<tr>
<td>Indoor</td>
<td>PNC</td>
<td>508</td>
<td>662</td>
</tr>
<tr>
<td></td>
<td>I/O</td>
<td>0.12</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>t(h)</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Outdoor</td>
<td>PNC</td>
<td>4102</td>
<td>3190</td>
</tr>
<tr>
<td></td>
<td>t(h)</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

Table 3: Time-averaged particle number concentrations (PNC) of total airborne particles (tPM, 1000 particles per m³), biological aerosol particles (bioPM, particles per m³), and indoor-to-outdoor concentration ratios (I/O) in the diameter range 3.0-5.0 µm.

<table>
<thead>
<tr>
<th>Condition</th>
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<th>ACMV on, unoccupied</th>
<th>ACMV on, occupied</th>
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<tbody>
<tr>
<td></td>
<td>tPM (×1000) bioPM</td>
<td>tPM (×1000) bioPM</td>
<td>tPM (×1000) bioPM</td>
</tr>
<tr>
<td>Indoor</td>
<td>PNC</td>
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<tr>
<td></td>
<td>I/O</td>
<td>0.06</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>t(h)</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Outdoor</td>
<td>PNC</td>
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<td>1387</td>
</tr>
<tr>
<td></td>
<td>t(h)</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

5. Conclusions

The real-time tPM and bioPM monitoring instrument is a useful tool, with the potential to provide important insights linking indoor environments with building operation. The number concentrations of
tPM and bioPM of the particles in size range 1.0-3.0 µm and 3.0-5.0 µm in an unoccupied meeting room was lower than the outdoor level by one to two orders of magnitude. It is also worth noted that the I/O ratios in the unoccupied room reduced significantly when ACMV system was operating. The reduction can be attributable to particle removal effect provided by high grade filters and reduced outdoor particle penetration due to pressurization of indoor environment. Activity of human occupants was an important source for tPM and bioPM. Light walking resulted in a 2-3 times higher indoor bioPM concentration than that outdoors. Data indicate that the biological proportion of total airborne particles was one order-of-magnitude higher during light walking, compared to times when the room was vacant. Further investigations with real-time UV-LIF instruments have the potential to inform deeper understanding of indoor bioaerosol dynamics.

The experimental procedure undertaken here could fruitfully be applied to explore additional aspects of indoor bioaerosol dynamics: i) other factors that are expected to influence indoor concentrations (e.g. air exchange rate, human activity intensity, etc.) and ii) the efficiency of control strategies (e.g. building air filters, air purifier, etc.). Given the limitation of the UV-LIF technique specified in introduction, it is also valuable to explore the collaborative work with DNA-based methods. Coupling two measurement approach can usefully evaluate to what extent and what type the UV-LIF technique captures the biological components in the air of built environments.

Acknowledgements

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Ventilation for Reduced Heat Stress in Apartments

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Abstract: The increase in building code requirements of modern buildings are correlated with increased overheating, particularly in apartment buildings. This research addresses the comparative performance of the Australian apartment stock with international heat wave regulations, six apartment buildings were performance modelled based on the extremes of the 2009 Victorian heatwave that began on the 27 January with daytime temperatures topping 43°C across 3 days, with night-time minimums of above 25°C. All 6 apartments failed the four international summer comfort standards that were reviewed. The worst performing apartment underwent further investigation. Retrofit strategies were tested to determine the most effective method for reducing overheating. As found in the literature, improved ventilation is often the most effective retrofit method. Further investigation revealed that ventilation opportunities are significantly restricted by the Australian NCC window protection requirements that restrict window openings, reducing typical ventilation area from a window from 50% to 20%. This has a significant impact on the ability to use natural ventilation for reducing of overheating in apartments.

Keywords: climate change; heatwave; comfort; apartments.

1. Introduction

Everyone has the right to live well, living in a place that is safe and comfortable. As we move into the uncertainty of climate change the increase in weather extremes, excess heat in Melbourne is expected to have significant negative impacts on comfort for existing apartments. People in homes that do not have cooling systems are facing potentially higher health risks. Further, if there are infrastructure failures and there is absence of energy for cooling even more people will be at risk. This was the situation in 2003 when France had a deadly heatwave; their authorities responded by regulating that all homes need to be comfortable for 5 days in “free running mode” (without heating or cooling).

In the original study, six apartment buildings (including low and high-rise, old and new, minimum standards and best practice) were modelled for their performance based on the extremes of the 2009 Victorian heatwave that began on the 27 January with daytime temperatures topping 43°C across 3 days, with night-time minimums of above 25°C (BoM 2016a). The research showed that all of the apartments tested failed to comply with 4 different international ‘summer comfort’ standards. This research builds...
on the previous study by looking at retrofit strategies using computer modelling, with specific emphasis on natural ventilation to determine possible improvement pathways.

2. Literature Review

2.1. Heat Waves

According to the last State of Climate report (State of the Climate, 2016), the duration, frequency and intensity of extreme heat events have increased across large parts of Australia, as well as globally. During the 2003 European heat wave, France claimed over 14800 excess deaths (Fouillet et al., 2006) due to heat stress. Following this extreme heat event, France, which shares the same temperate oceanic climate (Cfb) with the Australian southern east coast, based on the of the Köppen-Geiger climate classification (Peel et al., 2007), decided to integrate a new requirement into their building code called “summer comfort”. It is now a requirement of the French Building Code to design buildings able to maintain a “comfortable” indoor temperature during a heat event without help of active systems such as air conditioners. Similar standards are now in place in other countries including the UK and the U.S. Despite this global movement, there is no common standard or calculation methods to define summer thermal comfort parameters, which consider multiple variables such as air temperature, mean radiant temperature, humidity, air velocity, metabolic rate and clothing insulation. Instead each standard has individual specific criteria used to determine compliance.

As well as introducing the new requirements, France started to review their Social Housing Stock (SHS) and supported by architects such as LAN6, Druot and Lacaton et Vassal, innovative solutions have been implemented using prefabricated glazed facade modules. As well as preserving and extend the life of buildings, it also improve their thermal performance and therefore reducing energy and carbon emissions, while also improving the aesthetic of the facades and ensuring resilience against heat events.

2.2. Overheating

Overheating criteria was developed as early as the 1980’s for building performance analysis but countries used different criteria (for a summary see Cohen, Munro, & Ruyssevelt, 1993). Despite the absence of an exact definition of overheating, the international thermal comfort standards such as ISO 7730, ASHRAE Standard 55, and the EN 15251 European Standard have commonly defined overheating as when “the level of indoor temperature exceeds a maximum comfort temperature, and this, over a defined length of time”. By contrast, Heat Stress is a term used to define the physiological state in which a human body is no longer able to cool itself satisfactorily. This maximum comfort temperature varies according countries, function of buildings, rooms in buildings, time of the day, and if buildings are conditioned or not. For examples the British CIBSE Environmental Design, Guide A recommends a maximum temperature of 28°C for living room and 26°C in bedrooms for less 1% of running time annually, while also allowing this maximum temperature to rise up to 31°C when using adaptive comfort approach (variable comfort temperature dependent on occupant behaviour and clothing) for buildings in free running mode (Dengel & Swainson, 2012).

Despite being a continent of extreme heat waves, there is currently no comprehensive requirement for building summer comfort in Australia. The 2016 NCC which incorporates the Building Code of Australia (BCA) allows for energy efficiency measures in all classes of buildings (Australian Building Codes Board, 2016). Volume 1, (class 2-9; apartments are class 2 & 4, and 3 & 5-9 are the commercial classes) considers
the building envelope and the services with regards to energy efficiency. There is no consideration of thermal comfort or overheating. Despite the energy requirements of these buildings being addressed by energy modelling software, additional modelling for thermal comfort would be required in addition to current requirements thereby representing additional costs to do so.

Table 1. Comparison of Maximum Temperature for summer comfort per nation and standard.

<table>
<thead>
<tr>
<th>Country</th>
<th>UK</th>
<th>France</th>
<th>Germany</th>
<th>USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation</td>
<td>CIBSE</td>
<td>NF HQE</td>
<td>Passivhaus</td>
<td>ASHRAE Std 55-2013</td>
</tr>
<tr>
<td>Indoor Temperature for Summer Thermal Comfort</td>
<td>28°C in Living areas. Not exceeded &gt;1% of annual operation time</td>
<td>28°C not exceeded for &gt; 3% of annual operation time</td>
<td>25°C to be met in all living areas, no more than 10% of hours in a year over</td>
<td>Predicted Mean Vote (PMV) under 0.5</td>
</tr>
</tbody>
</table>

2.3. Retrofit Opportunities

At the same time that France introduced summer comfort to its National code, they also started to review their Social Housing Stock (SHS) and implemented innovative solutions using prefabricated glazed facade modules. This strategy preserves and extends the life of buildings, and also improves their thermal performance and ensures resilience against heat events (Affordable Housing Hub, 2016). By avoiding the destruction of elderly SHS, extending their initial layouts and making them energy efficient, this retrofitting solution has proven to be cost effective and well received by the community (Rahola et al., 2014). With the target to renovate 800,000 of the most energy inefficient SHS by 2028, the French government offers financial support ranging from tax deduction to zero interest loans (Fawcett et al., 2013). France is not the only nation to invest in retrofitting its SHS, this is a global trend around the world. In Germany for example, the renovation of 13000 apartments of the vast housing complex Märkisches Viertel in Berlin is about to be completed with an estimated cost of 480 million euros (690 million AUD) (Nordregio, 2011). A 2012 Deutsche Bank study revealed that every $1million invested in energy efficient retrofits of affordable housing, $1.3 million was generated and $3.9million energy savings were achieved in energy savings and increased GDP (Deutsche Bank, 2012). Social Housing is indeed a great investment however in Australia considering the big demand and the small existing stock (AIHW, 2015), most of investments are concentrated on new construction (Cranston, 2016).

2.4. Overheating in Existing Buildings / Ventilation

In 2017, Building Research and Information published a special issue on overheating in buildings, and noted that of the 12 published articles, 8 were from the UK (Building Research and Information 2017) and the remainder predominantly concerned with temperate climate regions, where retaining of winter heat is the dominant design requirement, with specific reference to the Passivhaus standard. In order to provide a summary of the research contained in this special issue, the findings generally supported the view that:

- Overheating was a significant problem in both existing stock and new buildings, including low energy buildings and generally exceed the performance requirements in the relevant standards
• Occupant awareness and operation of ventilation was poor and contributed to the overheating experienced, and in some cases were more important than climatic and location factors.
• It can be difficult to determine overheating performance using energy modelling due to the number of uncertainties (occupant, behaviour, weather events).

Research found that dwellings which had a focus on winter heat retention by thermal design requirements in temperate climates were more exposed to heat stress, resulting in reduced health and wellbeing of occupants. It is noted that with the prevalence of air conditioning overheating episodes are reduced however still occur due to equipment or electricity grid failure. Although the problem is well recognized, it is still not adequately considered in practice (Porritt, Cropper, Shao, & Goodier, 2013). This is for good reason as the rate of mortality from excess cold still outweighs that from overheating by an order of magnitude in the UK. As the climate warms, the balance of mortality due to temperature extremes will shift towards overheating from heatwaves.

The very nature of apartment design has added to the problem of overheating when compared with detached housing. The primary factors are lower ceilings, single sided ventilation, single orientation, lack of solar shading devices, and often a high ratio of glass to floor area (Baborska-Narożny et al 2016). These negative physical properties of the building are also accentuated by the propensity of apartment buildings to be inner urban, where the urban heat island effect occur. With these restrictions to apartment design in mind, retrofit strategies are significantly limited.

2.5. Ventilation Restrictions in Australian Building Code

In 2013 Advisory Note 2013-1 was issued regarding the protection of openable windows with regards to The Deemed-to-Satisfy Provisions of NCC Volume One Clause F4.6 and NCC Volume Two Clause 3.8.5.2 (ABCB 2013). The advisory note applies to windows in a habitable room including permanent openings, windows, doors or other devices which can be opened, and restrict the maximum opening to 125mm such that a young child’s head cannot pass through it. Research has shown that children are most at risk from falls from high windows when climbing on furniture such as beds and chairs, often unsupervised. Therefore, these new measures are included in the BCA to minimize the risk.

Figure 2: NCC requirement for openable window protection
Such a measure will reduce the effective openable area and therefore affect the potential of the opening for ventilation. At the time of the advisory note, the BCA has a pre-existing requirement for not less than 5% of the floor area of the room required to be ventilated. The advisory note specifically states that the ventilating area “must not be less than 5%”. Therefore, the window is not required to be always fully open; it just needs to be openable or capable of being opened. In calculating the 5% ventilation the windows physical opening area is used even without the window being able to be opened this amount. In summary, the NCC requires a restriction to openings to a maximum of 125mm, yet also calculates the effective ventilation potential of the window as the entire physical opening area. The new allowance has therefore resulted in a significant reduction in the ventilation opening area of the openings in apartment buildings.

3. Methods

3.1. Computer Modelling

Performance modelling is an exploratory and or optimisation process typically employed to improve both thermal comfort and reduce energy use through heating, cooling and ventilation. Using the latest dynamic modelling software (IES VE-Pro - BESTTEST approved), a detailed 3D model is constructed to represent the proposed building in a virtual environment. The interaction of the construction elements, glazing, climate, solar access, occupants and HVAC systems predicts real life performance and consequently allows analysis of all of the factors that dictate the final performance - of individual rooms or the dwelling as a whole. Hourly temperature data as well as solar exposure are standard outputs from this process, amongst many others. Such computer modelling is powerful in absolute terms (i.e. predicting performance with high accuracy), but is equally useful for comparative analysis. The main opportunity for this project was to look at the performance of case study dwellings compared to the international standards; and model alternate scenarios, such as for example, adding insulation and additional ventilation

3.2. Weather File Details

A special annual weather file was created (collected from the Melbourne Regional Office and was supplied by the Bureau of Meteorology) to simulate the heatwave of January-February 2009 for the modelling. The figure 2 shows the temperature fluctuations across the 3 day heat wave period. These 3 consecutive days had temperature exceed 40 °C (29th to 31st of January).
3.3. Occupancy Settings

All occupancy settings were adopted from the NatHERS Standards, which governs the energy modelling strategy in the Building Code of Australia (http://nathers.gov.au/). Of specific importance to overheating is the ventilation strategy, which varies greatly between occupants. As found in the literature review, occupant understanding of ventilation through window opening is poor. The strategy for the building ventilation was that all windows were kept closed during the heatwave period.

3.4. Case Study Building

The original study included six buildings from Melbourne to provide a representation of typical social and private apartment housing in Melbourne, with a range of ages. The results of the previous study showed that building 2 was the worst performing of the six and therefore it was chosen for the more detailed analysis into retrofit opportunities presented here.

Building 2

Building 2 is a heavy weight twenty-storey apartment building. The structure is entirely made from concrete, with concrete floors, external walls and internal partitions. The apartment tested adjoins between two adjacent tenancies and has two bedrooms, one bathroom, a separate water closet, a storage area and an open plan kitchen/living area. The apartment shares 42% of its boundary walls with adjacent tenancies. The external walls, internal partitions, floors and ceilings are not insulated. The windows are clear single glazed in standard non-thermally-broken aluminium frames. Weather stripping is quite old and only provides moderate level of draughts sealing. Some of the windows are operable, but the fenestration has not specifically been designed to take advantage of natural ventilation.

4. Retrofit Opportunities Tested

A Retrofit test was conducted to determine what simple non-invasive strategies might be useful in upgrading the existing building used in the study. Each strategy was chosen as a potential upgrade that was common or likely to have a significant effect on summer comfort. Shading of windows is a critical strategy to reduce heat gain, and has been modelled as designed for the apartment. Additional shading
was excluded from the study due to the real world restrictions in application. It is expected that shading would benefit some of the apartments, dependent on current shading, orientation, size of window, ability to operate, and location (external vs internal). The strategies that have been tested to improve thermal performance are:

- External Insulation
- Light coloured walls
- Natural ventilation

Table 2: Retrofit solutions considered

<table>
<thead>
<tr>
<th>Insulation</th>
<th>100mm of expanded polystyrene (R2.5) applied externally to the walls, to keep the thermal mass in contact with the inside air.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light coloured walls</td>
<td>Absorptance of external wall set to 0.2, and emissivity of same set to 0.9. This would mimic painting the external wall white.</td>
</tr>
<tr>
<td>Natural Ventilation</td>
<td>All windows set to be 50% openable and remain open as long as the external temperature is lower than the internal temperature. This improves the building to match the performance of a building that incorporates natural ventilation into its adaptive comfort strategy.</td>
</tr>
</tbody>
</table>

5. Results

5.1. Building Performance with Retrofit Strategies

The chart below graphically shows the impact of each strategy and compares them again to the CIBSE standards (as the toughest of the four). Even with all strategies applied together for the greatest effect, the model shows that Building 2 still cannot comply with CIBSE standard (the most stringent), despite significant improvements in indoor conditions.

Figure 2: Benefit of Retrofit strategies as a % of time above CIBSE Threshold of 1%

50% openability of windows is the single most effective retrofit strategy for the apartment in a heatwave.
Figure 3: Impact of NCC ventilation Restriction on CIBSE Compliance

Figure 4: Indoor temperature based on Ventilation allowance

6. Discussion

Of the three retrofit strategies tested, only strategy that has resulted in an increase in the hours above the maximum threshold temperature was external insulation (when applied in isolation), suggesting this
is not a good strategy alone for retrofit for heat wave scenarios, where the insulation prevents the heat from escaping through the envelope with minimal reduction in heat gain. However, paired with appropriate heat rejection mechanisms (such as ventilation), external insulation could theoretically have a positive impact on the temperature. With all strategies applied, and the addition of insulation to the walls, wall colour and ventilation resulted in further reduction of hours inside the heat stress zone by up to 85%.

The single strategy that has the most impact is natural ventilation, with a reduction of up to 71% in the number hours above the maximum temperature threshold alone. The openability of the windows is important, with a 32% percent benefit in having normal openability compared to the restricted window opening as is required by window fall protection required by the NCC for elevated windows. The resultant temperatures during the heat wave period of the three ventilation scenarios is shown in figure 5, showing significant nighttime benefits with the openable windows. This benefits consists of lower daytime and nighttime benefits demonstrating the impact of thermal mass coupled with nighttime ventilation.

7. Conclusion

This research provides a detailed understanding of retrofit opportunities for a typical apartment building in Melbourne. The results show that a combination of insulation, light coloured external walls and increased ventilation can reduce overheating by 85%. Of these results ventilation is the most effective (71%) and can be easily retrofitted. In recent years, the National Construction Code (NCC) has included provisions to protect occupants from falling from the openings where they are elevated. This protection restricts openings to a maximum of 125mm and also makes allowance for there to be no addition openings to make up for the loss of natural ventilation opening area. As a result of this change, the benefit of ventilation from the study apartment is reduced by 32%. Future research could be expanded to test more apartment configurations including those with a low opening percentage such as curtain wall apartment buildings, as well as more detailed testing of particular protected window opening systems that maximise ventilation.

References


Abstract: The impact of IEQ (daylight, temperature, acoustics and indoor air quality) in school settings is a subject of concern for many scholars and parents and teachers. This review has appraised the breadth of studies that have examined the influence of IEQ on learning performance and health in schools. Using the replicable search processes of a systematic literature adopted from medical research practice, one hundred and fifty relevant articles were retrieved from four search databases (Science direct, Scopus, PubMed and Google Scholar). Analysis of these articles has revealed that the impact on students’ health and comfort of each individual IEQ variable is significant. This, in some studies has been shown to influence learning performance. However, while these variables are interlinked in building design they are not studied together in health and learning performance studies. An evidence-based method is proposed for investigating what relative contributory effect these four variables have on learning performance. As these IEQ variables individually have a very significant effect on student performance, this study has the potential to guide important changes in the design and refurbishment of new and existing school buildings. If successful, it could support educational quality and effectiveness of teaching and learning.

Keywords: Daylighting; temperature; acoustics; indoor air quality

1. Introduction

Indoor Environmental Quality (IEQ) as a phrase is typically used to refer to the quality of the conditions inside a building’s environment in relation to the comfort, health and wellbeing of its occupants. There are many variables that influence the quality of the indoor environment including: external conditions (air pollution, external temperature), building (construction materials, furniture), building services (HVAC systems) and people and activities (HVAC use, cleaning), etc., (Almeida, de Freitas, & Delgado, 2015). But studies have shown that among these variables, daylight, temperature, acoustics and Indoor air quality (IAQ) are perceived as the four major variables that define the quality of the environment inside a space (Akpan-idiok & Ackley, 2017; Wall, 2016; Dorizas, Assimakopoulos, & Santamouris, 2015; Barrett & Zhang, 2009). This is because, they are associated with the visual, thermal comfort and energy-efficiency design of a building (De Dear et al., 2015).
These variables are of primary importance in schools because they help to enhance IEQ and reduces building energy consumption. They also impact on students’ health, comfort, and performance (De Dear et al., 2015). A child spends an average of 1,480 hours in a school building yearly. When this figure is multiplied by eight years (from kindergarten to 12th grade) they spend an average of 11,840 hours of their lives in a school building (Cheryan, Ziegler, Plaut, & Meltzoff, 2014) – which is about 25% of their waking lives. Considering the number of hours spent in the classroom, the impact of IEQ in school settings remains a subject of concern for many scholars and parents and teachers. Many of these studies show that IEQ in classrooms’ can facilitate or hinder learning performance. Inadequate IEQ in these studies is related to worse test scores. The results are robust even when statistically controlling for other variables such as; the socioeconomic status of students, absenteeism, grade level, teacher bias, etc. (Heschong Mahone Group, 1999; Tanner 2008). A daylight study by Heschong Mahone Group, (1999) showed that, even with the analysis of the teacher characteristic, student absenteeism data, and grade level variables, the daylight variable stayed highly significant as a factor that impacts learning performance. In their teacher survey analysis, thermal and visual comfort, acoustic and adequate ventilation were all frequently listed as top priorities.

In section two, the methodology and data extraction process of the systematic literature review is described. Section three identifies models that describe the inter-relationship between learning performance and health and discusses the themes arising out of the review. Section four summarises the trends observed.

2. Methodology

Three hundred and eighteen potentially relevant scholarly articles were retrieved from computerised searches using four search databases (Science direct, Scopus, PubMed and Google Scholar). The articles were catalogued in a data base that stored at a minimum the titles, abstracts and keywords. A second refinement was performed using titles and abstracts to exclude papers that lacked measurable associations between IEQ and learning performance and health in a school. Duplicate articles and other works that did not have information’s related to the study’s inclusion criteria were disregarded. The articles were either included or excluded based on their relevance to indoor environmental quality and their influences on school building occupants. Thus, 150 of the 318 articles were selected and analysed.

3. Discussion

3.1. The Influence of IEQ on Students Learning Performance in Schools

Daylight

Within the specific focus on IEQ and students’ learning performance, only three articles showed a statistically significant association between daylighting and improved learning performance. Nicklas & Bailey (1997) compared the test scores of students in daylit schools to those in non-daylit schools. Their findings reveal that students in the daylit schools out-performed the students who were attending non-daylit schools by 5 to 14%. Similarly, a study carried out by the Heschong Mahone Group (1999) provided proof of an association between high quality daylight in classrooms and improved students’ performance. Their findings showed that students in classrooms with the most daylight had 7% to 18% higher test scores than those in classrooms with the least. They also found that, when compared to classrooms with the
The least amount of daylighting, the classrooms with a higher amount of daylighting had a 26% faster learning performance rate in reading tests and 20% in mathematics tests all through the studied school year. In addition, they reported that the influences of daylight in schools could directly help the students by improving their mood or help to indirectly improve the teacher’s mood. When teachers were interviewed, their perception that windows and daylight improved the learning mood of their students by keeping them calm and improving their attention spans agreed with the positive effects of daylight on students learning performance. Furthermore, in New Zealand, a study by Jackson (2006) explored the possibility of generalizing the findings of the Heschong Mahone Group (1999) study by replicating their methodology in the New Zealand context. Their study found a correlation between daylight and improvement in students’ test score and established that the HMG process could be replicable in another environment. However, their study suggested that direct sunlight penetration into classrooms may cause glare, which leads to negative student performance.

Though there is a significant association between good quality daylight and positive student performance, there is a question about what causes the improvement in students’ performance in daylight classrooms. Recent studies (Bellia et al. 2015; Heschong Mahone Group 1999) have suggested that the positive effect of daylight on students learning is because of its effects on melatonin suppression in the body. When classrooms are adequately daylit, melatonin production becomes suppressed, leading to an increase in alertness and concentration that will enhance learning performance. This assertion is affirmed by Bellia et al., (2015) whose study suggested that in the presence of daylight during typical clear and overcast winter days in Italy melatonin was suppressed.

The common conclusion of these three daylight studies is that, they support the argument that there is a predictable and well-founded influence of daylighting on students’ learning performance. The study by the Heschong Mahone Group (1999) remains one of the most conclusive studies relating daylight and improvement in students’ performance to date because; they use a large pre-existing data set to show the effects of the physical environment on students’ performance by showing the association between building design and the social aspects of the school environment. Though the study by Jackson, (2006) agrees with this, they argue that, “There can be no assurance that daylight will always be successful in maximising human performance”. However, their study findings could not be generalised to the entire New Zealand context because, their data set was insufficient to meet the target 95% confidence level which was required to make these generalizations.

**Temperature**

Fifteen articles showed a statistical significant association between temperature and improved learning performance. These evidences are found in a study carried out by Wargocki & Wyon (2007). They mentioned in their study that a research carried out by Wyon et al. (1979) showed the magnitude of the negative effect of temperature on students’ performance. Their research strategically exposed 10-year-old children to three different classroom temperatures of 20°C, 27°C, and 30°C for two hours and another set of 11- to 12-year-old children were similarly exposed to a temperature of 20°C in two classes and 30°C in another two classes in the morning and in the afternoon. The children performed maths and reading tasks to assess their speed of work and the number of errors made. The performances of the children were significantly lower at a higher temperature of 27°C and 30°C as compared to those in the lower temperature of 20°C. The reading speed of the children reduced and a lower rate of working in the numerical tasks were identified in the classes with higher temperatures. The negative effects of raising
classroom temperatures were more significant in the afternoon than in the morning, which is thought to be due to fatigue.

Wargocki & Wyon, (2007) carried out two intervention experiments to investigate the influences of high indoor temperatures on students’ performance in Danish classrooms. In the first case, the classroom temperature was gradually cooled from 25°C to 20°C. 10–12-year old children were given reading and mathematics task to assess their speed and accuracy of task performance. As temperatures decreased from 25°C to 20°C, the children’s average speed of task performance increased by approximately 2% per 1°C temperature decrease. However, there was no measurable effect of the changes in temperature on the number of normalized errors. This finding argues for an infinitesimally small change when temperature decreases by 5°C. An investigation into the comfort of secondary school buildings in Cyprus compared perceived learning performance in air conditioned and fan-assisted naturally ventilated environments. The study findings reveal that students with uncomfortable thermal sensation reported worse perceived learning performance in fan-assisted naturally ventilated environments than those in air conditioned environments (Katafygiotou & Serghides 2014).

Many Scholars have studied the temperature range associated with better learning, they suggest that the optimal temperature range for learning appears to be between 22°C and 25°C (De Dear et al., 2015; Katafygiotou & Serghides, 2014). This assertion is line with the findings of Allen & Fischer, (1978) who investigated the influences of temperature on students’ learning. Their study showed that, when the male undergraduates learned a test of word associations in a 22°C classroom, they performed best. They significantly performed worse when the temperatures became more extreme in either direction.

These studies agree that an increase in temperature above 25°C negatively affects students’ learning and task performance while lower temperatures enhanced learning. However, the studies did not show if very low temperatures could also impact learning performance. In addition, most of the studies on the impact of thermal comfort on students’ learning performance were intervention studies conducted in controlled spaces. New findings may be revealed if the effect of very low temperatures on learning performance is conducted. Also, a comparison of students’ learning performance in naturally ventilated classrooms during the summer when temperatures are high and during the winter when temperatures are lower without HVAC systems will be interesting to explore.

*Indoor Air Quality (IAQ)*

On the association between indoor air quality and learning performance, fifteen articles showed a statistical significant association. For example, in Denmark, the second intervention experiment carried out by Wargocki & Wyon, (2007) showed an improvement in student performance when classroom ventilation rates were increased. It was found that, an increase in the outdoor air supply rate from 5.2 to 9.6 L/s per person significantly improved students’ test performance. This suggests that air temperature, humidity and air flow are important components that determine IAQ in a building. Air temperature is affected by relative humidity and indoor air, outdoor humidity and surface temperatures influences the accumulation of moisture within a building envelope. Walinder et al. (1997) compared a naturally ventilated primary school with a mechanically ventilated school in Sweden. They found a high level of indoor air pollutants (respirable dust, bacteria, mould and VOCs) which was due to inadequate outdoor air supply and were 2 - 8 times higher in the naturally ventilated school. This, they say may cause a swelling of the nasal mucosa in the upper airways. This shows that there is a need for adequate flow of outdoor air in naturally ventilated classrooms, because inadequate outdoor air supply could lead to a contamination of the air within the space which may lead to health issues that will adversely affect
learning performance. In England, an intervention experiment was conducted by Bakó-Biró et al. (2012) to investigate the effects of classroom ventilation on pupil’s performance and learning. The results reveal that compared with the low ventilation conditions, the higher ventilation rates had a more precise and faster response for word recognition (15%), picture memory (8%), colour recognition (2.7%) and choice reaction (2.2%). This study agrees with the assertion that increased ventilation rates could improve learning performance. This will be best achieved in naturally ventilated classrooms when there is adequate flow of outdoor air supply.

In as much as air movement, relative humidity and air temperature determine the condition of indoor air, good air quality can be examined by the number of contaminants which could lead to health problems. Contaminates are mostly categorised as; inorganic compounds (carbon monoxide, sulphur dioxide, oxides of nitrogen, carbon dioxide, sand, etc.), organic compounds (urea formaldehyde foam insulation, etc.), particulate matter (sprays, mist and dust, etc.), and biological contaminants (house dust mites, pollens, microbes such as fungal spores, viruses, bacteria and algae, etc.) (Mclntosh, 2011). Particulate matter can cause respiratory difficulties, coughing, sneezing, dry eyes, throat, nose and skin irritation, and contact lens problems. Carrer et al., (1990) states that there is often higher concentration of particulate matter in classrooms than in offices because, children have higher indoor physical activities and they easily carry the particles on their shoes. Biological contaminants can actively grow in classrooms with poor IAQ (Armstrong, and Liaw, 2003). Where there is high humidity, water or dampness, fungi are most likely to grow. When these contaminants become airborne, the cause infections, respiratory diseases, allergy and asthma attacks (Mclntosh, 2011). Mclntosh, 2011 reveal that 83% of classrooms in their study had bacterial counts similar to those found in water treatment plants or higher. Where there is high humidity, bacteria, fungi and colonies of dust mites do grow rapidly.

High CO2 levels which exceed 800 ppm are associated with lack of fresh air in a building and levels around 500-600 ppm have been suggested to be acceptable for school children (Daisey et al. 2003; Kruisselbrink et al. 2016). In Greece, a study by Dorizas et al., (2015) found that a 17% increase in the indoor CO2 concentrations leads to a reduction in students’ performance by 16%. They identified a negative correlation trend between students achieved scores and the CO2 concentrations and a positive correlation trend between their marks and the ventilation rates. The reported studies on the association between IAQ and learning performance have shown that poor air quality has a significant effect on students’ performance in schools, but the detailed nature of its influences is not straightforward because; the nature of task carried out, the duration of exposure, the socio-cultural background of the students and the means of adaption available could all have different levels of contribution in determining the overall effect on performance. Furthermore, it establishes that, issues of IAQ in classrooms also poses a health risk and appears as the major IEQ variable that leads to health problems.

**Acoustics**

Seven articles in this review showed a statistical significant association between acoustics and learning performance. Poor acoustic properties of school buildings which allows the transfer of external noise into classroom spaces are more likely to result in lower student performance (Cheryan et al., 2014). Shield & Dockrell (2003) agrees with this view by stating that there is increasing evidence that poor acoustic properties in the classroom can create a negative learning environment for many students. For instance, Evans, G. W., & Maxwell (1997) compared reading test scores of students in two schools with different demographic factors. While one the schools was in a quiet neighbourhood the other was in a flight path of a major airport. The study found a significantly worse performance of students in the flight path school.
than those in the quiet neighbourhood school. In Sweden, pre-recorded noises of aircraft, road traffic, train, or verbal were compared with that of quiet conditions in an experimental demonstration consisting of 12- to 14-year-olds. The test of reading comprehension showed that students performed significantly worse when exposed to aircraft or road traffic noise than in the quiet conditions. There was no interference of the reading comprehension by noise from trains (Dockrell & Shield 2006; Hygge 2003). Noise levels in schools and classroom are of great concern to teachers. A study by Lackney (1999) found that teachers believe that noise impairs learning performance and noise causes more discomfort and decreases teacher's efficiency than for students. Poor acoustic properties have the potentials of affecting the quality of teaching, learning and ultimately performance. Teachers appear to be more concern about high noise levels, because it affects teaching communication, leads to discomfort and negatively affects learning performance. Unfortunately, the number of studies showing acoustic problems in schools is limited, thereby giving concerns for more research to identify the possible common sources of noise within the school environment which can affect learning.

3.2. The Influence of IEQ on Health in Schools

Daylight

The evidence associating daylight with health is found in a study carried out by Küller & Lindsten (1992) who assessed the effects of light on sick leave and the production of stress hormones. They identified an existence of a systematic seasonal variation with more stress hormones in summer than in winter. They suggest that basic hormone pattern may be distorted by working in classrooms with poor day-lighting. This could likely influence the annual body growth and sick leave of children and impact their ability to concentrate or co-operate. Lighting is a very vital element for cavity prevention in children. There is a strong relationship between the amounts of light a child is receiving to the level of dental decay. Hathaway et al, (1992) study into the effects of various lighting systems on elementary school’s students’ dental health reveal that, over a 2-year period, students who received ultraviolet light supplements had fewer dental caries, better attendance, greater gains in height and weight, and better academic performance than did students who did not receive the supplements.

Daylighting is widely believed to promote health, because it is known to increase the production of vitamin D as its deficiency is caused by lack of adequate exposure to daylight (Nathaniel 2008). Exposure to high illumination levels is said to be key to help in the regulation of the body’s circadian rhythms and it has been associated and recognized as a treatment for seasonal affective disorder (Zeitzer et al. 2000). Poor lighting makes reading visually stressful for students and could cause eye strain. Adequate daylight is good for school children, because it helps them to sleep at night. When people receive enough daylight within the day, their nocturnal melatonin production occurs sooner and they can enter into sleep more easily at night (Nathaniel, 2008). Light suppresses the brain hormone production of melatonin and increases alertness. Melatonin is primarily secreted at night and influences the body immunological functions including the production of estrogen by triggering a host of biochemical activities (Heschong Mahone Group, 1999; Zeitzer et al., 2000).

Furthermore, scientific evidences suggest that children spending much time outdoors is crucial in reducing myopia progression and a healthy development of their eye (Cohn, 1886; Kathryn, Ian, Wayne, George, Paul, & Seang-Mei, 2008; Morgan, iG; Xiang, F; Rose, KA; Chen, Q; He, 2012; Wu, Tsai, Wu, Yang & Kuo, 2013). This assertion is still being debated and explored. These researchers strongly suggest that the amount of light a child get as they grow determines whether they will develop myopia. Currently,
there is no evidence that daylight in classrooms prevents myopia (Hobday, 2015), but there are limited studies that have shown that daylight in classrooms reduces the progression of myopia in children. In Taiwan, Wu, Tsai, Wu, Yang, & Kuo, (2013) conducted an intervention study on 571 students to examine the relationship between schools, age, gender, baseline refraction, and myopia prevalence. While some schools had children going outdoors for break, the other schools were a controlled group. After a year, new cases of myopia were significantly lower in the group of schools where the children were let to go outdoors during breaks than in the control group (8.41% vs. 17.65%P_0.001). They conclude that; “clinical trials support outdoor time as an effective intervention in reducing the progression of myopia”. Similarly, in China, Morgan, Xiang, Rose, Chen, He, (2012) conducted a study in Guangzhou and found that, there was an association with a reduction in myopia onset by the participation of students in an additional outdoor class after school each day. In Sydney and Singapore respectively, a study was conducted to compare the myopic prevalence and risk factors in 6 and 7-year-old children of Chinese ethnicity. 124 primary school children participated in the study in Sydney while 628 participated from Singapore. The researchers found that the prevalence of myopia was significantly lower in Sydney (3.3%) than in Singapore (29.1%). They concluded that the lower prevalence of myopia in the children in Sydney was associated with increased hours of outdoor activities. They suggest that; “though they do not know exactly what activity protects from myopia, but they do know from their findings that the total time spent outdoors was protective” (Kathryn, Ian, Wayne, George, Paul, & Seang-Mei, 2008).

The strongest assertion of these studies is that time spent outdoors is crucial in reducing the progression of myopia, because daylight stimulates the release of the retinal transmitter dopamine (an organic chemical that plays an important role in the brain and body), which is known to inhibit axial growth of the eye. Children who are exposed to lower levels of light appear to be at a greater risk of myopia progression. However, these studies did not show what could be the causal biological mechanism through which outdoor activity influences the progression of myopia in children. They did not also state the amount of light needed, its intensity, the range of illuminance values, and spectral composition that affects refractive development. Myopia appears to be caused by several other factors which there may be other potential contributors to its onset and progression, but the reviewed studies argue that daylight plays an important role in reducing the progression of myopia in children in schools. This further supports the argument that daylight is an important IEQ variable that could enhance student’s health and wellbeing in schools thereby enhancing learning performance.

Temperature and Acoustics

Only two articles showed a statistical significant association between temperature and health, of the two only one of the article showed this association in a school setting. This was the study by Puteh et al. (2014) who conducted a survey to identify and investigate students’ perceptions towards classroom thermal comfort and the schools’ surrounding in Malaysia. The study findings reveal that, due to contaminated air (poor IAQ) caused by heat, watery eyes, redness and blurring of the eyes were the most frequent health problems identified by the students. Only one article showed a statistical significant association between acoustics and health. In Egypt, teachers were assessed for vocal levels and effects of experienced noise in classrooms and throat symptoms as well as their effects on working and social activities. It was found that, 48% reported moderate or severe dysphonia (speaking difficulty) within the last 6 months. Frequent feelings of being in noise were reported by all the teachers and 82% of them felt it mostly during the working day, which made them to raise their voice (Abo-Hasseba et al. 2016). This suggests that poor thermal performance and acoustics could cause health problems in schools.
**Indoor Air Quality (IAQ)**

The eight articles showing a statistical significant association between IAQ and health associated the prevalence of allergic and respiratory diseases among school children with poor IAQ in classrooms (Cartieaux et al. 2011; Dorizas et al. 2015; Ferreira & Cardoso 2014; Salthammer et al. 2016; Fisk et al. 2013). Ferreira & Cardoso (2014) found that CO₂ concentration which went as high as 1,942 ppm were above the maximum reference value, especially during the fall and winter seasons thereby causing health risk for children in schools. Wheezing, sneezing, rales, rhinitis, asthma, irritation of mucous membranes, cough, headache, and poor concentration were the associated health symptoms identified. In another study, Cartieaux et al., (2011) observed that respiratory diseases such as asthma and allergies caused by several pollutants in the classroom were predominantly prevalent. Smedje & Norbäck (2001) found a positive association between mould and airborne bacteria and asthma in school children. These evidences support the argument that there is a relationship between the concentrations of pollutants in classrooms and the onset of health problems in school children. The experimental investigation of Dorizas et al., (2015) reveal that, the predominantly observed health symptoms affecting students in their studied schools were fatigue, allergies, and nose irritation, this significantly correlated to the levels of indoor particulate matter and CO₂ concentrations. Mendell et al. (2013) investigated the association of classroom ventilation with reduced illness absence. They found a statistically significant 1.6% reduction in illness, absence per each additional litre per second per person (l/s per person) of ventilation provided. This they mention is a much smaller change in illness, absence per unit of ventilation rate and that the evidences associating inadequate classroom ventilation rates with increased illness absence are limited. They suggest that increasing ventilation rates above the recommended minimum levels even up to 15 l/s-person or higher may further substantially decrease absence due to illness. Ventilation experiments that are measurable are normally designed with mechanical systems in place. Findings reveal that classrooms CO₂ levels can be significantly reduced by installing a CO₂ controlled mechanical ventilation system. It can be challenging to execute this design in classrooms, especially when the majority of classrooms is naturally ventilated and measurable rates of ventilation are not easily guaranteed with openable windows.

**4. Conclusion**

Generally, the studies have shown that they are many factors that influence the performance and health of students in school buildings. They include items such as control of confounding and demographic variables, survey instruments used to assess building conditions, and the way in which academic performance is reported. Though the studies have shown the influences of IEQ on students learning performance and health, none of the articles have shown a statistical significant relationship combining these four independent variables (Daylighting, thermal comfort, and acoustic and indoor air quality) as well as socio-economic considerations on the student’s health and performance.

However, in building design, IEQ variables are interlinked, but this review of 150 health and learning performance studies shows that they are not studied together in these studies. This gives concerns about “what is the relative contributory effect of the four IEQ variables on learning performance”? This is a research gap that needs further investigation. If researchers, architects and planners are too strongly affirm to policy makers that, the combined effects of IEQ should be top priorities when considering changes to classroom environments, they may want to know the relative importance of each of the four leading IEQ variables as well as their contributory effect. Hence, this paper recommends that, researchers...
should explore the use of an evidence-based method to investigate what relative contributory effect these four IEQ variables have on learning performance. As these IEQ variables individually have a very significant effect on student performance and health.

References


Biomimicry as Innovation
A Systematic Review

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Abstract: Systematic literature reviews originated in biomedical science. They are methods to systematically identify, select and critically appraise evidence. They form the foundation of the process reported here which has investigated whether there is any evidence in the literature showing that biomimicry might be a generalizable principle that could assist designers to improve the thermal performance of buildings. In its defining papers biomimetic design is argued to be an applied science that derives inspiration from the natural world and opens avenues for technological/sustainable design and innovation. It suggests that study of nature can reveal more sustainable solutions in terms of efficient processes, functions, systems and materials. For example, thermal adaptation of natural organisms to extreme conditions takes place through behavioural, morphological and physiological mechanisms. However, the literature review has revealed that there is no publication outlining a systematised procedure to attribute thermal issues to corresponding natural adaptation strategies applied by specific organisms. Biomimetic design concepts often seem to be written about with very specific examples which seem more to be about the metaphorical use of one-off examples of nature-inspired design than about a general approach to the mining of biological information systems for design inspiration.

Keywords: Biomimicry; natural adaptation mechanisms; biological samples; energy efficiency.

Introduction

This paper reports a systematic literature review (Gough et al., 2012) looking for a systematic way of using biomimicry principles to identify possible innovative solutions for improving thermal performance in buildings. “Searching the literature involves the formulation of a search strategy, which includes inclusion and exclusion criteria, keywords, sources of evidence, the documentation of the search, and selection of the research reports to be included” (Ten Ham-Baloyi & Jordan, 2016).

‘Bionics’, Biomimetic, and biomimicry have also been used interchangeably in recent research. Biomimetic is involved with artificial mechanisms to produce materials similar to ones that exist in nature (Reap & Bras, 2009). Papanek (1974) believes that bionic is more related to ‘cybernetics’ and Vogel (1998) claims that it focuses on artificial intelligence. Bionic design considers taking control of nature (Wahl, 2006) and seeks resolving engineering problems using data related to biological functions (Reap & Bras,
2009) while biomimicry is primarily focused on sustainability (Wahl, 2006) and imitates nature’s efficiency (Reap & Bras, 2009). Despite the dominant role of biomimicry in the industrial sector, the philosophical aspects of this science have remained underdeveloped and descriptive (Mathews, 2011). In this paper, the principal focus is the ability of the philosophical approach to aid in the finding of new techniques in nature for use in buildings.

Benyus (1997) has also defined a set of dimensions for biomimicry: nature as model, nature as measure, and nature as mentor. Some researchers believe that these dimensions form the basis for classifying the different approaches to biomimicry (McGregor, 2013; P. A. Reed, 2003). Janine Benyus argues that looking at nature and imitating its existing models, systems, and process can solve design problems sustainably (Benyus, 1997). Biomimicry is argued to serve two main purposes: innovation and sustainability. Pawlyn (2011) suggests biological organisms can be considered as embodying technologies which offer sustainable solutions. Technological innovations and sustainability criteria could be interrelated aspects of biomimicry as Rao (2014) explains: “biomimicry uses an ecological standard to judge the sustainability of our innovations”.

The systematic literature review, therefore, sought to find precedents in the literature for a systematic means of searching nature for architectural innovations that addressed a sustainable design outcome. In order to achieve this, a commonly used analogy in biomimicry was explored, namely, drawing inspiration of architectural form and technology from the way in which natural organisms are capable of adapting their body temperature to the fluctuating temperature in the surrounding environment. It has been argued that this process takes place through behavioural, morphological and physiological adaptation (Angilletta, 2009; Caddy & West, 2004). There is clear evidence that building designers have enabled improved building performance through drawing inspiration from nature’s approach to design challenges such as adaptation to climate (Tachouali & Taleb, 2014; Wang 2011; Zuazua-Ros et al., 2016). However, the focus of the literature review was to find papers outlining how new biomimetic approaches might be discovered from nature. It sought to focus on papers that identified a system or procedure for discovering biomimetic solutions to new thermal adaptation issues rather than those papers merely reporting existing examples of biomimetic design.

Many studies suggest that bio-inspired design can lead to energy efficiency (Al Amin & Taleb, 2016; Alkhateeb & Taleb, 2015; Han et al., 2015; Kim & Torres, 2015; Nessim, 2015; Tachouali & Taleb, 2014). These specific examples are often metaphorical. They are illustrations of an idea, not demonstrations of how a new idea or concept might be drawn from nature (Nanaa & Taleb, 2015; Reichert et al., 2015; Turner & Soar, 2008; Zare & Falahat, 2013; Zuazua-Ros et al., 2016). Some document the metaphor but do not prove they do actually deliver on the claimed improved performance (Ahmar & Fioravanti, 2015; Worall, 2011).

Methodology

A systematic review is designed to be replicable. It documents carefully its search terms, the databases examined, and the inclusion and exclusion criteria applied to each document found. They began in the 1970s with the ‘evidence movement’ looking for high-quality evidence to support public policy. “Critical appraisal and synthesis of research findings in a systematic manner emerged in its first formal guise in 1975 under the term 'meta analysis'. It was an approach championed by medical researchers who sought to synthesise research systematically. (EPPI, 2017) Here it is used to document as systematically as possible what data exists on ways of using biomimicry principles to find new behavioural, morphological and physiological approaches to design for thermal adaptation.
2.1. Search Process

According to Alice (2013) the following research databases are the most trusted ones. Google Scholar, CiteSeer (includes papers in the field of computer science), GetCited (the web page does not work anymore), Microsoft Academic Research (one related paper was found based on filtering biomimetic, engineering and computer aided design), Bioline International (includes papers related to public health), Directory of Open Access Journals (no paper was found), Plos One (only includes biological papers, no architectural research is included), BioOne (no paper was found), Science and Technology of Advanced Materials (material is not the focus of this research), New Journal of Physics (not related), Science Direct. Scopus is the largest database of peer-reviewed literature which provides a comprehensive source of scientific/technological papers and SAGE is the world’s 5th largest journals publisher. Four databases were searched in detail as they had the most likelihood of finding a significant number of documents: Scopus, Sage, Science Direct and Google Scholar. The basic key words were biomimicry, architecture, thermo/thermal regulation. Table 1 shows the search results.

Table 1: Search terms within the databases ‘Google Scholar’, ‘Sage’, ‘Scopus’, and ‘Science Direct’: (date of last search: 28 July 2016)

<table>
<thead>
<tr>
<th>Database</th>
<th>Keywords</th>
<th>Number of Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Google Scholar</td>
<td>(thermal regulation AND Biomimicry AND architecture) NOT ('medical' [All Fields]) NOT ('morphogenesis' [All Fields])</td>
<td>177</td>
</tr>
<tr>
<td>Google Scholar</td>
<td>('thermoregulation' AND 'Biomimicry' AND 'architecture')</td>
<td>2350</td>
</tr>
<tr>
<td>Sage</td>
<td>All Fields ('thermal regulation' AND 'biomimicry')</td>
<td>11</td>
</tr>
<tr>
<td>Scopus</td>
<td>All Fields ('thermal regulation’ AND’ biomimicry’ AND ‘architecture’)</td>
<td>63</td>
</tr>
<tr>
<td>Scopus</td>
<td>TITLE-ABS-KEY ('thermal/thermo regulation’ AND’ biomimicry’)</td>
<td>1</td>
</tr>
<tr>
<td>Science Direct</td>
<td>Field of Engineering ('thermal regulation’ AND’ biomimicry’ AND ‘architecture’)</td>
<td>14</td>
</tr>
</tbody>
</table>

Bibliographies of selected articles were also screened and the references added to this total. The references were divided into 4 main categories: 1) Thermal comfort/standards in buildings/urban environment, thermal performance of reflective coating, modelling impacts of roof reflectivity, studying the impact of photovoltaic panels or green roof on energy consumption, and etc. 2) Biomimicry/biomimetic as a new way of design, 3) Energy simulation of buildings considering the impact of occupancy, electronic equipment and etc. 4) Thermal adaptation (heat gain/loss) in organisms

2.2. Inclusion and Exclusion Criteria

Eligibility for inclusion was determined by reading abstracts and, sometimes the whole articles. Three key words: “medical”, “morphogenesis”, and “material” were excluded in the searches since they identified papers that were irrelevant.

As the grey cells of “number of results” column show, 203 papers are finally selected after excluding some key words. Screening the papers, out of 203 papers, three duplicates were found. At the first stage
of the review, 127 papers dropped off based on irrelevant titles and 44 paper abstracts were screened and dropped off because those papers did not address exactly the context of the research. Irrelevant papers have been related to the following subjects: tissues engineering (medical science), cellular biology, the role of biomimicry in the future of cities (not related because of the scale of the research), principles of organisation of ecological communities (i.e., ecosystems) for creating sustainable human communities, papers focused on computation and genetic algorithms, bio-inspired structure of the buildings, bio-inspired textiles, and etc. Finally 29 papers were selected: (203 -3(duplicates) – 127(irrelevant titles) - 44(irrelevant abstracts) =29)

2.3. Data Extraction

Articles were grouped according to this set of steps: Step 1) if the article is a one-off study with no description of how the biomimetic analogy was found, and no repetition of the analogy in other design situations (Y=Yes, N=No). Step 2) practical implies the energy efficiency of the case study has been analysed using energy simulation; Theoretical implies this step is omitted (T=Theoretical, P=Practical). Step 3) names the natural organism(s) used as an inspiration for design in three categories (animals, plants, and human anatomy); it is inferred that this suggests pre-existence of biological systems. Step 4) introduces the architectural objectives mentioned by the authors. Step 5) identifies the architectural solution(s) or technologies designed and developed in the article to overcome thermal issues. Step 6) labels which climate has been considered in recent research in biomimicry (NA = Not Available, CC= Cold climate, HC= Hot climate, H&A c= Hot and arid climate, DC= Different climate). Step 7) indicates whether there are explicit links to previous data collections or strategies identifying relevant thermal adaptation strategies found in nature(Y=Yes, N=NO).

Table 2: Search terms within the databases ‘google scholar’, ‘sage’, ‘Scopus’, and ‘Science Direct’: (date of last search: 28 July 2016)

<table>
<thead>
<tr>
<th>References</th>
<th>Steps</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Park &amp; Dave, 2014)</td>
<td>Y P Animals’ eyes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Daylight distribution</td>
<td>Adaptable façade systems</td>
<td>NA</td>
</tr>
<tr>
<td>(J. Wang &amp; Li, 2010, March)</td>
<td>Y T Butterfly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Kinetic building envelope</td>
<td>Conceptual energy efficient buildings</td>
<td>NA</td>
</tr>
<tr>
<td>(Wang 2011)</td>
<td>Y T Butterfly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bio-inspired kinetic envelope</td>
<td>Conceptual energy efficient buildings</td>
<td>CC</td>
</tr>
<tr>
<td>(Zare &amp; Falahat, 2013)</td>
<td>Y T Reptiles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Thermoregulation system</td>
<td>Smart wall</td>
<td>HC</td>
</tr>
<tr>
<td>(Tachouali &amp; Taleb, 2014)</td>
<td>Y P Flamingos</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Indoor space temperature</td>
<td>Suggesting strategies</td>
<td>H&amp;A C</td>
</tr>
<tr>
<td>(Zuazua-Ros et al., 2016)</td>
<td>Y P Tuna</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Altering the heating demand</td>
<td>Heat management in building</td>
<td>DC</td>
</tr>
<tr>
<td>(Al Amin &amp; Taleb, 2016)</td>
<td>Y P Desert snail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Enhancing thermal comfort</td>
<td>Reducing energy consumption</td>
<td>HC</td>
</tr>
<tr>
<td>(Busto et al., 2016)</td>
<td>Y T Beehives</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Control of the air cavity</td>
<td>Redesigning Peltier cell prototypes</td>
<td>NA</td>
</tr>
<tr>
<td>(Ahmar &amp; Fioravanti, 2015)</td>
<td>Y P Termites</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Daylight control</td>
<td>Design in hot climate</td>
<td>H&amp;A C</td>
</tr>
</tbody>
</table>
## Results

This section summarizes the references considering the steps described in section 2.3.
3.1 One-off Examples

Of the 29 studies which met the basic search criteria, 22 were one-off examples. Most studies in the literature are therefore describing metaphors. Thermoregulation is achieved by morphological imitation of natural organisms’ patterns or structures. In the research conducted by Park & Dave (2014) as an advantage, daylighting is improved, and energy consumption is dropped however the proposed architectural system requires expensive automatic sensors as well as high maintenance expenses. The emulation process is also limited to mimicking formal configuration of natural organisms. Bio-inspired kinetic envelope suggested by Wang and Li (2010) is claimed to be able to respond to the environment by adjusting spatial, physical and material aspects, but only the spatial aspect of this claim is examined. In Wang’s (2011) research, there is no thermal analysis report to support optimization of the energy consumption. Translation of biological principles to architectural parameters still follows a morphological approach.

16 of the studies do not provide enough evidence to prove that biomimicry can effectively enhance the thermal regulation in buildings. The biomimetic approach of one of them is architectural rather than morphological, aiming merely to translate biological principles into architectural ones (Zare & Falahat, 2013). In contrast, practical studies prove the energy efficiency of biomimetic design approaches by running energy simulations. For instance, Tachouali and Taleb (2014) translate flamingo’s breathing mechanisms into new methods of ventilation, resulting in thermal comfort in the interior environment based on Ecotect energy simulation. Likewise, Zuazua-Ros et al. (2016) use OpenStudio and prove that the heating demand of a working place drops significantly if the space arrangement is designed based on the strategy that tuna use to conserve energy. Al Amin & Taleb’s (2016) research is robust in terms of providing evidence since by running energy simulation in Ecotect they prove that adding bio-inspired architectural strategies the cooling load is dropped up 40%.

10 percent of studies relate to imitating termite mounds’ thermal regulation strategies. Inspired by termite mounds, Ahmar and Fivoravanti (2015) suggest a porous double skin facade for reducing cooling loads in hot climates. Their study, despite being successful in thermal performance, follows a morphological approach. Worall (2011) is more focused on biological aspects rather than architectural ones. Turner and Soar (2008) suggest these termite mound analogies are not always successful, pointing to temperature regulation in the Eastgate building in Harare, Zimbabwe which is achieved by huge fans consuming high amounts of energy to run.

While all of the above mentioned one-off studies are inspired by animals/insects, a group of research are inspired by plants and their bio-inspired design approach falls in to two categories: focusing on 1) morphological configuration of the building envelope (Han et al, 2015; Alkhateeb & Taleb, 2015; Ananna & Taleb, 2015) and 2) material of the building envelope (Reichert et al., 2015; Lopez et al., 2015; Marl et al., 2015; Alston, 2015). Besides two categories related to animals and plants, the literature introduces a third category of studies focused on human anatomy as a source of inspiration for thermal regulation in buildings. Architectural strategies in Lee’s (2008) study are not scientifically employed in the design process and energy efficiency of the proposed system is not evaluated. There is only one paper in this category in which energy efficiency is proved by energy simulation (Nessim, 2015).

3.2 Varied Samples

Some studies have focused on multiple biological samples to discuss the idea of bio-inspired thermal regulation in buildings (Badarnah et al., 2010). Scartezzini et al. (2015) also promise a range of possibilities
for future bio-inspired projects ranging from passive design strategies to manipulation of control networks but none of these ideas are either well explained or developed.

3.3 Flora and Fauna

Not much research is conducted based on investigating thermal adaptation strategies of animals and plants in general (Ahmar & Fioravanti, 2014, 2015; Kim & Torres, 2015). Mahmoud (2010) also investigate thermal adaptation methods in flora and fauna in order to design a conceptual three-layers “breathing wall”. This is a very rare case where bio-architectural solutions are generally applicable to all buildings and have the potential to be technologically developed. However, the energy efficiency of the proposed system remains unknown.

3.4 Theoretical framework

Generally, there are two distinctive approaches for bio-inspired design: bottom-up (solution-based) and top-down (problem-based) (Lidia Badarnah & Kadri, 2015). The former does not address any application of a scientific systematic method for bio-inspired design because specific knowledge on biology leads to solutions which are not necessarily predetermined (Vincent et al., 2005). In contrast, in the latter, there is a potential for creating a systematic search process as real-world problems are identified and designers look to nature and use the assistance of biologists to solve the problem. Amongst 29 references, only one research has made an effort to suggest a system for generating biomimetic design solutions following the problem-based approach (Badarnah & Kadri, 2015). However, the so-called “BioGen” methodology offered by them suffers from a lack of clarification in the “exploration and investigation” stage, where the purpose is to find relevant biological samples, but without explanation of how this search should be conducted.

Conclusion and suggestions for future work

The results of this systematic review as summarised in Table 2 are:

- **There is evidence to show improved energy performance.** Building thermal comfort has been enhanced by applying bio-inspired thermal adaptation strategies to building design (Alkhateeb & Taleb, 2015; Kim, 2015; Nessim, 2015).
- **Most papers focus on hot climates.** Where thermal comfort examples have been found, most report on biomimetic solutions for hot and arid climates. The fact that more research has been conducted in hot climates suggests four possibilities: 1) there is insufficient information about thermal issues in cold climates; 2) adaptation strategies for organisms in cold climates have not yet been investigated; 3) thermal issues in cold climates are not of concern for architectural designers; or 4) hot climates are simpler examples because their one dimensional need to be cool is simpler than many cool climates which need a more complex, orientation and time dependent solution.
- **There has been an evolution in design approaches.** Designing a building skin based on biomimicry principles has evolved from the geometrical/morphological manipulation of the pattern of the facade to designing specific types of wall systems or creating advanced materials (Alston, 2015; Reichert et al., 2015).
• **Most papers found were one-off examples.** Of the 29 references found, 65% were focused only on one biological sample’s thermoregulation strategy. No comprehensive research has been found describing generalizing biological principles.

• **Only one paper shows evidence for Biomimetic design in the absence of pre-existing knowledge of biology.** Using natural systems to overcome building thermal issues necessitates a systematic biomimetic design approach. Almost all research based on pre-existing knowledge about biological samples fails to refer to any specific process by which relevant information (therm eral regulation strategies in nature) about natural organisms have been found. Only one paper has made a notable effort to define a systematic design approach. The process suggested in this paper still suffers from a lack of clarity as to when biological factors need to be connected to relevant natural organisms.

• **Most papers have imitated morphological aspects of natural organisms.**

• **The focus of recent literature is on the building envelope/façade to improve energy efficiency.** None of the papers have considered the whole building as a living organism.

The literature review has highlighted the shortcomings of the currently available frameworks for generating biomimetic design concepts focused on thermoregulation in nature. A new approach is needed to ease the transfer of biological thermal adaptation principles from the realm of biology to architecture with the aim of energy saving. At a minimum, there is a need for databases which store biomimetic design ideas in a manner where they can be ‘mined’ for useful principles for new design situations.

**References**


End of Life Care in an Australian Hospital

The Role of the Built Environment in End of Life Nursing

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Abstract: Healthcare design is a growing field of research with recent studies revealing the impact the built environment has on occupants’ health and well-being. In a qualitative mixed methods case study, data was collected from a spatial evaluation and focus group interview with nursing staff from the Royal Adelaide Hospital Emergency Extended Care Unit in Adelaide, South Australia. Seven design elements were identified as central to the design of end of life spaces in a hospital context. Participants prioritised facilities for family and visitors and home-like components and furnishings above the other design elements. The results of the study suggest that for nursing staff the built environment needs to support both patients and visitors at end of life. This paper discusses the observed spatial qualities and reports the design elements identified by nursing staff as important in end of life spaces in an Emergency Department. The outcomes from this research are useful for designers, as well as nursing staff, in order to develop a deeper understanding of the impact of the built environment on qualitative experiences.

Keywords: End of life space; nursing; case study; hospital design.

1. Introduction

In Australia palliative care-related hospitalisations have risen by over fifty percent in the last decade (Australian Institute of Health and Welfare, 2015). Moreover, since 2002-03 the number of days patients have been admitted to hospital for palliative care has risen by 31% (Australian Institute of Health and Welfare, 2014, p. 25). Australia has an increasing ageing population and the prevalence of cancer and other chronic diseases will continue to amplify the demand for end of life services within hospitals (Australian Institute of Health and Welfare, 2014, p. 2).

End of life is impending in a hospital hence nursing practice is focused on holistic care of the patient, the emotional and psychological care is as important as treating the physical symptoms. Consequently, over the past two decades, the concept of therapeutic landscapes has been the subject of a growing body of literature exploring how the physical, social and symbolic attributes of place in the hospital environment can positively impact health and health outcomes (Gesler, 2004 p. 119). A hospital can be a traumatic experience for patients at end of life due to their loss of bodily functions, restricted ability to
communicate, physical discomfort and lack of privacy (Olausson et al., 2013, p. 235). To mitigate against this, current literature recommends home-like qualities in the hospital environment to reduce the stress experienced by patients (Wood et al., 2015, p. 84) ‘Home’ is a subjective, multi-faceted phenomenon formed by personal beliefs, culture and prior experiences (Manzo, 2003, p. 48). The concept of home presents a challenge for designers on how to craft space that fulfils the complexity and diversity of home and doing so in an institutional setting.

It necessarily follows, then, the increasing demand for end of life care services in Australia and the growing discussions surrounding home-like design qualities within the hospital environment, it is prudent to identify what users perceive to be important design elements in end of life spaces. Patient and family experience in health environments is well established but less so in the health staff population. Hence, the aim of this study is to identify what design elements nursing staff perceive to be important in end of life patient rooms and explore whether a difference in preferences and perceptions exist between the current literature and nursing staff providing end of life care.

This research reports findings from the first stage of a multistage participatory design research case study in which a furnishing item is designed in consultation with nursing staff. The intent of this study is to contribute to the overall knowledge base surrounding the design of end of life spaces within a hospital context.

2. Methods

This qualitative case study grounded in social science mixed method data collection (Teddlie and Tashakkori, 2009), was utilised to identify what nursing staff perceive to be important design elements in end of life spaces within the hospital context. The study was conducted in the Royal Adelaide Hospital (RAH) Emergency Extended Care Unit (EECU) in Adelaide, South Australia. The RAH is a public, metropolitan hospital and at the time of this study, the RAH EECU was one of the largest Emergency Departments in Australia (SA Health, 2016). In 2006, The South Australian Government announced a new Royal Adelaide Hospital (nRAH) was to be constructed and replace the Royal Adelaide Hospital. In September 2017 all medical care transitioned to the nRAH and the Royal Adelaide Hospital closed down. It was identified that these circumstances categorised the RAH EECU as an unusual and ‘extreme’ case (Flyvbjerg, 2006, p. 230).

2.1. Ethics and Participants

Human Research Ethics approval was granted from the Central Adelaide Local Health Network (CALHN), the overarching authority of the RAH, and the University of South Australia’s Human Research Ethics Committee. Purposeful sampling of key informants (N=10) was used to select participants for the focus group interview. As key informants (National Health and Medical Research Council, 2007, p. 22), participants were selected on the basis of relevance and knowledge; hence, the inclusion criteria stipulated that participants were nursing staff who provided end of life care in the RAH EECU. All participants were female and their experience as a nurse ranged from 4 to 46 years, Figure 5: Participant Nursing Experience

On average, participants had 7.2 years of experience nursing in the RAH EECU. One participant reported having less than a year’s experience nursing the RAH EECU whereas four participants stated they had over ten years’ experience nursing in the RAH EECU, Figure 6: Number of years nursing in the RAH EECU. One nurse did not disclose the number of years they had provided end of life care in the RAH EECU.
2.2. Data Collection

An exploration of documentation drawings of the RAH provided an understanding of the hospital in its broader context, spatial connections and hierarchy. Photo documentation of the interior design of the EECU revealed the design qualities, such as spatial layout, form, materiality, lighting, colours, textures and patterns, and furniture (Groat and Wang, 2013, p. 417). A semi-structured focus group interview with the RAH EECU nursing staff enabled discourse between the Author and participants. The open questions provided rich insight into the lived experiences of providing end of life care in a hospital as well as their perceptions of important design elements in end of life spaces, Appendix. The interview was audio taped and transcribed verbatim. In addition, supporting field notes documented verbal and non-verbal cues of participants.

2.3. Data Analysis

The interview transcript was post-coded using thematic analysis through a three stage coding procedure: open coding, axial coding and selective coding (Liamputtong and Ezzy, 2005, p. 267-8). The physical artefacts such as diagrams from the spatial evaluation were examined using on a four stage direct analysis based on the visual anthropology approach of Collier (2004, p. 43). The data was triangulated to identify converging lines of enquiry and develop a rich understanding of the case (Yin, 1984, p. 92).

3. Findings

The study findings outlined in this section are summarised into the seven themes which emerged from the spatial evaluation and focus group interview data: (i) private dedicated end of life room, (ii) privacy, (iii) home-like components, (iv) ventilation and smell, (v) light and light fittings, (vi) facilities for visitors, and (vii) furniture and fixtures, Figure 7: Design Elements Identified by Nursing Staff
3.1. Private dedicated End of Life Room

In an open question to provide context, participants were asked to describe their ideal end of life space. 100% of participants responded and coded at a high N=18 instance rate. Participants reported that they “don’t have any specific end of life care facilities” in the EECU. Instead, there are four single bed rooms, known as side rooms, which participants aim to use for end of life patients, Figure 8.

It was observed that each side room was equipped with a private ensuite and window; participants described that the rooms are quieter and more private than other spaces in the EECU. A participant reported that the side rooms were their “gold standard” for end of life care. Thus, these responses indicate that nurses observe their built environment and design qualities of space. A private, single bed end of life space was coded at a high rate (N=10), no participants reported a desire for a shared room configuration.
Participants (N=8) stated that the side rooms were not designated end of life rooms. Participants discussed the logistics of a dedicated room including staffing (N=4), practicalities of an empty room (N=2) and whether families would feel a sense of isolation (N=2). The response to this open question suggested that the participants hold definite opinions regarding the preference of room type for end of life patients.

3.2. Privacy

Privacy was coded N=10 occurrences, detail codes associated with privacy included shutting the door (N=4) and general privacy (N=6). Participants did not discuss the curtains in the wards. This suggests that privacy was discussed in relation to the single bed rooms so curtains in the wards may not be at the forefront of participants’ minds.

Participants emphasised the importance of privacy during the end of life phase, particularly for visitors and family, and the ways in which they balance nursing care with providing families and visitors the opportunity to be with patient.

Cause you don’t go in there that often and be intrusive. You go in there for a reason. To indicate if they need pain management or for turnings and mouth care and just personal stuff. But you do not try to stay hovering around; you let the family cry and do whatever they want to do. You don’t try to invade their space. (Participant)

3.3. Home-like Atmosphere

A home-like atmosphere was coded at a high N=18 rate (N=7 sense of home and N=11 home-like components). Participants described the current design atmosphere as clinical and expressed their aspirations for the end of life spaces to evoke a sense of home. “It’s so clinical. You need to have something that feels more like their home”. Participants reported N=3 instances that there is no time for family and visitors to decorate rooms with personal belongings as end of life is imminent for patients in the EECU. These results suggest that a home-like environment is desired but needs to be created using design qualities such as furnishings and home-like components in favour of patients’ personal belongings.

Home-like components were coded N=11 occurrences. Participants listed seven specific home-like components including a TV, artwork, oil burner, music, soft furnishing, blanket and telephone should take place of personal belongings in creating a space that evokes feelings of familiarity and comfort, Figure 9: Home-like components Identified by nursing staff.
3.4. Ventilation and Smell

Ventilation and smell of patient rooms and cubicles was a recurrent theme with N=7 instances. The discussion was divided between responses regarding ventilation (N=3) and the necessity for oil burners, diffusers or candles (N=4) to improve the aroma in patient rooms.

Adequate ventilation because there’s a lot of people in there and you shut the door, so if you have five to ten people in a very, very confined space... It’s not conducive. It’s very hot and stuffy. (Participant)

Participants reported that the windows in the EECU are openable but are locked, which was consistent with the observation that 100% of awning windows were shut in the side rooms and wards. Patients and visitors can request a key from maintenance to open the window. This suggests while ventilation is available it is not easily useable.

3.5. Light and Light Fittings

Participants response about light and light fittings were coded at a low (N=6) rate. Specific responses about natural light were coded only twice whereas artificial light and light fittings were coded at a higher frequency (N=4). Participants reported that softer artificial lighting in end of life spaces as being important aspects of the built environment to create a sense of calm.

An Emergency Department is a violent, 24 hour, brightly lit, like a Casino kind of space and we’re trying to create a spot somewhere that’s calm. (Participant)

This is consistent with the spatial evaluation which observed fluorescent ceiling lighting and wall light above the patient bed. It was observed, that the windows in the EECU all had blinds that were partially or completely shut, limiting the amount of natural light penetrating into the rooms, Figure 10: Image of windows in a ward in the RAH EECU (Author) A participant described that the blinds were “broken and crappy” which suggests that faulty blinds and equipment could be a contributing factor for obstructing natural light into patient rooms.
3.6. Facilities for Visitors

Facilities for visitors were discussed N= 15 instances, of the responses N=8 reported the desire for sleeping facilities for visitors and N=7 responses regarding tea and coffee facilities. N=4 responses spoke generally about providing “the option for them [visitors] to stay overnight” and having sleeping facilities within the patient room for visitors and family. A daybed was coded only once whereas N=3 responses proposed that a double bed for a patient and their partner or family member would enrich the end of life care experience.

Another thing that would be nice as well would be a double bed... For the patient and their partner. Or even if it was my mother, I could easily crawl into bed with my Mum and hug her. Like, it’s just so clinical, it’s like it doesn’t feel like it should be a priority. (Participant)

N=7 participant responses placed accessible tea and coffee making facilities in high importance, Figure 11. One participant stated that providing each end of life space with their own tea and coffee making facilities would be their principal recommendation for improving the end of life facilities. Participants reported that facilities for visitors foster a supportive healing environment and a key design aspect in end of life care spaces.
3.7. Furniture and Fittings

Furniture and fixtures were coded N=10 instances, specifically, N=7 responses focused on chairs which resulted in three sub-categories, comfortable chairs (N=4), matching chairs (N=2) and daybed (N=1). The participants placed a high emphasis on the type of chairs in the ECCU commenting on the comfort and coordination of design as key elements that create a positive end of life care space.

The participants did not report on the visitor chair to patient bed ratio. During the spatial evaluation it was observed that there were three visitor chairs in a four bed ward, and one chair in a single bed side room. The number of chairs available for visitors is contradictory to the room capacity, as evidenced by a participant commented that “you have five to ten people” with a patient at end of life.

The quality of the facilities and equipment produced N=3 responses despite this being a strong theme in the spatial evaluation. A converging line of inquiry was identified regarding the quality of visitor chairs, it was observed that a visitor chair was worn and in one case ripped, similarly a participant commented that the chairs where “ripped and dirty”. These results suggest that nurses are observing and recalling the impact loose furniture has on the patient and visitor experience of the built environment.

4. Discussion

In questions where participants were asked to describe their ideal end of life space 100% of responses described a single bed room. Thus, room type is at the front of recall about end of life and the impact the built environment has on the experience of end of life. Despite the conversation in literature surrounding the benefits of room types (Williams, 2015), participants expressed definite opinions that a private room is a key design element. Participants reported that end of life is impending in the ECCU; a single bed room ensures visitors can grieve and show emotion while a private space supports a patients need for privacy and dignity.

It has been proposed that end of life spaces should evoke a sense of home to reduce the stress experienced by patients (Wood et al., 2015, p. 84). Recommendations to create a home-like environment include space for personal belongings such as photographs of family and friends to create feelings of familiarity and serve as reminders of life (Olausson et al., 2013, p. 241). Seamon (1979), Somerville (1997), and Wardaugh (1999) posit that control and personalisation contributes to feelings of at-homeness. However, participants’ responses differed to current literature regarding the ability to personalise rooms. In the Emergency Department patients are acutely unwell and end of life can be imminent. Participants reported that there is no time for family and visitors to decorate rooms with personal belongings. As such, it was suggested that home-like components including a TV, artwork, oil burner, music, soft furnishing, blanket and telephone could take the place of personal belongings in creating a home-like space.

Bromley (2012) identified lighting options and temperature control contributes to a patient’s sense of control (Bromley, 2012, p. 1060). It was observed that bright, fluorescent lights above the patient bed were a main source of light in the end of life spaces. Participants identified the need for softer lighting which could be achieved by incorporating different light sources and dimmable options. While participants identified natural light was a desirable design quality participants did not report on views from windows and whether views impact health outcomes. The growing body of research regarding hospital design asserts that a window with a view of nature connected patients with positive memories, the meaning of home and personal life stories (Timmermann et al., 2013, p. 122). Ulrich’s (1984) study quantified the impact of a view and discovered patients who had a room with a view of trees had shorter postoperative stays, fewer moderate and strong analgesic medication and fewer negative evaluative
comments from nurses (Ulrich, 1984, p. 421). This suggests that, unlike architects and environment psychologists, a view to nature may not be at the forefront of nurses’ minds and any direct questions may unintentionally be leading questions.

In an open question where participants were asked the meaning of end of life care a nurse described, “It’s providing comfort to the patient and to the relatives. It’s not just the patient you care for”. Participants identified that their role was not only to provide nursing care to patients but to support and guide families through the end of life phase. As a result, the presence of facilities for family and visitors was at the forefront of recall regarding the desired design elements in an end of life space. This reinforces the findings of previous research in relation to the presence of a patient’s supportive network provides connectedness and feelings of being loved (Olausson et al., 2013, p. 239-241).

5. Conclusion

In this study, nursing staff identified significant elements in the design of the physical environment in end of life spaces. Whilst the majority of results align with current literature concerning hospital design and palliative care spaces nursing staff held definite opinions that a single-bed, private room type is a key design consideration for end of life spaces. The data obtained from this study supports two interesting conclusions. Firstly, nurses identified that their role was not only to provide nursing care to patients but to support and guide families through the end of life phase. As a result, the built environment requires facilities for visitors as well as patients. Secondly, participants identified that time prevented personalisation of rooms but instead home-like components and furnishings are integrated into the room to evoke a sense of comfort and familiarity. Extending the participant criteria to a larger sample including patients, families, support and administrative staff could have provided greater insight into the design end of life care spaces in the RAH EECU. Further research across all stakeholders concerned in end of life care should be considered to examine whether a consensus exists regarding the design qualities in end of life spaces.

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**Appendix: Focus group interview questions**

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<th>Table 1: Focus group interview questions.</th>
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<td><strong>Interview Questions</strong></td>
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<tr>
<td>1. What does ‘palliative care’ or ‘end of life care’ mean to you?</td>
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<td>3. How long do patients typically spend in the RAH Extended Care Unit for palliative care?</td>
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<td>5. How would you describe the design of the end of life care facilities in the Emergency Extended Care Unit?</td>
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<td>7. What would be your ideal end of life space?</td>
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<td>9. What areas of the design of the Palliative Care facilities within the EECU could be improved?</td>
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<td>11. What sort of furnishing item would assist you in providing care for Palliative patients?</td>
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<td>2. How does providing end of life care make you feel?</td>
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<td>4. Can you describe the typical patient journey from when they arrive at the RAH Extend Care Unit?</td>
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<td>6. What are the strengths of the design of the EECU?</td>
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<td>8. In what ways can patients personalise their room?</td>
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<td>10. What type of care of care do you provide at end of life?</td>
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<td>12. How do you manage privacy at end of life?</td>
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The Impact of Thermal Comfort Criterial on Energy Consumption of Residential Buildings

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Abstract: In Australia, the current Nationwide House Energy Rating Scheme adopts a variation of the ASHRAE 55-2013 adaptive thermal comfort method with a criterion of 90% acceptability. It has been debated that such a high acceptability requirement may be too strict for residential buildings, and a criterion of 80% or even 70% acceptability may be adequate. This study evaluates the impact of thermal comfort criteria on space cooling energy requirement in three typical climates (Melbourne-heating dominated, Sydney-balanced heating and cooling, Darwin-cooling dominated) in Australia through building simulation. The results show that under both current and future climates (assuming a global warming temperature of 2°C), the decrease from 90% to 70% in the acceptability has minor or no impact on housing cooling energy consumption in Melbourne and Sydney. However, it may have significant impact on space cooling energy consumption in Darwin (saving more than 40%). It was found that for high-set lightweight houses in Darwin, easing the acceptability limits will increase energy star rating by 3.6 stars and 1.6 stars under current and future climates respectively. It was also found that for both current and future climates easing the acceptability limits from 90% to 80% has greater impact than reducing from 80% to 70%.

Keywords: Adaptive thermal comfort; acceptability limit; cooling load; future climate change.

1. Introduction

Hoyt et al. (2009) pointed out that to achieve thermal comfort, the high energy consumption of air-conditioning is not really necessary and large amounts of energy can be saved through allowing air-conditioning systems a wider range of indoor temperature fluctuation. Nicol (2017) collected the information from dwellings in a range of climates and buildings, and found a very wide range of indoor temperatures in dwellings. This study by Nicol (2017) suggested that the adaptive behaviors of building occupants occur when buildings are mechanically heated or cooled as well as when they are naturally ventilated and free-running.

The adaptive method was developed from field studies in mainly naturally ventilated office buildings (Nicol and Humphreys, 1973, 2002, 2010; Auliciems, 1981; de Dear, Brager, and Cooper, 1997; de Dear and Brager, 1998; Humphreys, Rijal, and Nicol, 2013) by relating indoor operative temperatures
(acceptable ranges) to prevailing outdoor temperatures. The acceptable range is the comfort temperature band within which the great majority of people, described by the percentage of acceptability, are adequately comfortable. The acceptability limits largely depend upon the occupant group, such as age, health, social strata, expectation, etc. This acceptable temperature range is wider than ‘ideal’ conditions and would encompass feeling such as ‘slightly cool’, ‘slightly warm’ and ‘neutral’. Thermal comfort is subjective and personal, and there may be no single condition that is comfortable for all the occupants at any given time. Hoof and Hensen (2007) pointed out that the heating and cooling capacities required would be prohibitive if 100% of occupancy time has to be met, and it was debatable on how realistically indoor temperature ranges can be acceptable in residential buildings.

Nowadays there are three international standards commonly used to evaluate the thermal environments: ISO 7730-2005 (International Standard Organization 2005), ASHRAE 55-2013 (American Society of Heating, Refrigeration and Air-Conditioning Engineers 2013) and EN 15251-2007 (European Standard 2007). The Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD) method developed by Fanger (1970) is the basis of ISO 7730-2005 and the Graphic and Analytical Comfort Zone methods in the ASHRAE 55-2013 standards. Both ASHRAE 55-2013 and EN 15251-2007 adopted the adaptive thermal comfort method. It is based on the adaptive principle that occupants are active and not passive (the PMV method) relating to their thermal environment, i.e., “If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort” (Nicol, Humphreys, and Roaf, 2012). To do that, occupants may change their clothing, posture, activity, etc. or change their surrounding environment using windows, blinds, fans and in certain conditions mechanical space heating or cooling. Under the hypothesis of adaptive thermal comfort that people gradually lessen the human response to repeated environmental stimulation through both behavioral and physiological as well as psychological adaptation, and past thermal history will modify the occupant’s thermal expectations and preferences, people in warm climates will prefer higher indoor temperatures than those living in cold climates (de Dear and Brager, 1998).

The ISO 7730-2005 standard does not incorporate the adaptive thermal comfort method, but specifies the thermal indoor environment to be within 70% of the acceptability limit for naturally ventilated buildings (Hoof and Hensen, 2007). Both EN 15251-2007 and ASHRAE 55-2013 standards adopted the adaptive thermal comfort method for the evaluation of the indoor environment of naturally ventilated buildings. For naturally conditioned spaces, ASHRAE 55-2013 specifies the acceptability limit to be 80%.

There are a variety of climates across Australia, from the tropical north to the temperate south-east (such as much of Victoria and Tasmania). Currently, the Australian Nationwide House Energy Rating Scheme (NatHERS) adopts a variation of the ASHRAE 55-2013 adaptive thermal comfort method with a criterion of 90% acceptability (Baharun, Ooi, and Chen 2009). It has been debated that such a high acceptability requirement may be too strict for residential buildings, especially for tropical regions. It is arguable that a criterion of 80% acceptability proposed in ASHRAE 55-2013, or even 70% in ISO 7730-2005 may be adequate for Australian residential building applications. Although there are many studies on thermal comfort and energy efficiency of residential buildings (Yoshino et al., 2006; Han et al., 2007; Chen and Zhu, 2007; Hong et al., 2009; Romerco et al., 2013; Tweed et al., 2013; Derbtz et al., 2014), few studies were conducted to analyze the impact of the acceptability on the building energy performance, especially for Australian housing. This study aims to investigate the impact of acceptability limits of indoor temperature on residential building energy performance under current and future climates across Australia through building simulation using AccuRate (Delsante, 2005).
2. Simulation of the impact of acceptability limits of indoor temperature on residential building energy performance


In this study, the energy performance of residential buildings is simulated by the modified version of AccuRate, which allows a variation of thermostat settings (Ren et al., 2013). AccuRate was a benchmark software of NatHERS (http://www.nathers.gov.au, accessed 29 June 2017), which was developed by coupling a frequency response building thermal model (Walsh and Delsante, 1983) and a multi-zone airflow model (Ren and Chen, 2010). Taking into account the building fabric and local climate, AccuRate automatically switches the building operation between natural ventilation and mechanical air conditioning if mechanical air conditioning is required to satisfy the occupant thermal comfort. It calculates a whole year’s energy requirement for space heating and cooling (H/C) at a time step of one hour. Based on the annual total H/C energy requirement, a star rating between 0 to 10 stars is assigned to the residential building for a specific climate zone using the star bands defined by the Nationwide House Energy Rating Scheme (NatHERS, 2012). Zero star rating means the building shell does nothing to protect the occupants against outdoor environment. Occupants of a 10 star house are unlikely to need any artificial heating or cooling (NatHERS, 2012). The more stars, the more energy efficient the house is. The AccuRate engine was tested satisfactory against BESTTEST (Delsante, 2004).

The thermostat settings used in AccuRate for house energy rating are based on the Protocol for House Energy Rating Software published by Australian Building Codes Board (ABCB, 2006). For heating, a thermostat setting of 20°C is used for living spaces (kitchen and other spaces typically used during the waking hours). 15°C is used from 24:00 to 7:00 and 18°C from 7:00 to 9:00 and 16:00 to 24:00 for sleeping spaces (Delsante, 2005). For the cooling thermostat setting, a combination of the adaptive thermal comfort method (ASHRAE 55-2013) and the new effective temperature (ET*) by Aynsley and Szokolay (1998) was used, which took into account air temperature, air speed, mean radiant temperature and humidity (Delsante, 2005; Baharun, Ooi, and Chen, 2009). The neutral temperature and the cooling effect of air movement are given by:

\[
T_n = 17.8 + 0.31 T_{om} \quad (1)
\]

\[
\Delta T = 6(U-0.2) - 1.6(U-0.2)^2 \quad (2)
\]

Where: \(T_n\) = the neutral temperature in °C, i.e. the temperature at which occupants feel neither too cold nor too warm; \(T_{om}\) = the mean monthly outdoor temperature in °C; \(\Delta T\) = the cooling effect of air movement in °C; and \(U\) = the air movement speed in m/s, limited to 1.5 m/s (Delsante, 2005).

In AccuRate, the cooling thermostat is set equal to the neutral temperature defined in Eq. 1 for the corresponding climate zone, up to a limit of 28.5°C, above which both are taken to be 28.5°C. The upper and lower limits of the comfort zone at 50% relative humidity is taken to be \(T_n \pm T_{al}\) (\(T_{al}\) is the upper/lower temperature bandwidth of the comfort zone, 2.5 °C was used in the current version of AccuRate, corresponding to the 90% acceptability limit in ASHRAE 55-2013). Taking into account the cooling effect of air movement, the extended upper temperature limit at 50% relative humidity will be \(T_n + T_{al} + \Delta T\).

Three different levels of acceptability (category A for 90%, B for 80% and C for 70%) are introduced in the standards ISO 7730 and ASHRAE Standard 55. In this study, these three levels of acceptability are used for simulation to evaluate the impact of acceptability limits on residential building thermal performance. The upper/lower temperature bandwidth (\(T_{al}\)) of the comfort zone is shown in Table 1.
2.2. Local Future Climates under Global Warming

Adaptive thermal comfort criteria in different climates have different impacts and obviously have most impact in hot climate zones (de Dear and Bragger, 2002). There are 69 climate zones across Australia, as defined by NatHERS (2012).

AccuRate contains 69 Typical Meteorological Year (TMY) weather files with hourly data over a period of one year for each corresponding climate zone. The main weather parameters are dry-bulb air temperature, absolute humidity, wind speed and direction, atmospheric pressure, cloud cover, direct solar irradiance and diffuse solar irradiance.

The TMY files were composed using the weather data centered around 1990 from the 1980s to 2000s. They are used as the reference climates for building simulation. With a global warming scenario (e.g., 2°C) being given or projected by the model for the assessment of greenhouse gas induced climate change, climate changes in Australia can be simulated using Global Circulation Models (GCM) (Wang, Chen, and Ren, 2010). In this study, the GCM of CSIRO MK3.5 (Gordon et al., 2010) is used to predict changes in the monthly-mean local ambient temperature, relative humidity and solar radiation since 1990 in relation to the global warming temperature. Then the future hourly weather data are constructed using ‘morphing’ approach (Belcher, Hacker and Powell, 2005) as described in Eqs3-5.

\[
T = T_0 + \Delta T_m \quad (3)
\]

\[
RH = RH_0 + \Delta RH_m \quad (4)
\]

\[
l = (1 + \alpha_m) I_0 \quad (5)
\]

Where: \(T\) = the projected future hourly dry-bulb ambient air temperature in °C; \(RH\) = the projected relative humidity in %; \(l\) = the predicted solar radiation intensity in W/m²; \(\Delta\) = the change in corresponding weather parameter; \(\alpha_m\) = the percentage change of solar radiation in %; subscripts 0 for the reference climate and m for monthly-mean.

The Paris Agreement of climate change set out a global action plan to keep global temperature increases by the end of the century to a manageable 2°C (Paris Agreement, 2015). In this study, the global warming temperature of 2°C is used for Australian future climate projections.

2.3. Description of the Residential Buildings

In Australia, around 70% of the dwellings are detached houses (Murray and Dale, 2015). To illustrate the impact of the acceptability limits on the energy requirement for air conditioning, two detached houses of different sizes and constructions (House 1 – heavyweight and House 2 - combination) are used for simulation in three typical climate regions (Melbourne - heating dominated, Darwin - cooling dominated

\[
\begin{array}{|c|c|c|c|}
\hline
\text{Acceptability} & \text{temperature} & \text{bandwidth} & \text{Source} \\
\text{%} & (K) & & \\
\hline
90 & 2.5 & ASHRAE Standard & 55-2013 \\
80 & 3.5 & ASHRAE Standard & 55-2013 \\
70 & 4.0 & European Standard & 15251 \\
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and Sydney - balanced heating and cooling). Both houses have the common concrete slab-on-ground floor construction. House 1 is a two-storey double brick cavity detached house. It has four bedrooms, a kitchen/family area, a living/dining area, a rumpus, a study, a TV room, a laundry, a separated room, a toilet and a double garage, with a gross area of 267.9 m² (195.4 m² air-conditioned). House 2 is a single-storey detached house with colourbond external wall (steel cladding on 90 mm stud). It has four bedrooms, a kitchen/family area, a dining/lounge area, a laundry, a separated bathroom and toilet, with a gross area of 160 m² (140.8 m² air-conditioned). In this study, for both houses the floor plans are maintained, and changes are made to ceiling insulation, wall insulation, window types, infiltration controls, etc. to achieve energy star ratings (under current climate and the acceptability of 90%) of around 6 stars for House 1 and 3 stars for House 2 in the three cities. House 1 with 6 stars is chosen to represent new housing stock built since June 2011 that satisfy current National Construction Code (NCC) energy efficiency standard, and House 2 with 3 stars represent housing stock built 1990-2004 (Ren, Paevere, and McNamara, 2012). These 2 houses are evaluated for all the 3 regions under current and future climates.

A high-set (fully raised off the ground by 2.32m) lightweight house (House 3) is chosen to represent a typical passive house designed for tropical and sub-tropical regions. It is a single-storey house with weatherboard external wall and timber floor, which has three bedrooms, a kitchen/living/hall, a laundry, a separated bathroom and toilet, with a gross floor area of 90.7 m² (70.8 m² air-conditioned). The high-set lightweight house is only evaluated in the tropical region – Darwin.

3. Results: Case Study Simulations

The results under current (TMY) and future climates (with global warming temperature of 2 °C) are shown in Figures 1 and 2 for Houses 1 and 2 respectively. It can be seen that under current and future climates, for both houses, the decrease from 90% to 70% in the acceptability limits has relatively minor or no impact on the cooling loads in Melbourne and Sydney. However, it may have significant impact in Darwin:

- **House 1**: the cooling loads are reduced by 3.1% (0.2 star increased from 6.1 to 6.3 stars) and 2.3% (0.2 star increased from 3 to 3.2 stars) under current and future climates respectively;

- **House 2**: the cooling loads are reduced by 13.7% (1 star increased from 3.1 to 4.1 stars) and 13.3% (0.9 star increased from 0 to 0.9 star) under current and future climates respectively.

It can also be seen that the decrease from 90% to 80% in the acceptability limits has greater impact on cooling load than that from 80% to 70%.

With the global warming temperature of 2°C, for both houses with the acceptability limits of 90%, 3 stars are lost in Darwin (6 to 3 stars for House 1 and 3 stars to 0 star for House2) due to significant increase of cooling loads (see Figures 1 and 2).

With the acceptability limits of 90%, the global warming has increased 1.4 stars for House 1 and 1.7 stars for House 2 in Melbourne due to reduction in the heating loads, while in Sydney it reduced 1.8 stars for House 1 due to significant increase in the cooling loads and increased 0.3 star for House 2 due to the reduction in the heating load being greater than the increase in the cooling load.

<table>
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<th>Current climate</th>
<th>Future climate</th>
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Figure 1: Sensitivity of space H/C loads to indoor thermal acceptability limits under current and future climates for House 1 in Melbourne (top), Sydney (middle) and Darwin (bottom).
Figure 2: Sensitivity of space H/C loads to indoor thermal acceptability limits under current and future climates for House 2 in Melbourne (top), Sydney (middle) and Darwin (bottom).
In warm tropical climates, lightweight buildings may achieve better thermal comfort after sunset by removing unwanted heat quickly. In tropical and sub-tropical regions in Australia, there are high-set lightweight houses, which are raised off the ground to facilitate cross ventilation to cool down the buildings quickly at night. House 3 is a lightweight house with timber/uPVC frame single glazed clear glass windows and medium size gaps of the windows and doors. Its floor is raised 2.32m off the ground with under floor space totally open to the surroundings. The impact of easing the thermal comfort criteria on its energy performance under current and future climates in Darwin is shown in Figure 3.

![Figure 3: Sensitivity of space H/C loads and star to indoor thermal acceptability limits under current (left) and future (right) climates for House 3 in Darwin](image)

Under current climate, with the easing from 90% to 70% in the acceptability limits, the cooling load is reduced by 45.5% and the energy star rating increased by 3.6 stars (from 3.4 to 7 stars). Under future climate, the easing of the indoor thermal acceptability limits will reduce the cooling load by 22.8% and the energy star rating increased by 1.6 stars (from 0 to 1.6 stars). In terms of cooling load and star rating, for both climates the easing from 90% to 80% in the acceptability limits has greater impact on the cooling load than that from 80% to 70%.

It can also been seen that with the global warming of 2°C, the cooling load is increased significantly (by around 72% under the acceptability limit of 90%). This results in the energy star rating falling 3.6 stars and 5.4 stars under the acceptability limits of 90% and 70% respectively.

4. Conclusions

This study used building simulation software (AccuRate) to investigate the impact of the indoor thermal acceptability limits on the housing energy requirement for space cooling in three typical Australian climate zones (Melbourne – cooling dominated, Sydney – balanced heating and cooling, and Darwin – cooling dominated). The case study shows that under both current and future climates (with global warming temperature of 2°C), the easing the acceptability limits from 90% to 70% has relatively minor or no impact on the cooling loads of House 1 (heavyweight) and House 2 (combination) in Melbourne and Sydney. However, it may have significant impact on the cooling loads in Darwin – a tropical region in Australia. With the easing from 90% to 70% in the acceptability limits, the cooling loads were reduced by around
13.5% and the energy star rating increase by around 1 star for House 2 under current and future climates. Under both current and future climates, the acceptability limits have greater impact on the medium weight colourbond slab-on-ground (House 2) than on the heavy double brick cavity houses (House 1). For high-set lightweight houses typical in the tropical north (House 3), the impact is greater than that for House 1 and House 2. Under the current climate and with a decrease from 90% to 70% in the acceptability limits, the cooling load is reduced by 45.5% and the energy star rating increased by 3.6 stars for House 3. It was also found that the easing from 90% to 80% in the acceptability has greater impact on the cooling loads and energy star rating than that from 80% to 70%.

With an assumed global warming temperature of 2°C (target of Paris Agreement by the end of this century), this degree of climate change has significant impact on building energy performance for all of the three houses in the three cities. In Melbourne, the impact on House 2 is greater than House 1, and in Sydney the impact on House 1 is greater than House 2. In Darwin, the most impacted house is House 3 (lightweight), and the least impacted is House 1 (heavyweight). Considering the houses built now will last in the building stock for the next 50 years or more over this century, the impact of global warming on residential building energy performance should be taken into consideration for building designs.

References


Example of Medical Information on Asbestos

Transdisciplinary Research in Architectural Science

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Abstract: In recent years, there has been an increase in discussion of the role transdisciplinary research can play in many fields of study, opening the questions of its definition, similarities and differences with other seemingly similar approaches. This paper discusses the importance of the transdisciplinary research using the example of integration of medical and architectural information when evaluating building materials. Specific focus is on the impact building materials present for human health, which is one area of study which cannot belong solely in architecture or health sciences, and consequently requires some collaboration or integration between these disciplines. It is proposed that transdisciplinary research offers a significant platform for study of health impacts of building materials but also for research in architectural science in general. This paper examines a range of studies related to human health impacts from one building material, asbestos, observing the key patterns in the used research strategies. Based on this analysis, it is possible to identify and recommend an effective transdisciplinary approach. The core value of this paper is that it contributes to development of new research practices which can foster more effective development in architectural science.

Keywords: Transdisciplinary research; toxicity; building materials; asbestos.

1. Introduction

In recent years, the need for pro-sustainable change has accelerated interest in a variety of research approaches capable of bringing solutions to problems which are too complex for one discipline on its own. The importance of the multidisciplinary, interdisciplinary and transdisciplinary research approaches reflects the need to move away from specialisation of knowledge towards integrations. Each of these approaches assumes a constructive relationship between at least two bodies of knowledge, conventionally seen as belonging to separate academic disciplines. However, each of these approaches assumes different relationships between the collaborating disciplines. Generally, multidisciplinary research is seen as drawing on knowledge from different disciplines while staying within their boundaries, while interdisciplinary research is considered to provide a more coordinated and coherent approach both in analyses and synthesises, creating more explicit bridges between disciplines (Choi and Pak, 2006).
Generally, the early 1970s are attributed articulation of these terms, with both appearing in the dictionaries around this time (Choi and Pak, 2006).

One obvious problem with engaging with transdisciplinary research is a lack or relative imprecision of its definition. Although listed in reputable dictionaries, as already observed by Choi and Pak (2006) these define transdisciplinary through reference to interdisciplinary, without explaining the differences between the two. However, the developing scholarship in the area of transdisciplinary research provides more helpful definitions.

2. History of the Term Transdisciplinary Research and its Definitions

It has been noted that the articulation of the term transdisciplinarity occurred independently in two different places at the start of the 1970s. Swiss psychologist Jean Piaget used the term ‘transdisciplinarity’ at a seminar on interdisciplinarity in the universities held at the University of Nice in 1970 (Piaget, 1972; Barnstein, 2015; Nicolescu, 2002). Piaget only briefly proposed transdisciplinarity as a higher stage to succeed interdisciplinarity by providing a total system without firm delineation between disciplines (Piaget, 1972; Barnstein, 2015). However, the same year, an American doctoral student, Jack Lee Mahan, independently produced a dissertation which also proposed transdisciplinary inquiry as way of transcending disciplinary boundaries in an attempt to bring continuity to inquiry and knowledge (Barnstein, 2015).

Reflecting these early definitions, transdisciplinarity can be seen as providing holistic view of the dynamic system while subordinating individual disciplines to this view of the whole (Choi and Pak, 2006). Examples of such approach are structuralism and Marxism. Despite the initial enthusiasm for transdisciplinarity, this approach did not become common nor did it enter the dictionaries during the 1970s (Choi and Pak, 2006).

Since the 1990s, transdisciplinarity has been increasingly discussed, with two significant schools of thought dominating the file: the Nicolescian approach and the Zurich approach (McGregor, 2015b; Augsburg, 2014; Segalàs and Tejedor, 2013). Professor Basarab Nicolescian, a Romanian quantum physicist based in Paris, started working on the methodology of transdisciplinarity during the late 1970s. In 1987, he established the CIRET (International Center for Transdisciplinary Research) in Paris, but more importantly in 1994, Nicolescu took the lead in formulation of the Charter of Transdisciplinarity at the First World Congress of Transdisciplinarity held in Portugal (Augsburg, 2014; McGregor, 2015b; Nicolescu, 2002). Nicolescian approach is described as theoretical and focused on development of methodology for creative unified knowledge beyond the disciplines capable of dealing with complexity (Augsburg, 2014; McGregor, 2015b). At its core, this approach is described as ‘complementing of disciplinary approaches,’ because of the inherent assumption that complexity is a fundamental feature of reality (Barnstein, 2015).

Nicolescian approach is still an active line of transdisciplinarity, not superseded by the Zurich approach, which was developed in 2000, at the International Transdisciplinarity Conference in Zurich (Augsburg, 2014; McGregor, 2015b). Nicolescu was initially involved with the Scientific Council for this conference (McGregor, 2015b). This conference defined transdisciplinarity as:

Transdisciplinarity is a new form of learning and problem solving involving cooperation among different parts of society. Transdisciplinarity research starts from tangible, real-world problems. Solutions are devised in collaboration with multiple stakeholders. (Segalàs and Tejedor, 2013)
As a result of this conference, the Swiss Network for Transdisciplinarity Research (often abbreviated as td-net) was established. This approach has been described as phenomenological because of its focus on application in context, specifically on research which can solve real-life, practical problems (McGregor, 2015b). On that level, it is no longer bound by the sciences, but ready to integrate scientific knowledge with the real-life solutions. However, this opens the Zurich approach to criticism from the Nicolescu and others for the lack of methodological clarity: how can trans-sector transdisciplinary problem solving take place within the constraints of real-life (McGregor, 2015b)?

In recent years, transdisciplinarity has been increasingly associated with sustainability (Felt et al., 2016; Segalàs and Tejedor, 2013; Lang, et al., 2012). The reasons for this are obvious: climate change and sustainability problems are frequently recognised as complex and wicked, and such links were already recognised by the 1992 United Nations Conference on Environment and Development in Rio de Janeiro (Segalàs and Tejedor, 2013; McGregor, 2015a; Barnstein, 2015). Conceptually, transdisciplinarity always aspires towards an integration of previously disperse knowledge, and this inherent trend becomes extremely important when approaching real-life sustainability-related problems.

3. Transdisciplinarity in Architectural Science Research

From an architectural perspective, it is important which disciplines are being integrated in the transdisciplinary research, and this is an area of some debate. In 1975, Piaget was criticised for relative exclusion of humanities with an assumed definition of disciplines limited to only science and an overemphasis on ‘technicism’ (Squires, 1975). However, in 2008, transdisciplinarity has been focused to set up a dialogue between the knowledge in natural or technical sciences and the humanities or social sciences (Darbellay et al., 2008). Both Nicolescuian and Zurich approaches allow for such integrations.

For architectural research, a useful definition of transdisciplinary research is that it aims to overcome the inadequacies of academic knowledge when responding to real social problems (Hoffmann-Riem et.al., 2008). In order for this to be achieved, any number of relevant divides could need overcoming, and the transdisciplinary research can be seen as transgressing through any number of relevant bodies of knowledge in order to extract a complete insight on the problem in question, and develop an integrated solution. In recent years, examples which include a wide range of seemingly unrelated bodies of knowledge have been reported. For example, Johann Tempelhoff’s research on water engages with social science, environmental and earth science, public health, humanistic psychology and musicological dimensions (Barnstein, 2015).

Transdisciplinary knowledge production in architecture has been described as ‘a fusion of academic and non-academic knowledge, theory and practice, discipline and profession’ (Doucet and Janssens, 2011). This is where transdisciplinary research can provide high value to architectural research, as it can address one of the most enduring divides important to architecture: the one between the professional practice and academic research. In contrast to relatively pure methods of the traditional discipline-bound research, transdisciplinary research develops new methods around the specific problems, at times developing more hybrid, uniquely appropriate methodological approaches.

The impact of building materials on human health presents one area where multiplicity of interests and research disciplines intersect. On one hand, the research in this area cannot belong solely in architectural or health sciences and consequently requires some collaboration or integration between these. On the other hand, many building and certainly all furnishing materials belong to a broader category of consumer goods, and the consumer appears encouraged to be selective. Existing standards and industry capabilities also have an impact on what is on the market. Fundamental to these complex decisions is the availability of scientific knowledge as to what presents as problem. Unfortunately, currently even that information can be difficult to find for many building and furnishing materials.

Within architectural science this problem has been recognised for a reasonable period of time. During the 1950s and 1960s, efforts in this area have reportedly faced challenges not only with the limitations of the existing knowledge and technical limitations, but also no clear publishing opportunities (Andersen and Gyntelberg, 2011). The establishment of the *Indoor Air* journal in 1991 created a focal publishing point for such efforts (Nazaroff, 2011). These works often involved more than one discipline and were scientific in nature, and much effort was invested into establishing this reasonably new field of study, by using conference papers and journal articles as the main form of communication.

Around the same period of time, more significant publications also appeared, taking the form of books summarising the information found in shorter research papers and articles. Curwell and March’s *Hazardous Building Materials* (1986) is one early example of such efforts. While seminal on its own right, and later expanded and re-published in 2002, this book captured well the problems inherent in most of the knowledge summarising literature in this area: it relied on existing standards. In 1986 in Britain this included accelerated recognition of the issues associated with lead and asbestos, while limited use of asbestos and lead in paint was still allowed in construction. In fact, during the printing of the book, British regulations on lead in paint changed rendering the appendix summarizing the lead content of various paints outdated by the time of book’s release (Curwell and March, 1986). Unfortunately, this trend of reliance on standards and similar regulatory frameworks continued in much of architectural science books in this area: even several reasonably recent publications have had elements out of date within the first couple of years since their publication (Pacheco-Torgal, Jalali and Fucic, 2012; Attmann, 2010; Fernandez, 2006).

The reliance on regulations in architecture and construction literature creates significant delays in dissemination of new scientific knowledge. The problem is that many regulatory changes occur only when there is an overwhelming body of knowledge proving that the problem is extensive. In many cases, it takes as long as 20-30 years for such complex body of knowledge to be developed.

As a way of overcoming this problem, this paper proposes direct transdisciplinary reviews and integration of medical information as a method which can achieve more up to date insights, and potentially even anticipate regulatory changes.

5. Transdisciplinary Review of the Health Impacts From Asbestos

Asbestos presents a good example for examination of the transdisciplinary integration of knowledge, primarily because much of the relevant information is known, making more sophisticated insights and
mapping the key trends over time easier. Although asbestos is not a significant contemporary material, the quality of insight this older example can provide exceeds what the more recent examples offer.

### 5.1. Architectural and General Knowledge on Asbestos

Information commonly reported on asbestos in architectural sources can be summarised as follows. The human use of asbestos began 4500 years ago, significantly increased only during the 20th century, and peaked during the mid-1970s (Park et al., 2012). Asbestos is a commercial name for a group of naturally occurring mineral silicate fibres of the serpentine and amphibole series, with crystalline weakness causing break into long thin fibres (Donaldson and Poland, 2012; Park et al., 2012). In building industry, such properties can help reinforce the surrounding material, such as cement and this is how asbestos was commonly used in products such as roof tiles, wall claddings, vinyl flooring. It was also used as sprayed fire protection, due to its chemical composition being resistant to fire.

It is also well known that asbestos exposure can lead to a series of different lung diseases, such as pulmonary fibrosis, pleural abnormalities, and malignancies (Liu et al., 2013). Already in 1898, association between the health problems and industrial use of asbestos was recognised, and by in 1950s and early 1960s relationship between asbestos exposure and lung cancer and mesothelioma was medically confirmed (Department of Labour, 2006). Unfortunately, these insights did not discourage the accelerated increase of its use since. Although regulations against certain uses of asbestos were introduced over time, more complete ban in many countries took place during the 1990s and the early 2000s (Paglietti et al., 2012; Olsen et al., 2011; Park et al., 2012). Through the early 2000s the global use of asbestos has been at about half of the global level at its peak in around 1977 (Park et al., 2012).

While this provides some useful general information about asbestos and why it should be avoided, only when looking beyond the architectural sources it is possible to learn more.

### 5.2. Medical Information on Impact of Asbestos on the Human Body

What is unlikely to be covered within architecture related sources is that the same feature that gave asbestos fibre good applicability in the construction industry is the foundation of the health problems that it causes. Unfortunately, although much research has been undertaken over the last few decades, the precise molecular mechanisms responsible for these adverse impacts from asbestos are not yet fully understood (Liu et al., 2013). What is known is that due to their small diameter, proportionally long length, and biopersistence, these fibres are easy to inhale, and once in the body they can cause a number of problem processes in the lung (Donaldson and Poland, 2012). We also know that the long biopersistent fibres can generate free radicals chronically that directly damage DNA, leading to a long accumulation of dose and interaction with cells of the immune system. In addition, the long fibres create a series of processes which inhibit positive cell functioning and trigger the defensive mechanism, which becomes chronic due to cellular inability to expel pollution of the size and proportion of asbestos fibre (Donaldson and Poland, 2012).

In recent years, a new line of medical investigation has been developing to address health problems from inhalation. It has already been established in toxicology research that the human body has the ability to self-heal and contemporary medicine is still unable to explain why these self-healing mechanisms are at times active or inactive (Philip, 2001). Studies on the relationship between genes and adverse reactions to inhaled pollution suggest that there is more than one genetic marker which makes an adverse reaction more likely, although the cataloguing of this is still in the early stages (Gaffney and Christiani, 2015).
Similarly, there is ongoing research into vaccines against well-known cancers associated with inhaled pollution, such as asbestos, but it is still to arrive to any tangible conclusions (Tan et al., 2014). However, the researchers in such areas warn of the possibilities of genetic discrimination when employment in high-risk industries in concerned, which could lead to social injustice (Gaffney and Christiani, 2015). Thus, even the researchers involved with such efforts recommend the focus should still remain on exposure reduction, as increases in exposure still hold a reliably linear relationship with increases in adverse reactions for all.

5.3. Lower and Harder to See Health Impacts from Asbestos

One of the challenges with research on asbestos is the long latency period between exposure to asbestos and presentation of health concerns, ranging from 15 to 40 years (Lui et al., 2013). This is related to the damage which asbestos fibres create due to the body’s inability to eliminate them effectively, which keeps certain protective and eliminative processes in a state of chronic overuse, thus gradually creating health problems (Sanchez et al., 2009; Donaldson and Poland, 2012). Delays like this have historically made conclusive research more difficult and contributed to blurring of the recognition of the problem. The evaluation of the health impact of asbestos have been further complicated by its natural variability, leading to suspicions that some forms are less harmful. Unfortunately, more recently it has become clear that this variability plays no real impact and that all asbestos should be treated as equally problematic (Kanarek, 2011; Paglietti et al., 2012).

While for many other harmful exposures, such as lead, there are available systems for measuring the level of past exposure, for asbestos questionnaires and interviews are used to obtain descriptive accounts of possible asbestos exposure (Pretez et al., 2008; Olsen et al., 2011). This, together with the long latency period, makes accurate studies very difficult, especially for low level exposures. This is especially problematic with the more recent increase in exposures which can easily be overlooked. Olsen et al. (2011) discuss the impact of asbestos in three waves: 1) First wave: the workers mining and milling raw asbestos and manufacturing asbestos products; 2) Second wave: the workers who used asbestos products in industry, such as the building industry; and 3) Third wave: the people diagnosed with asbestos-related diseases after a short-term and/or low-level exposure in the home or workplace, often due to activities related to home maintenance or renovation involving asbestos-containing building products.

The third wave of impact is the most common nowadays in many developed countries, yet also the most difficult to accurately quantify. In many developed countries, where it is possible to assume that products containing asbestos have been eliminated from the market, much of asbestos still remains built into existing structures, often as asbestos cement materials used in cladding, roofing or piping (Olsen et al., 2011), but also in or underneath vinyl and linoleum floors and as a sprayed compound (Level, 2017). Difficulties with planning any remedial or remodel work are in the fact that asbestos content varied between 5% and 95% even in very similar products (Dumortier and De Vuyst, 2012). Nowadays, prevalence of asbestos particles in air can be measured (Reid et al., 2013), which can help with remedial work. Unfortunately, much of work of this nature is carried out by low-skilled casual labour often with incomplete use of the now standard safety procedures (Dumortier and De Vuyst, 2012; Department of Labour, 2006). Unskilled, DIY removal of asbestos can be a particular problem because it is very hard to regulate it and monitor. Such exposures are also likely to be poorly reported in subsequent questionnaires and interviews about exposure and could remain unrecognised.
5.4. Replacements of Asbestos and the Future Learning from the Past Asbestos Lessons

Replacements for asbestos in construction industry are generally called ‘manmade mineral fibres’ and often take a similar physical form of long, thin fibres. Although generally these are considered to break transversely (absence of such beaks makes asbestos dangerous), concerns have been raised that a similar pathology could be observed even with these newer, replacement materials. Carbonari et al. (2011) studied in vitro impact of glass fibres, ceramic fibres and Wollastonite fibres (a form of asbestos), and found that naturally occurring Wollastonite fibres induced blood vessel formation in a similar fashion to that observed for other asbestos, while ceramics and glass did not exhibit such similarities. They concluded that the size and shape of the fibres and their chemical composition and biopersistence are important factors influencing the development of adverse effects and that very thin, persistent fibres are the most harmful (Carbonari et al. 2011). However, when evaluating for the impact of dermal exposure to ceramic fibres introduced as an asbestos replacement, a high level of dermal irritation was observed (Keić-Świerczyńska and Wojtczak, 2000). Unfortunately, this range of materials have been less studied and it is possible that over the years more scientific knowledge will become available explaining the health impacts from the materials now used to replace asbestos.

Another area where learning from asbestos could prove to be very relevant is the development and increase of use of nanotechnology, and this is where the greatest opportunities inherent in nanotechnology could prove to present the greatest health risk also. In nanotechnology, already known materials are cut at scales smaller than ever before and depending on the shape of the nanoparticles, the same basic material can produce a wide range of new and very different physical properties. Unfortunately, these obvious differences in physical properties come together with differences in impacts on human health. Researchers on microparticles have already remarked that nanoparticles are likely to impact the human body similarly to microparticles, such as asbestos (Donaldson and Poland, 2012; Sanchez et al., 2009; Pacheco-Blandino et al., 2012). If learning from the experiences with asbestos, the problem would seem to be the shape and size of particles and their biopersistency within the human body. For asbestos, it was the long this shape and very long biopersistency that produced inflammation and subsequent onset of disease after a long latency. Because this knowledge is available, it seems reasonable to use it when developing new materials with similar properties. However, texts that deal with design and the exciting opportunities nanotechnology offers fail to mention risks associated with such particles (Yeadon, 2011), indicating that the same mistakes might be repeated.

6. Discussion of Transdisciplinarity of the Example

The transdisciplinary review of medical and other information about asbestos and related materials demonstrates the advantages of investigating a problem from a wide range of perspectives. What this example shows is that while health risks of asbestos are reasonably well-known in the general population and amongst the architectural profession, additional information from medical circles expands the range and quality of insight. Architectural science and construction industry can benefit greatly from better understanding of the adverse impacts of these materials, yet the research on the actual health impacts has to take place in medical science. Unfortunately, because of their separate disciplinary bases, it is difficult to find reviews which bring as varied range of information together in one place, which possibly does not aid either of the disciplines involved. It is especially important for the existing medical information to be available to those developing and specifying new materials using mineral fibre, microparticles or nanoparticles, because this is where it is possible to make alternative choices.
It is important to understand that the medical knowledge has been treated in this paper as one unified discipline, although practically this is not the case. Reviewed medical information greatly range in scale and type of consideration from within the detailed understanding of impact of asbestos on cells, immunity and DNA to public health and epidemiology studies of the prevalence of health problems associated with asbestos. In lay terms, some of the researchers mentioned here were working in labs with experimental cultures, while others were conducting social science research on broad patterns in distributions of diseases. Clearly, such different studies required very different research methodologies and specific disciplinary or sub-disciplinary specialisations. Therefore, medical knowledge used in this review is in itself transdisciplinary.

Underlying this review is one of the significant reasons for greater inclusion of transdisciplinary approaches: the expansion of research insights in recent years, in different disciplines, paired with greater ease of access to this information. Jointly these forces allow for easier access to more information and calls for more multidimensional approaches to all science. But for this easily available information to become really useful it is essential to continually work on integration of the existing knowledge. Allowing the information to cross between disciplines and be integrated with other existing knowledge is the key.

The varied sub-disciplinary medical specialisations come with their own disciplinary jargon and assumptions. For the findings to be useful for audiences outside of these specific sub-disciplines, it is important to not only understand but also eliminate some of that jargon and adjust the language to be more easily understood by a more general audience. On this level, transdisciplinary research calls for translations and better communication between disciplines.

However, the greatest advantage of the transdisciplinary approach in this review is the real-life problem-centred search for all relevant information. The medical information was complemented by the real-life parameters, such as issues with the quality of implementation of the on-site safety. This is clearly reflective of the problem-solving approach to transdisciplinarity. The review presented in this paper also allows for the specifier of building components, the consumer of these to be empowered with an integrated summary of a wide range of existing knowledge when making their decisions. This linking between scientific knowledge and practice is another important characteristic of the transdisciplinary approach.

6. Conclusion

While architectural science of the past might have been unable to easily access a wide range of relevant information, the works of today and the future of architectural science have to acknowledge that transdisciplinary integration of knowledge is essential. In many ways, such integrations offer great opportunities for architectural science because of the inherent opportunities to integrate humanities, science, and technology with practice and industry innovation. Transdisciplinary integration could prove to be the most important aspect of the future architectural science.

This is especially important in the context of existing environmental and climate problems, and the high impact built environment puts on those. In order to develop more sophisticated sustainable solutions to the challenges facing the built environment of today, more information is needed on all commonly used components. For this, transdisciplinary integrations such as the one presented here could prove to be essential.

As this paper shows, transdisciplinary research might be still articulating its own definitions, but it shows great promise in supporting future development of architectural science.
References


Fisherman Settlement and Housing Innovation based on Bioclimatic Design in Surabaya

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Abstract: Fisherman settlements at the eastern coast of Surabaya are characterized by densely populated areas, some substandard houses and poor infrastructure conditions. Since some houses are crowded and substandard, innovation of the settlement and houses become very important. The innovation, as the process of introducing new idea should be directed to create more healthy and comfortable settlement, with adequate infrastructure, at least for the next 50 years. The aim of research was to find an innovative design of fisherman settlement and houses based on bioclimatic design. The bioclimatic design was chosen, since this was based on the strategy to give comfort to the house dwellers, bearing in mind the climatic conditions of the coastal environment and climate change in the future. Together those, improvement in the sanitation and infrastructure will create healthier fisherman settlement. The method used in the research surveyed in the crowded settlement and houses, to indicate the inadequate settlement and house design, which made the conditions uncomfortable to the dwellers. Mapping of the settlement’s infrastructure and sanitation was done, to indicate the improvement required. The result of the research shows that the innovation of the settlement and houses based on bioclimatic design was acceptable to the fishermen, if the innovation was matched to their activities.

Keywords: Bioclimatic design; fishermen settlement; houses; innovation

1. Introduction

The appropriateness of fishermen settlements is closely related to the sustainability of Surabaya city development in the future as a coastal city, especially in line with the occurrence of climate change and the rising of sea level (Isworo et al, 2014). Therefore, the good arrangement of fishermen settlement becomes very significant, mainly due to two things; firstly, by improving the quality of fishermen settlement, it will have a positive impact on the improvement of fishermen’s economy which is still at the lower level. Secondly, the importance of fishermen role in preserving coastal ecosystem in Surabaya in the framework of more extreme climate change (RTRW Surabaya, 2010-2020). Generally, the condition of fishermen settlement is barely making a noteworthy progress, fire-prone buildings, lack of sanitation, occupy unsuitable areas, scarcity of decent water and sanitation (Defiana et al, 2016). The Innovation or
new idea for the fishermen settlement and houses improvement were based on bioclimatic design, since this approach can provide the more comfortable living for the people. The research limitation is that this research should be done in two phases due to budget limitation. Phase one is the design proposal based on bioclimatic and phase two is the use of simulation of the proposed design. The intention is to integrate the practical implication with social implication. The social implication of the innovation of the settlement and houses also cover in phase two. This paper is based on the result of phase one while the phase two research has not been conducted.

2. Theoretical Review

2.1. Fishermen Settlement

Fishermen settlement is residential environment with basic infrastructure and the most population is fishermen that have a special bond among the people, and between the fishermen. The sea is a place for generating their income, though some of them are still connected with the land (Umbara, 2013). Along with city development, fishermen settlement develops in disorderly and denser due to natural population growth and urbanization.

The healthy living settlement is an environment consisting of organized healthy houses and have adequate infrastructure (such as roads, sewerage, toilets, clean water resources) and environmental centres, such as school, office, health/medical centre and place of worship (Patandianan and Zenaide, 2011).

Houses were built by the process, depended on the needs of the inhabitants (Turner, 1972). For example, adjusting the houses or adding some parts of the house. The settlement pattern usually follows the geographical condition of the natural environment. The existence of water affects the form of the settlement, be it linear or circle, following the physical shape of the water (Cakaric, 2010). The topographical aspect of the coast also dictates the settlement pattern and house form (Santosa et al, 2015).

2.2. Bioclimatic Design

Bioclimatic architecture was initiated by the thought of Olgyay (Olgyay, 1963). The Olgyay’s bioclimatic chart simply introduce the climate potential in determining the position of the thermal comfort zone. The accuracy degree of climate analysis holds the key factors in bioclimatic concepts which is useful for designing building (Zuhairy and Sayigh, 1993). In its development, bioclimatic architecture involving elements of form, material and its building system (Hyde and Sunaga, 2008). The characteristics of humid tropical climate are high humidity level, uncomfortable temperature and high wind speed in coastal areas.
Figure 12: Graphic of average air temperature, humidity and wind speed in Surabaya in 2009-2014 (source: BMKG Perak, 2014). With climatic conditions as mention above, if it is applied to the Szokolay psychrometric chart (2004), the expansion of bioclimatic comfort can be done through the utilization of wind speed.

3. Design Method

The data were collected through field survey to obtain primary data of settlement arrangement, physical conditions, settlements structure and people activities related to housing and existing spatial design. The respondents were 20% of the households. Settlement and housing condition were documented with photograph and drone to obtain an overview of activities, settlement structure and problems. The compilation data of survey result and secondary data are the main material that will be analysed to formulate the innovation of housing pattern and future housing design in accordance with fishermen need and coastal environment preservation.

Design criteria, arranged in this research, were based on questionnaire and field analysis results. Design criteria, based on natural condition of coastal, is the adequate distance between buildings and also distance between settlement and the coastal line.

Other criteria are the width of the road, which separates the building, is 2 meters based on the existing condition. Those distance between buildings aims to provide the flow of wind and the use of natural lighting. Wind flow is needed to keep the spaces not become moist. It is proposed to give a minimum 8-meter distance between buildings, at the side and back.

The design criteria to increase the fishermen welfare and social relation, are giving common space, fish processing space, marketing space and space for repairing the boats and nets. Fish processing space was needed to avoid the usage of road in front of fishermen houses to process their fish.

4. Result and Discussion

4.1. Climate Analysis

The climate was analysed as consideration in formulating the concept design with nature as the context. Climate data from BMKG Perak which is set as open country climate, were used as the data source. Climate data, used to formulate the concepts, are temperature, humidity and wind velocity in five years (2009-2014).
Highest humidity (85%) is in December-April and the lowest (66%) is in August-October. The lowest humidity, which is in October, is in dry season. The highest air temperature in October is about 29.8°C which is also the highest air temperature during the year. The lowest air temperature is in January which is also in the highest humidity. Average macro wind velocity is quite high in 7.4 m/s. The highest wind velocity in August was 7.8 m/s and the lowest wind velocity in December was 5.7 m/s. In those months fishermen usually do not go to sea.

4.2. Settlement Arrangement

In general, the existing condition of fishermen's settlement is in line with the coastline. The alleys leading to shore, houses orientation was set to face each other with the alleyway in the middle. Occupancy coinciding in the back and sides. The other condition is settlements adjacent to the coast (Figure 2).

![Wind direction](image)

Figure 13: Existing condition of fishermen settlement and the wind direction in research location (Source: Google Earth)

The proposed concept from this research is intended to settlement that is adjacent closely to the coast. The ideal H / W (Height/Width)-related carrier ratio is 0.5 for areas with low latitude (Oke, 1988). In relation to the proposed mass arrangement, the concept is to provide distance with H / W ratio of 2. This is based on the wind velocity in the open country which is very high, this opportunity could be used as a natural ventilation. This distance is adjusted to the existing condition in order not to make extreme changes but still achieves the availability of natural wind and natural lighting. However, settlement arrangement should still pay attention to coastline border (Figure 3).
4.3. Spatial Configuration

Based on the questionnaire results, the building area is limited to 24-50 m². The consequences are the limited spatial function and the activities blend in some spaces till utilizes the road to do some activities. To anticipate, it is proposed to provide communal space, flexible living room space and ease of access to the coast where their boats are moored.

In general, they use brick wall as a building envelope and roof tile. With that composition, it has a time lag of about 5-6 hours. This means that if the building envelope receives solar radiation at 15:00 then the inner space will receive heat at 20:00-21:00 at night. Therefore, it retains the existing building envelope material, including using wood materials for roof construction.

The proposed plan for the fisherman's house innovation is shown in Figure 5. This proposal considers also the material age and the possibility of developing business activities within the next 50 years. For toilet and fish processing space on the front, it can shorten the distribution network of clean water and used water.
There are 2 alternative house designs namely landed and floating level house. The landed level concept is made to adapt to the existing building character at this time. While the floating-level concept is proposed to reduce the impact when the tide occurs from the sea, in addition to add a flexible space at the first floor.

Spatial arrangement and function of existing buildings have been accommodated in the new space design concept considering all the functions that occur in the existing building. Flexible space that located on the outside of the 1st floor can be used to accommodate activities related to cleaning and processing fish catches and also for household activities. While flexible space on the inside can be used as a gathering space for families, kitchen and dining room for the residents. While bedroom with this new concept is increasing its number into 3 bedrooms with a more feasible size than the existing buildings.

The proposed building form considers several factors: the limitation of existing land so that the development towards the vertical. The material used are materials that available around the environment which is fabrication materials. The building orientation is north-south. Openings and ventilations are set according to the standards of the Ministry of Public Works (2010) which is 20% of the total area.

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**Figure 16: Proposal of Fishermen House Plan 1st Option**
4.4. Building Systems

Building system in the fishermen settlement consists of ventilation system, natural lighting system, sanitation, and drainage. With the distance between buildings that meet the H / W ratio then it has opportunity to provide open space. The availability of open space supports the application of WWR (window to wall ratio) 20-40% (Evans,) and uses the window shutters with jalousie model in order to set the opening angle.

4.4.1. Natural Lighting System

Narrow distance in existing condition will reduce the natural lighting utilization. Aperture is designed to meet the requirements of 10% of the floor space. The existence of these openings is expected to support natural lighting utilization. To meet the natural ventilation and natural lighting, building is designed for two floors.

4.4.2. Ventilation System

The distance between buildings that meet the requirements can create openings that face outside building. Those openings are likely to flow the wind and continue the natural lighting. In addition it can reduce the humidity inside the room. Good natural ventilation is with cross ventilation. Therefore it is proposed to provide the distance between building at back and side the building of 80 cm. This distance is predicted to provide the difference in air pressure that can deliver air.

Natural ventilation and lighting applications can reduce the use of electrical energy with standard of use of 35 watts / m2 / hr of overall energy (SNI 03-6389-2011). Therefore artificial lighting is used in spaces that have a long duration of occupany, such as flexible room.
4.4.3. Sanitation

According to Regulation of Ministry of Public Works Number 14/2010, every person needs about 60 litres of clean water every day. This is counted for all activities for example bathing, cooking, washing, drinking, etc. In this research, the needs of clean water supply would be more than 60 litres because they need more water to process the fish. Clean water should be supplied to the houses directly and to the communal space. Furthermore, it is need that the waste water system should be well maintained. The recycle water can be used by people in the site. Sewerage is need for fish processing also. Since they use much water to processing fish, in consequence they need good sewage system so the used water will not back to the sea directly.

4.4.4. Drainage

Drainage should meet the requirement of public works regulation. According to the regulation, drainage should be provided in settlement area to prevent inundation in the settlement. In existing condition, several houses were built on the vacant land without adequate infrastructure. Sewerage and drainage should be built bellow the alley way since the width of alleyway is only 2 meters.

Figure 18: Proposed Building Façade 1st Option

Figure 19: Proposed Building Façade 2nd Option
4.5. Affordability

The innovative housing design concept is possible to be realized with the help of cooperation of various related parties. Various related stakeholders such as local municipalities, local universities, private parties and the citizens themselves.

4.5.1. City government

City government could be the program providers. The program can also associated with self-help schemes which are provided by the central government. There are several self-help fund schemes, for example stimulant fund aid. With this stimulant fund, residents are expected to be stimulated to make more liveable housing. In accordance with the terminology of stimulant funds, the funds provided are in limited budget because it is only used as initial stimulation. A stimulant aid that is properly utilized by the community would stimulate not only the housing development but also would stimulate the people to be more developed in the future. The government would also able to arrange various housing development-related policies.

4.5.2. Local Universities

Local universities can help in facilitating the community in realizing the innovative housing design concepts. As a facilitator, the university can be a liaison between various parties that can accommodate the process. This facilitator also could help in assisting the community to decide several decisions related to the development.

4.5.3. Private Sector

The private sector may support community’s needs for development. The private sector does not support all needs, the community itself should provide some of the development’s needs. The private sector can help through the Corporate Social Responsibility (CSR) program. This is commonly done by several companies in support of prominent kampong programs in Surabaya.

4.5.4. Community

The community as the main actor should always be included in the development process. The role of community is very important since it is the one who will occupy this house. It involvement in the entire process is expected to gain their sense of belonging. The community can role also in providing some resources, including development funding, or sweat equity.

Development schemes can also be done differently. Funds from the government and CSR can be forged the construction of foundation, house on the 1st floor, post beam, to the roof. To add a wall and any other features on the 2nd floor can be a self-help by the community. Community can gradually build according to their abilities.
5. Conclusion

Innovation of settlement and houses based on bioclimatic design was suited with the existing condition. There is minimum distance between building which is generated from H/W and window to wall ratio (WWR). Those gaps will provide the opportunity for wind to flow naturally (natural ventilation) and daylight to enter the building. Furthermore, based on activities analysis, fishermen need a communal space for most of their activities especially for processing the fish. The design concepts also proposed the provision of communal space. Aside from answering the fishermen needs, this communal space also helps in implementing WWR for the buildings. This research has resulted in providing a settlement and housing concept that answer the need of spatial accommodation and answer the nature condition. It is needed a further research that deepening the bioclimatic design for fishermen settlement and other research that deepening the feasibility of providing this houses and settlement for fishermen.

References

Soundscapes in Public Libraries

A Case Study

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Abstract: This study investigates the acoustic conditions of reading spaces in a public library in Melbourne. An acoustics performance survey for library users was developed to evaluate library use, sound environment and noise, and a face-to-face survey was conducted in the library. The library users described their sound environment as ‘pleasant’, ‘appropriate’ and ‘calm’. The respondents of two reading rooms expressed a high level of satisfaction with sound environment and a neutral perception of noise, neither noisy nor quiet. Three main sources of noise, namely, ‘footsteps’, ‘people’ and ‘chair dragging’ were also found in the reading spaces. Interestingly, it was found that noise from lift, windows and doors opening, traffic and construction noise and noise from birds outside the building, resulted in the difference between user perceptions of noise between two reading rooms. It could be interpreted that this result was related to the library space layout, building design and building services. It is recommended that the link between architectural characteristics and space use pattern and acoustic performance be examined in public library buildings.

Keywords: Soundscape; acoustics; public libraries.

1. Introduction

Contemporary public libraries provide a wide range of services in addition to traditional reading spaces. Libraries have experienced increasing usage as they have transformed into multipurpose facilities, adapting to changes in technology and society. However, a substantial group of library patrons still come to the library looking for quiet reading spaces for concentrated study. Public libraries are reviewed regularly by local authorities to improve the services they provide to the citizens. As a result, more physical facilities are often provided to cope with the needs of library users and this has led to increasing noise levels, especially in quiet study and reading rooms (Franks and Asher, 2014). Proper acoustic conditions are believed to improve the effectiveness of comprehension and the development of cognitive skills. This study investigates the acoustic conditions of reading spaces in a public library in Melbourne. A pilot survey was conducted to examine overall user perception of the sound environment and noise in the library and also to identify main activities and space usage. Subsequently, two sets of user surveys were conducted in the reading rooms to investigate how the quiet spaces support users acoustically.
2. Soundscape and Noise

Soundscape can be defined as human perception of acoustic environment and it refers to the acoustic environment perceived, experienced and understood by people. Acoustic environment, however, can be defined as sound at the receiver from all sound sources as modified by the environment. It can be actual or simulated, outdoor or indoor, as experienced or in memory (ISO, 2014). The human ear senses sound based on the frequency and strength of vibrations, being affected by the listener’s health state and age. Thus, a complex sound such as noise in daily life can be difficult to measure as it is due to high frequency overtones. Acoustic comfort has been studied in the architectural science discipline using objective environmental measurements (Rajagopalan et al., 2016) and in combination with subjective measures (Chen and Kang, 2004; Dokmeci and Kang, 2012; Aremu et al., 2015). Noise can be defined as unwanted sound with random vibrations and no regular pattern. It is the major source of distraction in a concentrated work environment such as offices, classrooms and libraries. It was found that various distractions such as noise from telephones, conversations, building systems and office equipment were related to openness of space plan and such distractions from noise is one of the most frequent complaints among office workers (Brookes and Kaplan, 1972; Hedge, 1982; Sundstrom et al., 1994; Lee and Brand, 2005). Noise from conversations can adversely influence high level cognitive work such as logical thinking, continuous access to working memory and concentration, and interrupt these internal processes (Heerwagen, 2000). In public libraries, noise problems caused by deficient acoustic design can be divided into: noise coming from outside due to poorly insulated facades, lack of consideration in separating quiet and noisy areas, excessively reverberant spaces with limited absorption, and poor speech intelligibility. The level of acceptable noise depends on subjective psychological factors such as the state of mind and expectations of the listener as well as objective physical ones (Szokolay, 2014). Similarly, the responses to noise not only rely on its physical properties such as degree of loudness, but also on the individual’s sense of control (Sundstrom, 1986).

3. Research Design

The State Library of Victoria which is a landmark and cultural icon of Melbourne was selected as a case study. The library is located in the centre of the city and accommodates 1.8 million visitors annually. It also employs 259 staff as one of Australia’s oldest cultural institutions. Architecturally, it is a nineteenth century ‘Victorian Period Academic Classical’ style building listed on the Victorian Heritage database (Heritage Council Victoria, 2008; State Library Victoria, 2017). Figure 1 shows the floor plan of the library showing the two reading rooms namely Redmond Barry reading room and La Trobe reading room which is also known as the ‘Dome’. Acoustic evaluation was mainly conducted through user survey. The survey results were later analysed in conjunction with the sound levels measured in the respective reading rooms.
3.1. User Survey

An acoustics survey for library users was developed to evaluate the pattern of usage, sound environment and noise. The library use includes visit frequency, time spent, type of activity performed and space used. In order to measure the user perception of sound environment, the Swedish Soundscape Quality Protocol (SSQP) was adapted in the survey. Axelsson et al. (2010) developed ‘a principal components model of soundscape perception’, identifying the eight adjectives (i.e. pleasant, exciting, eventful, chaotic, annoying, monotonous, uneventful and calm) considered as equally distant and strong semantic concepts in relation to soundscape in the model. Employing the eight adjectives, perceptual ratings of sound environment were measured on a 5-point Likert type scales (5= strongly agree to 1= strongly disagree). The overall acoustic satisfaction was also questioned using a 5-point Likert type scales (5=very satisfied to 1=very dissatisfied). In order to identify noise sources in the library, a total of thirteen noise sources were identified and measured on a 5-point Likert type scales (5=very noisy to 1=very quiet). The noise sources include those resulted from user behaviour (e.g. conversation, page turning, footsteps, chair dragging), equipment (e.g. photocopiers, printers), building services (e.g. HVAC, lighting, lift), building (e.g. windows and doors opening), outside building (e.g. traffic, construction) and sound from nature (e.g. trees and birds). Participants were asked about the overall perception of noise using a 5-point Likert type scales (5 =very noisy to 1=very quiet). Two additional questions about noise control methods and preferred actions to be taken to control noise in the library were also asked. A two-page structured questionnaire, entitled ‘acoustics performance of public libraries for users’, was developed and a face-to-face survey was adopted to achieve a higher response rate. The survey was granted ethics approval.

3.2. Acoustic Measurement

Sound levels at various locations inside the selected rooms were measured using a Bruel & Kjaer handheld analyser Type 2270 (Figure 2). The sound is captured by the Brüel & Kjaer Prepolarized Free-field ½” microphone with a wide frequency range. The measurements were conducted in compliance with the Australian Standards for noise measurement (AS/NZS 2107, 2000) and the methods prescribed by Environmental Protection Agency guidelines (EPA, 1991). The microphone is placed away from shielding,
reflecting, or absorbing objects during the measurement. Sound levels were recorded continuously for a period of 15 minutes at each location. The average noise levels (LAeq) measured in dBA were used for analysis.

4. Results and Discussion

4.1. Pilot Study

A pilot survey was conducted in the foyer (refer to Figure 1) of the state library to understand the duration of stay, main activity and main location where users spend most of the time in the library. A total of 29 responses were collected through a face-to-face survey on a Friday afternoon. Less than half of the respondents used the two reading rooms (Redmond Barry reading room and La Trobe reading room as shown in Figure 1) which can be classified as quiet spaces, and the rest of the respondents stayed at the information centre on the ground or at the Dome gallery/Dome viewing balcony during their visits (Table 1).

<table>
<thead>
<tr>
<th>Location</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 2/Ground Information Centre</td>
<td>7</td>
</tr>
<tr>
<td>Redmond Barry Reading Room</td>
<td>8</td>
</tr>
<tr>
<td>La Trobe Reading Room</td>
<td>5</td>
</tr>
<tr>
<td>Dome gallery, balcony, etc</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>28</strong>*</td>
</tr>
</tbody>
</table>

*one missing response
The user perception of sound environment was measured by the eight adjectives identified in the Swedish Soundscape Quality Protocol (Figure 3). The respondents described their sound environment as ‘pleasant (4.15 out of 5)’, ‘appropriate (4.07 out of 5)’ and ‘calm (3.96 out of 5)’, reporting an overall satisfaction of 4.07. The user perception of noise was evaluated using the thirteen noise sources (Figure 4). The library users showed an overall perception of noise 2.61 out of 5 which can be interpreted as neither quiet nor noisy, close to a neutral point. They also pointed out ‘footsteps (2.69)’, ‘people (2.34)’, and ‘chair dragging (2.24)’ as main noise sources in the library.

Two additional questions about noise control methods and preferred actions to be taken were asked (Table 2 and 3). Half of the respondents indicated they used a noise blocker when they were distracted. Approximately one third would either ‘move to a quiet area in the library’ or ‘leave the library’ when they got distracted by noise. However, only one respondent would ‘make a complaint to the library’. Furthermore, a majority of the library users prefer ‘quiet zone signage’ to other actions such as background sound and building sealed.

Table 3: Noise control methods. Table 4: Preferred actions to be taken.

<table>
<thead>
<tr>
<th>Method</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Move to a quiet area in the library</td>
<td>7</td>
</tr>
<tr>
<td>Leave the library</td>
<td>4</td>
</tr>
<tr>
<td>Use a noise blocker</td>
<td>13</td>
</tr>
<tr>
<td>Make a complaint to the library</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>26*</td>
</tr>
</tbody>
</table>

*two missing responses

<table>
<thead>
<tr>
<th>Method</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quiet zone signage</td>
<td>18</td>
</tr>
<tr>
<td>Background sound</td>
<td>4</td>
</tr>
<tr>
<td>Buildingdoors/windows well sealed</td>
<td>6</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>31*</td>
</tr>
</tbody>
</table>

*multiple answers
4.2. Acoustics Performance of Reading Spaces

Library user surveys were conducted to investigate the sound environment and noise in two reading rooms: Redmond Barry reading room and La Trobe reading room (Figure 5). The Redmond Barry reading room has a floor area of 800 m² and a 15 m high ceiling and the La Trobe reading room has a floor area of 1000 m² with a 35 high domed ceiling.

![Image of Redmond Barry and La Trobe reading rooms]

Figure 5: Redmond Barry and La Trobe reading rooms

The sound level measured (according to the procedure explained in section 3.2) in the La Trobe reading room ranged between 49.6 dB and 51.2 dB. The sound level in the Redmond Barry reading room ranged between 45 to 47 dB. The balcony space of the Redmond Barry reading room is very popular among students as they provided quiet reading spaces. The sound levels measured in these spaces were between 44.5 to 45 dB.

The user perception of the sound environment in the two reading rooms is shown in Figure 6. A total of 74 responses from two reading rooms (N=37 from each reading room) were analysed and compared by mean scores. The respondents of both reading rooms described their sound environment as ‘appropriate’, ‘calm’ and ‘pleasant’, reporting the overall satisfaction of 4.05 with sound environment. This result is consistent with the result of the pilot study, which could be interpreted that the user perception of the library is likely to be in common regardless of space use or main activity, i.e. whether it is a quiet space or a space for other purposes. Figure 6 demonstrates the mean scores of the sound environment perceived by the library users in the Redmond Barry reading room (in blue) and the La Trobe reading room (in red).

To determine if differences between the acoustics perception of two reading rooms are statistically significant, an independent sample t-test was conducted. The purpose of the independent sample t-test is to test for a statistically significant difference between two independent sample means, which are the user perception of sound environment in ‘Redmond Barry reading room’ versus ‘La Trobe reading room’. In this circumstance the concern is not with the absolute values of means, but with the significance of the difference between them. It was found that the only adjective, ‘uneventful (p<0.05, two-tailed)’ showed a statistically significant difference between two reading rooms. The respondents of the Redmond Barry reading room described more ‘uneventful (3.17)’ than those of the La Trobe reading room (2.58).
To examine the sources of noise in the quiet reading rooms, the perception of noise was evaluated by the library users. Not surprisingly, the main sources of noise were found to be the same as those identified from the pilot study: ‘footsteps’, ‘people’ and ‘chair dragging’ (Figure 7). The library users expressed a neutral perception of noise, 2.21 in the Redmond Barry reading room and 2.51 in the La Trobe reading room respectively.

To determine if differences in noise between two reading rooms are statistically significant, an independent sample t-test was conducted (Table 4). Five noise sources out of thirteen showed statistically
significant differences between the Redmond Barry reading room and the La Trobe reading room: ‘Footsteps’, ‘Lift’, ‘Building’, ‘Outside building’ and ‘Outside’. These five sources were found to be relatively quieter except ‘footsteps’, however, differences are statistically significant. The respondents in the La Trobe reading room felt noisier with noise sourced from ‘Lift’, ‘Building’, ‘Outside building’ and ‘Outside’ compared those in the Redmond Barry reading room. Interestingly, the library users in the Redmond Barry reading room perceived more noise sourced from ‘footsteps’.

Table 5: Comparison of noise sources between ‘Redmond Barry’ and ‘La Trobe’ Reading Rooms.

<table>
<thead>
<tr>
<th>Source</th>
<th>Redmond Barry</th>
<th>La Trobe</th>
<th>t</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>People (conversation)</td>
<td>2.22</td>
<td>2.42</td>
<td>-0.86</td>
<td>70</td>
<td>0.39</td>
</tr>
<tr>
<td>Page turning</td>
<td>2.18</td>
<td>2.03</td>
<td>0.56</td>
<td>67</td>
<td>0.58</td>
</tr>
<tr>
<td>Footsteps</td>
<td>3.42</td>
<td>2.83</td>
<td>2.06</td>
<td>69</td>
<td>0.04*</td>
</tr>
<tr>
<td>Chair dragging</td>
<td>2.42</td>
<td>2.46</td>
<td>-0.15</td>
<td>69</td>
<td>0.88</td>
</tr>
<tr>
<td>Mobile device</td>
<td>1.86</td>
<td>1.97</td>
<td>-0.52</td>
<td>70</td>
<td>0.56</td>
</tr>
<tr>
<td>Books dropping</td>
<td>1.64</td>
<td>2.00</td>
<td>-1.59</td>
<td>70</td>
<td>0.11</td>
</tr>
<tr>
<td>Equipment</td>
<td>1.42</td>
<td>1.69</td>
<td>-1.51</td>
<td>70</td>
<td>0.13</td>
</tr>
<tr>
<td>Book trolleys</td>
<td>1.64</td>
<td>1.67</td>
<td>-0.12</td>
<td>70</td>
<td>0.90</td>
</tr>
<tr>
<td>HVAC/lighting</td>
<td>1.53</td>
<td>1.71</td>
<td>-0.90</td>
<td>69</td>
<td>0.37</td>
</tr>
<tr>
<td>Lift</td>
<td>1.33</td>
<td>1.83</td>
<td>-2.53</td>
<td>70</td>
<td>0.01*</td>
</tr>
<tr>
<td>Building</td>
<td>1.44</td>
<td>1.88</td>
<td>-2.06</td>
<td>70</td>
<td>0.04*</td>
</tr>
<tr>
<td>Outside building</td>
<td>1.28</td>
<td>1.72</td>
<td>-2.26</td>
<td>70</td>
<td>0.03*</td>
</tr>
<tr>
<td>Outside</td>
<td>1.17</td>
<td>1.69</td>
<td>-2.78</td>
<td>69</td>
<td>0.00**</td>
</tr>
</tbody>
</table>

* p<.05, ** p<.01 (2-tailed)

It can be seen that sound levels measured with the presence of occupants is higher in The La Trobe reading rooms compared to Redmond Barry reading room. In a previous study, Rajagopalan et al. (2016) measured the background noise levels without occupants in the state library. The authors found that the background noise levels measured in the La Trobe reading rooms were higher (40 dB) than those measured in the Redmond Barry reading room (38.5 dB). The reverberation time (RT) measured in the La Trobe reading room was up to 5.6 sec and the RT measured in Redmond Barry reading room was up to 2.6 sec. High volume of the La Trobe reading room contributes to the high RT. Furthermore, speech intelligibility was found to be worse in La Trobe reading room compared to Redmond Barry reading room. However, poor speech intelligibility corresponds to good speech privacy that can support group study environment. Building on previous research, it was found that noise sources such as lift, building windows and doors opening, traffic and construction noise from outside building, outside nature sound like trees and birds caused statistically significant differences between the noise perceptions in the two reading rooms. These noises are produced from building design and operation, the location and transmitted through the building facade. It seems that the La Trobe reading room has a lot more architectural significance which also attracts a large volume of visitors, compared to the Redmond Barry reading room.

5. Conclusion

Although public libraries have been transformed into multipurpose facilities and adapted to changes in technology and society, the role of traditional reading spaces is crucial to support a substantial group of library patrons who need quiet reading spaces for concentrated work in the libraries. It is evident that
proper acoustic conditions could improve the effectiveness of comprehension and the development of cognitive skills. This study investigated the acoustic conditions of reading spaces in a public library in Melbourne. An acoustics performance survey for library users was developed to evaluate library use, sound environment and noise, and a face-to-face survey was conducted in the library. The library users described their sound environment as ‘pleasant’, ‘appropriate’ and ‘calm’ regardless of their space use and main activity in the library. Acoustic performance in the two reading rooms was found to be acceptable based on both measured sound levels and user survey. The library users reported a high level of satisfaction with sound environment and a neutral to quiet perception of noise. Although three main sources of noise (‘footsteps’, ‘people’ and ‘chair dragging’) were also found in the reading spaces, the library users’ perception of the noise sources is closer to neutral and quiet except the footsteps in the Redmond Barry reading room. This can be explained by the old hardwood flooring in the room. Interestingly, statistically significant differences were found in building design related noises such as lift, building windows and doors opening, traffic and construction noise from outside building, and sound from birds outside. Although these noise sources do not seem to cause critical acoustic issues in the library, they are all related to the library space layout, building design and building services. Therefore, it is recommended that the link between architectural characteristics and space use pattern and acoustic performance in public library buildings be examined to achieve high levels of acoustic performance. The next stage of the study involves calculation of psychoacoustic descriptors for each room using the audio recordings.

Acknowledgements

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References


A Review of IAQ Standards and Guidelines for Australian and New Zealand School Classrooms

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Abstract: Information on indoor environmental conditions in Australian and New Zealand school classrooms is limited. The indoor environments in schools are less studied compared to other building types such as offices. Limited data and scientific studies on measurements of school environments, particularly on thermal conditions and indoor air quality (IAQ) are available. Moreover, majority of the studies have been conducted in the northern mid-latitudes. This lack of knowledge poses a big concern considering that children, unlike adults, are much more vulnerable, and are expected to perform work that is not optional and would almost always be new to them. This paper reports on the findings of a literature review that explores thermal comfort, particularly indoor air quality and ventilation requirements for Australia and New Zealand school classrooms. The objectives of the review are to identify national and international standards and guidelines associated with the provision of thermal environments and indoor air quality in educational facilities, to examine current knowledge on the relationship between indoor conditions and educational outcomes and identify findings of applicable indoor environmental quality (IEQ) research.

Keywords: Indoor air quality (IAQ); indoor environmental quality (ieq); school classrooms.

1. Introduction

Indoor air quality (IAQ) is recognized as one of the top five environmental hazards by the United States Environmental Protection Agency (US EPA). Numerous studies found that indoor pollutants may be 2 to 5 times, and occasionally more than 100 times higher than the outdoor (US EPA, 1993). Inadequate IAQ conditions have been found to be a cause for absenteeism and poor performance in both office and school environments (Daisey et al., 2003). Poor IAQ is also the source of respiratory and other health related issues (Csoobod et al., 2014). Although there are other pollutants and agents which characterise IAQ conditions (Stranger et al., 2008), indoor carbon dioxide (CO₂) concentrations and ventilation rates are commonly used as surrogates and indicators for air quality of indoor environments. Concentration levels exceeding 1,000ppm is an indication of insufficient ventilation and unacceptable conditions in relation to odours removal. Poor ventilation also result in unhealthy learning environments (Ferreira and Cardoso, 2014) and along with poor IAQ, are responsible for acute and chronic health effects (Annesi-Maesano et al., 2013), particularly respiratory health issues in young children (Taptiklis and Phipps, 2017).
An orientation of the literature suggest that there is no unified policies and guidelines for heating, cooling and ventilation in Australia, where each state has its own unique set of policies and guidelines and the provision of mechanical ventilation system is based on climate zones (Andamon et al., 2013). Furthermore, the IAQ regulatory framework in Australia is limited and there is insufficient information on the concentration levels of and exposure to pollutants in specific buildings types. In New Zealand, schools often endured poor IAQ with high indoor CO₂ concentrations and relative humidity, particularly in winter (Taptiklis and Phipps, 2017). Taptiklis and Phipps (2017) has also indicated that IAQ in New Zealand preschools is greatly under-researched. Information on the correlations between indoor environments, health and educational outcomes are sorely limited in both New Zealand and Australia.

2. IAQ in Schools

The scope of this review includes the best-practice standards and practices applicable to indoor air quality (IAQ) and ventilation within educational facilities in Australia and New Zealand. Other indoor environmental quality factors relating to thermal comfort, lighting quality (including daylighting), acoustic quality, odour quality (olfactory quality) and visual comfort are outside the scope of this review.

The method for undertaking the literature and policy review includes standard desktop searches of peer-reviewed publications, using online and scientific electronic databases including ScienceDirect, PubMed, Google Scholar, SAI Global, the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) and relevant guidelines from the New Zealand Ministry of Education.

Using a variety of search algorithms and combinations of key words, publications, policy documents, design guides and standards related to indoor environments, learning and school performance, educational outcomes, absenteism or health were sought. In addition, other articles and papers were reviewed as appropriate to provide background information on current conditions in education facilities. This paper reports on the key findings of a literature review that explores thermal comfort, particularly in indoor air quality and ventilation requirements for Australian and New Zealand public school classrooms.

3. Defining the Requirement for IAQ

As building designs trend towards energy efficiency to meet increasing demands of reduced energy consumption in buildings, the importance of indoor environmental quality (IEQ) is potentially being neglected. Poor IEQ in buildings is known to cause Sick Building Syndrome (SBS) and often related to indoor air quality (IAQ). Astolfi and Pellerey (2008) have identified IAQ satisfaction as the most important parameter in determining overall satisfaction with IEQ. ASHRAE (2016) defined acceptable IAQ as air with no known contaminants at harmful concentration levels, and in addition, 80% of the occupants do not express dissatisfaction, in terms of odours. Prescription of ventilation rates in standards and guidelines are deemed sufficient for acceptable IAQ. However, studies have shown these requirements are often not met (Daisey et al., 2003).
3.1. Indoor air pollution parameters

IAQ in a building is not constant and it is influenced by changes in building operation, occupant activity and outdoor climate. Indoor quality may be controlled by a combination of source control and ventilation. The standards for indoor air quality pertain to reducing the quantity of indoor air contaminants that are odorous, potentially irritating, and/or harmful to the comfort and well-being of occupants by providing the criteria for ventilation rates. The quality of indoor air is attributed to the amount of pollutants present in the indoor environment (Table 1). Bluyssen (2009) maintains that the concentration of these pollutants is dependent on:

- The emission rate of pollutants in the space;
- The ventilation rates of the space;
- The concentration of the pollutants in the ventilation air.

Exposure to these indoor pollutants can be affected by parameters such as ventilation rates, air velocity, temperature, relative humidity, and activities happening in the observed indoor space. Among these pollutants, carbon dioxide (CO₂) concentration levels are most commonly used as a surrogate and indicator for IAQ in many air quality related research and studies. Carbon dioxide is a simple and non-intrusive predictor is estimating ventilation rates, especially in high occupancy buildings such as schools and kindergartens (Hänninen, 2012).

<table>
<thead>
<tr>
<th>Groups</th>
<th>Subgroup</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical</td>
<td>Gases and vapours</td>
<td>Inorganic: CO, CO₂, NOₓ, SOₓ, O₃</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic: volatile organic compounds (VOCs), formaldehyde</td>
</tr>
<tr>
<td></td>
<td>Particulate matter</td>
<td>Fibres: asbestos (natural fibres), mineral wool (synthetic), ceramic (vitreous and crystalline structures)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Respirable suspended particles (RSP₃), PM10</td>
</tr>
<tr>
<td></td>
<td>Radioactive particles/gases</td>
<td>Particulate organic matter (POM): biocides, polycyclic aromatic hydrocarbons (PAH₅)</td>
</tr>
<tr>
<td>Biological</td>
<td></td>
<td>Micro-organisms, mould, fungi, mycotoxins, bioaerosols</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pollen, mites, spores, allergens, bacteria, airborne infections, droplet nuclei, house dusts.</td>
</tr>
</tbody>
</table>

3.2. Indoor carbon dioxide (CO₂)

The normal outdoor carbon dioxide (CO₂) levels range between 300 to 500ppm, and typical indoor CO₂ concentration levels range between 500 to 1,500ppm (Seppänen, 2006). Previously, ASHRAE Standard 62.1 (1989) recommended absolute values for indoor CO₂ concentration levels, minimum of 1,000ppm and a maximum of 2,500ppm. This 1989 guideline values were based on an assumed ventilation air rate (outdoor) of 7 Ls⁻¹ per person and an outdoor baseline CO₂ concentration of 300ppm. CO₂ poses no health concerns at the concentration levels generally found indoors. However, a study by (Satish et al., 2012) found cognitive ability diminished at 1,000ppm CO₂ concentration levels. Exposure to high concentration
levels also have health implications; occupants exposed to CO₂ concentration levels at 800ppm or more can suffer from tightness of chest and suffocation (Bluysen, 2009).

The measurement and analysis of indoor CO₂ concentration levels often assist to understand ventilation conditions within an indoor environment. Seppänen et al. (1999) suggest that the control of the ventilation is equivalent to control of CO₂ concentration levels in the same indoor space. Many studies have found classrooms with high indoor CO₂ concentration levels are potentially under-ventilated. Classrooms with ideal ventilation are typically where CO₂ concentration levels range between 600 to 800ppm (Figure 1).

![CO₂ ppm levels chart]

Figure 21: Carbon dioxide as an indicator of classroom ventilation. (Source: adapted from New Zealand Ministry of Education 2007, p16)

### 3.3. Ventilation

Ventilation is an effective measure to control indoor air pollutants, and is essential for the provision of thermal comfort of occupants, humidity control and odour removal in indoor environments. Although ventilation has no direct impact on occupants’ health, inadequate ventilation rates can affect indoor environment conditions and cause SBS (Seppänen et al., 1999). Furthermore, Sun et al. (2011) also found that inadequate ventilation can encourage the spread of infectious diseases and cause other undesired health issues.

Ventilation may also be the reason for high indoor humidity and dampness, which could result in microbial growth and consequently bring discomfort to occupants (Seppänen, 2006). Poor ventilation is a prevailing issue in schools as observed by the Schools Indoor Pollution and Health Observatory Network in Europe (SINPHONIE) study (Csobod et al., 2014). This extensive study of 114 schools in 23 European countries, found that 86% of values for ventilation rates were less than the desirable value of 4 Ls⁻¹ per child. High indoor CO₂ concentrations (above 2,700ppm) were found in classrooms in Australia due to inadequate ventilation (Luther and Atkinson, 2012). In New Zealand, ventilation rates were found to be 16 times lower than the recommended value of 8 Ls⁻¹ fresh air per person specified in Standards New Zealand 4303:1990 (Wang et al., 2016).

### 4. Standards and Guidelines

Although indoor air quality (IAQ) has been widely researched, there has been no agreement on a common standard (Olesen, 2004). International standards such as ASHRAE Standard 62.1 is the most commonly used guide for indoor air quality and ventilation (Olesen, 2004), and is used as the normative reference of many national standards (Standards New Zealand, 1990; Standards Australia, 2012). These standards are
essentially for the design of ventilation systems in order to meet health and comfort requirements of the built environments (Olesen, 1997).

A comprehensive standard that outlines the mechanical requirements of the ventilation systems is ASHRAE Standard 62.1 which specifies the minimum ventilation rates that is required to achieve indoor air quality suitable for human occupancy with the least negative health impacts. The previous 1,000ppm guideline value for CO₂ recommendation of ASHRAE (1989) was a guideline for comfort acceptability relating to odour removal and not a ceiling value for air quality. Although the 1,000ppm value was revised in the 1999 version of Standard 62.1, it is still widely adopted by numerous studies on IAQ, CO₂ and ventilation rates (Daisey et al., 2003; Shendell et al., 2004; Bakó-Biró et al., 2012). The 2016 and current version of ASHRAE Standard 62.1 (2016) specifies a revised steady state CO₂ concentration level of no greater than 700ppm (p40) above outdoor air levels, along with specified ventilation rates (Table 2).

Table 7: Minimum ventilation rates in Educational Facilities per ASHRAE 62.1-2016. (Source: adapted from ASHRAE 2016, p13)

<table>
<thead>
<tr>
<th>Occupancy Category</th>
<th>People Outdoor Air Rate</th>
<th>Area Outdoor Air Rate</th>
<th>Default Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L/s person</td>
<td>L/s m²</td>
<td>Occupant Density #/100m²</td>
</tr>
<tr>
<td>Classrooms (ages 5-8)</td>
<td>5.0</td>
<td>0.6</td>
<td>25</td>
</tr>
<tr>
<td>Classrooms (age 9 plus)</td>
<td>5.0</td>
<td>0.6</td>
<td>35</td>
</tr>
<tr>
<td>Lecture classroom</td>
<td>3.8</td>
<td>0.3</td>
<td>65</td>
</tr>
<tr>
<td>Lecture hall (fixed seats)</td>
<td>3.8</td>
<td>0.3</td>
<td>150</td>
</tr>
<tr>
<td>Art classroom</td>
<td>5.0</td>
<td>0.9</td>
<td>20</td>
</tr>
<tr>
<td>Computer lab</td>
<td>5.0</td>
<td>0.6</td>
<td>25</td>
</tr>
</tbody>
</table>

The benchmark of 1,000ppm is also adopted by Standards New Zealand NZS 4303:1990. The NZ standard recommends a fresh air requirement of 8 Ls⁻¹ per person in a class of 30 occupants, as cited in Designing Quality Learning Spaces: Ventilation & Indoor Air Quality (Ministry of Education, 2007). It also recommends more fresh air rate of 10-13 Ls⁻¹ per person for non-sedentary teaching spaces, such as gyms, where occupants are active. The NZ Standard prescribes ventilation based on the type of space and the number of occupants in the space, but does not indicate the area of the space (Table 3). In comparison, the Australian Standard AS 1668.2 (2012) sets out design requirements for mechanically ventilated buildings, based on the need to control odours, particulates and gases, to achieve acceptable IAQ. AS 1668 advocates minimum outdoor airflow rate between 10-12 Ls⁻¹ per person, and in addition, specifies a minimum floor area requirement per occupant. For example, 12 Ls⁻¹ per person and minimum floor area of 2m² per person in classrooms serving persons up to 16 years of age. There is little information on CO₂ or other indoor air pollutants exposure levels, minimum CO₂ concentration levels or emission rates in the specific building categories.
Table 8: Minimum ventilation for teaching spaces. (Source: New Zealand Ministry of Education 2007, p8)

<table>
<thead>
<tr>
<th>Type of space</th>
<th>Number of people</th>
<th>Fresh air requirement (litres per second per person)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classroom</td>
<td>30</td>
<td>8</td>
</tr>
<tr>
<td>Laboratories</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>Art, design and technology rooms</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>Libraries</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>Multi-purpose halls</td>
<td>150</td>
<td>8</td>
</tr>
<tr>
<td>Gyms</td>
<td>30</td>
<td>10-13</td>
</tr>
</tbody>
</table>

5. Current Conditions in Schools

Children spend the second largest portion of their time in schools and are a more vulnerable group due to their developing immune system (Csoobod et al., 2014; Taptiklis and Phipps, 2017). Classrooms in the US, Canada and Sweden were also reported to have CO₂ concentration levels exceeding 1,000ppm, and high CO₂ concentrations at 1,000ppm is associated with risen absenteeism (Shendell et al., 2004). A study of UK classrooms reported that occupants were exposed to unacceptable air conditions of CO₂ concentration of up to 5,000ppm (Bakó-Biró et al., 2012). Another study in Portugal across 51 elementary schools similarly reported high CO₂ concentrations of close to 2,000ppm (Ferreira and Cardoso, 2014). Fadeyi et al. (2014) also reported inferior IAQ of exceedingly high CO₂ concentration levels (> 1,600ppm) found in elementary classrooms in United Arab Emirates. In New Zealand, Wang et al. (2016) have measured high levels of CO₂ concentrations (exceeding 3,500ppm) in classrooms during school hours. Luther and Atkinson (2012) likewise found high CO₂ concentrations (> 2,700ppm) in Australian classrooms during winter, and concluded that poor IAQ is common in schools world-wide. Mendell and Heath (2005) have identified that students’ attention and performance are linked to ventilation rates. It is evident that deficient ventilation has direct impacts on health and students’ performance, yet IAQ and ventilation rates are rarely measured in schools (Daisey et al., 2003). Taptiklis and Phipps (2017) has indicated that IAQ in NZ preschools is greatly under-researched.

Standards for indoor environment conditions have been developed based on studies conducted with healthy and fit adults, and often in a workplace or office settings. School populations are much denser than offices; 4 times as many occupants per square metre as a typical office building (Chatzidiakou et al., 2012), with active children engaging in learning and non-sedentary activities. Furthermore, children are a more vulnerable group to poor IAQ conditions than adults. Thus, the application of IAQ requirements for offices is not appropriate for school environments. Moreover, in naturally ventilated schools, ventilation in classrooms largely depends on the opening of windows. Although well-placed cross ventilation strategies can offer effective ventilation (Luther and Atkinson, 2012), windows may not be open frequent enough, especially in cooler winter months, to avoid heat loss and thermal discomfort. This would result in high indoor CO₂ concentration levels (> 800ppm) (Taptiklis and Phipps, 2017). Whereas, a well ventilated space of CO₂ concentrations between 600 to 800ppm is considered conducive for learning (Kajtár and Herczeg, 2012).

This review outlines that current indoor air quality guidelines are informed by studies on working environments in office buildings and there is limited guidance to specific building occupancy types,
particularly school facilities. Moreover, although some guidance have been provided by authorities such as the National Health and Medical Research Council (NHMRC) and the National Occupational Health and Safety Commission (NOHSC), the regulatory actions related to indoor air quality in Australia in particular are limited (Brown, 2006). Furthermore, the selection of IAQ guidelines for the educational building categories should consider the protection of the sensitive population in this sector. The prescribed conditions and limits recommended by the standards often do not consider the impact on student performance. Limited data and inadequate clear documentation is available on the effects of poor indoor environments on the performance of schoolwork by students that much of the information have assumed that influences of indoor settings on adults have relevance to the influences of school environments on children (Wyon, 2004; Wyon and Wargocki, 2013). This knowledge gap presents opportunities to address the absence of quantitative studies on the current state of IAQ in schools. This review establishes the need for studies grounded on addressing the lack of clear documentation on the state of indoor environments in Australian and New Zealand school facilities backed by measurements and the relationship between aspects of indoor environments and student performance.

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Public Engagement in Urban Microclimate Research

An Overview of a Citizen Science Project

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Abstract: The term “citizen science” broadly describes public engagement in scientific research in collaboration with professional scientists. This paper discusses the application of citizen science in microclimatic research for a project recently funded by the Australian federal government. The aim of the project is to engage local communities across Australia in urban microclimate research and empower the public in adopting various mitigation actions. The different steps involved in the project, ranging from engaging councils and citizens, selection of precincts and measurement locations according to the strategic priorities of each council, designing instrumentation and cost-effective method of gathering high quality data are discussed. The main challenges anticipated in implementing the project at large spatial and temporal scale and how those challenges will be addressed are also explored.

Keywords: Citizen Science; urban microclimate; temperature; mitigation strategies.

1. Introduction

The term “citizen science” describes public engagement in scientific research in collaboration with professional scientists. The citizens are volunteers who participate in data gathering to assist with a large scale research (Shah and Martinez, 2016). With the advancement in technologies, Citizen Science has just entered into a new era of possibilities, including its latest applications in areas such as astronomy and earth observation (Schade and Tsinaraki, 2016). This interaction of scientists with citizens allows for public education and engagement in science and research to increase the awareness of problems that affect communities. It also provides assistance for the researchers to collect more data and meaningful observations than they could on their own. Citizen science is mainly driven by the engagement and dedication of many individuals. The European Commission white paper on Citizen Science (Socientize Consortium, 2014) identifies general public engagement in scientific research activities as a mechanism to improve science-society-policy interactions, alongside democratic research based on evidence and informed decision-making. This paper gives an overview of a Citizen Science project, one of the successful grants announced by the Minister for Industry, Innovation and Science, Arthur Sinodinos in May 2017, to mobilise a league of enthusiastic citizen scientists to assist Australia’s leading universities and scientific
organisations with their research. The aim of the project is to engage local communities in Australia in urban microclimate research and empower them for adopting various mitigation actions. The cost-effective method of gathering high quality data at large spatial and temporal scale is discussed. How the project directly engages people with environmental issues and their local environment are discussed and the potential challenges are identified.

2. Why Citizen Science?

Citizen science has the ability to provide public with practical and real-life opportunities to learn and implement the scientific method to solve problems facing their communities. Studies have shown the positive impact of citizen science on the public’s scientific literacy. A post survey of 700 citizen scientists showed that 78% of the participants felt that the project had led to processing scientific thinking as a result of making observations (Trumbull et al., 2000). The ways in which citizen scientists contribute to the scientific process vary from one project to another. Some projects involve participants in a single step of the research process, e.g., data collection, whereas others projects involve participants in multiple ways. Figure 1 shows various models of citizen engagement in science. This Citizen Science project will use at least two of the approaches including participatory experiments and data collection. To broaden the reach and impact of citizen science, Pandya (2012) recommended that new efforts should be made to engage community members as active participants in every aspect of the scientific process, where community members are partners in the design, implementation, and application of research; and where research questions are aligned with community priorities. As noted by Newman et al. (2012), the future of citizen science will likely be inextricably linked to emerging technologies. New technologies, such as mobile applications (apps), wireless sensor networks, and online computer/video gaming, show great promise for advancing citizen science and have potential to engage broad audience (Newman et al., 2012). For example, NASA’s longest running citizen science programs, The Globe Program, through the Globe Observer, have been engaging citizen scientists for data collection of cloud observations and mosquito habitat mapper via a free smartphone app, “GLOBE observer” (NASA, 2017). So far citizen science projects in Australia have mainly involved studying the ecology of urban, agricultural, and residential landscape, rare organisms, track invasions and migrations, documenting declines in species, conservation of sea creatures etc. and the application of in the built environment has been very limited. Therefore project brings opportunities for trialling innovative approaches using technologies such as wireless sensors and mobile app.
3. The Urban Microclimate Project

Urban heat island (UHI) is the most documented phenomenon of climate change (Landsberg, 1981) and is prevalent in many Australian cities. Uncomfortable outdoor environments and extreme heat adversely affect public health, particularly that of the elderly who are more vulnerable to heat (Loughnan et al, 2010; Nicholls et al, 2008). Extreme heat events have killed more Australians in the past 200 years than any other climate hazard, and have caused major economic disruptions (NCCARF, 2013). The four-day heat wave in Melbourne in 2009 resulted in 374 excess deaths, which mainly comprised seniors and people with cardiovascular problems (National Climate centre, 2009). Projected increases in heat-related mortality and associated morbidity will place pressure on emergency and health services. The Garnaut Review predicted that a 5°C temperature increase may result in a reduction of the Australian GNP of 1.3% by 2030. A number of mitigation strategies such as green spaces and cool materials are proved to be ameliorating the overheating effect and improving the health outcomes. High urban temperature decreases the potential of passive cooling techniques and enhances the use of mechanical cooling. Uncomfortably high temperatures also affect the physical and mental well-being of city inhabitants and the social and economic activities of a society. The increased temperatures also adversely affect the urban flora and fauna.

The social and economic activities of a society are also dramatically impacted by urban overheating as people tend to spend most of their time indoors during hot days. Urban warming seems to have an important impact on social behaviour and increased criminal activities (Cohen, 1990). Hotter urban climates also adversely affect the urban flora and fauna. Out of the approximately 375 species and 63,000
street trees currently planted in the City of Melbourne, a large proportion is vulnerable to climate change (Kendal & Baumann 2016). Thus, the UHI effect will be inflated by a reduction in leaf area, shade, rainfall interception and pollution reduction.

Considering the facts mentioned above, the main aim of this project is to work with local councils and citizens across Australia and design infrastructure for measuring urban heat island, overheating, and local climate change. The results will provide data required for citizens to understand, mitigate and adapt to extreme heat; and for policy makers to predict future health and energy needs and plan the urban built environment and open spaces. Importantly through data collection and participation, citizens will be empowered to respond to extreme heat through an understanding of influential factors.

The project is managed by a team of researchers from two universities: RMIT University, Melbourne and University of New South Wales, Sydney. The researchers are from building science and computer science disciplines, with majority of the members with building science background. This project is impossible to conduct solely by scientists who lack the resources to gather or analyse data on a large scale. Simultaneous measurement of microclimate at a number of locations using fixed stations need significant resources equalling to a number of research assistants working for significant number of hours. Moreover, the installation of permanent stations to collect data is very expensive compared to portable sensors proposed for this project.

4. Project Tasks and Milestones

The project methodology is explained in the form a number of tasks as described below. Various protocols are developed for selecting the measurement locations, recruiting the citizens, delivering and managing the equipment and performing the measurement during summer months. Citizens will be provided with necessary training enabling them to perform scientific measurements and use the mobile app interface specifically designed for this project. By performing the measurement, they can understand the parameters influencing the microclimate of selected locations and to roughly estimate the potential for major mitigation strategies.

4.1. Establish Council Engagement and Identification of Measurement Locations

Researchers will work with 12,200 local community members through 22 councils from various states representing different geographical locations. The locations will be selected based on factors such as density, population, physical features, overheating problems etc. Table 1 shows the name of the councils selected at each state. Multiple measurement locations will be selected in each area depending on the characteristics such as type of activities, urban density, surface materials, exposure conditions, solar radiation effects.

Councils participating in this project will be seen as a leading organisation with a proactive and precautionary management approach to the risks associated with climate change. The council citizens will gain knowledge about the various design features and materials that impact the local microclimate of their neighbourhood and be aware of the social, economic and environmental consequences of climate change. Better informed citizens can respond better to council’s climate change mitigation policies and climate change related legislations by the state and Federal Government. Ultimately it is hoped that as many numbers of citizens can be empowered and motivated to implement appropriate mitigation techniques to improve the microclimate in their home or neighbourhood.
Table 1: Preliminary list of councils

<table>
<thead>
<tr>
<th>State</th>
<th>Name of Councils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melbourne</td>
<td>Melbourne, Yarra, Stonington, Port Phillip, Glen Eira</td>
</tr>
<tr>
<td>Sydney</td>
<td>Waverly, Sydney, North Sydney, Leichhardt, Ashfiled,</td>
</tr>
<tr>
<td></td>
<td>Marrickville, Burwood, Canterbury-Bankstown,</td>
</tr>
<tr>
<td></td>
<td>Penrith, Blacktown</td>
</tr>
<tr>
<td>Adelaide-Queensland</td>
<td>Unley, Adelaide</td>
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<tr>
<td>ACT</td>
<td>Canberra</td>
</tr>
<tr>
<td>Western Australia</td>
<td>Perth</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>Darwin</td>
</tr>
</tbody>
</table>

After discussion with the officers from each council, few precincts will be selected for the measurement of micro climatic parameters including temperature, humidity, wind speed and solar radiation. Locations will be selected based on the characteristics such as density, intensity of the UHI, local activities, type of surface materials, exposure conditions, solar radiation effects etc. Figure 2 shows ‘Innovation District’, one of the precincts in Melbourne city council selected for the study. Bordered by RMIT University, the Queen Vic Market, the University of Melbourne and the Carlton Gardens, the Innovation District will be a place for exploring next generation pedagogy, next generation research, next generation vocational education and partnerships.

![Innovation District](image)

Figure 2: One of the precincts selected for measurement - Innovation district

4.2. Design and procurement of instrumentation

Properly developed measurement protocol in the form of assembly, calibration and distribution of instruments is very important. The engagement of the citizens will range from taking part in the experiments with handheld scientific grade equipment, using low cost sensors with mobile app, using a thermal comfort tool and a mitigation tool that will be developed for the project. A variety of
instrumentation ranging from high end scientific grade reference weather stations, kits including stationary Temp-RH sensors, portable Temp-RH sensors, portable infrared guns and infrared cameras, and low-cost sensors that can be easily used with the help of a mobile app will be developed. Reference weather station will be carefully placed at a height of 3.00 above ground surface but still lower than the BoM weather station. Security against tampering/vandals will be a consideration in the installation of these stations.

4.3. Design and development of mobile app

One of the main highlights of the project is the development of a free app which the citizens can download in their smartphones and view the data recorded by various instruments in real-time. Sensors will measure and transmit the data at specific intervals through Bluetooth Low Energy (BLE) technology. Some of the sensors are programmed to collect data over a period and these sensors will collect data autonomously, retaining data. Once time is up, app will remind user to collect data from sensor over BLE, will capture a maximum and a minimum and at what time these happen. The

4.4. Promotion and recruitment of citizens

Working closely with the university’s Media and Communications team, a communication strategy will be developed to engage local citizen and the wider community in the project and its findings. The project will be advertised through various local and national newspapers, social media websites, letters to citizens from local councils and community groups. RMIT University’s strong partnerships with the construction industry, professional bodies such as Australian Institute of Building, Royal Institute of Chartered Surveyors and Chartered Institute of Building; and local councils will help to grow participant involvement over time. Training for citizens will be provided through online interactive websites and face to face meetings conducted in the local councils. The citizens will be acknowledged in all the publications. The data will be made available to the public as per the term of use agreement for non-commercial use. The project will also be advertised through a custom designed project website, promotion on the RMIT and UNSW University websites, Melbourne and Sydney Forums organised by Australian Institute of Refrigeration, Air-Conditioning and Heating (AirRAH) and will be promoted as part of the National Science Week. Audio/video presentations will be shared through the project website and You Tube podcasting.

4.5. Data collection and data management

The sensors will be transported to various councils for distribution to participating citizens. Training for citizens will be provided through online interactive websites and face-to-face workshops conducted by the researchers. Websites provide an excellent platform for citizen engagement programs by making many of the traditional citizen science challenges more manageable. Issues such as efficient program management, citizen buy-in, quality assurance tools, volunteer recruitment, and marketing and communication mechanisms are all eased through the development and use of the website. Citizens will conduct the measurement at selected locations as per the prescribed measurement protocol. The data will be transmitted to the cloud via an encrypted wifi and/or 4G cellular system. Sensor laden drones and Energy Bus will be used to compliment the measurements. In addition to real-time viewing, the data collected by the sensors at various locations will be sorted and stored in a database. The appropriate format for the display of these data in the website will be decided.
4.6. Analysis and development of mitigation strategies

Citizens will use the mobile app and thermal comfort model developed to predict the subjective thermal comfort experienced at various locations. They will use a simple mitigation tool to understand various mitigation techniques and apply them in their homes and neighbourhood and estimate potentials of mitigation techniques.

4.7. Project Timeline

The total duration of the project is over two years. Table 2 shows the project timeline. It can be seen that the microclimatic measurement is planned for the summer months in the second year.

Table 2: Project timeline

<table>
<thead>
<tr>
<th>No</th>
<th>Activities</th>
<th>No of months</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Establish council engagement</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Identify measurement locations in each council</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Design and procure instrumentation</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>Design and develop the web based system and mobile app</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Pilot testing</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Promotion / engaging citizens</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>Actual Measurements and data collection</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>Analysis</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>YEAR 2017</th>
<th>YEAR 2018</th>
<th>YEAR 2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1-Q3</td>
<td>Y1-Q4</td>
<td>Y2-Q1</td>
</tr>
<tr>
<td>Y2-Q2</td>
<td>Y2-Q3</td>
<td>Y2-Q4</td>
</tr>
<tr>
<td>Y3-Q1</td>
<td>Y3-Q2</td>
<td>Y3-Q3</td>
</tr>
</tbody>
</table>

5. Benefits

Through participating in the measurements and viewing the measured data such as temperature, humidity, surface temperature etc. in real time using the app, citizens can gain thorough understanding about the parameters that influence the measured data. Subsequently the mitigation tool will help to understand various mitigation techniques and estimate their mitigation potentials. Citizens will then be able to engage in appropriate mitigation activities (planting trees, cool roofs, cool pavements, use of water, shading, and green roofs) that can improve the microclimate of their own residential and neighbourhood premises. This approach will help to transfer knowledge about the climate mitigation technologies to the participating citizens; involve them in the selection of appropriate mitigation measures through understanding of the effectiveness of the mitigation technologies; and promote their active participation in the implementation of mitigation techniques in their home and neighbourhood.

The data will be used to understand the existing urban characteristics affecting the microclimatic conditions in a number of locations simultaneously. Policy makers will be able to use the localised precinct based information to estimate the current cooling energy and peak energy demand and forecast the
future increase that need to be supported by the energy grid. Urban designers will be able to use the data to plan urban areas and open spaces. Areas having adverse effects due to lack of vegetation and inappropriate surface materials will be identified based on which Government can allocate resources for mitigation actions. Policies to improve microclimate that mitigate the effects of climate change and provide opportunities for physical activity, increase social engagement, and improve mental health can be developed. In summary, the results of the study can be used to map out the microclimatic data in various locations and to inform policies as outlined below:

- Predicting future cooling & peak demand: data for electricity modelling, Electrical power grid planning
- Identifying high health risk areas to prepare for emergency management
- Retrofitting buildings to adapt to climate change
- Planning urban areas and open spaces for better comfort using trees, shading, material use, and airflow
- Consistency between national standards and codes and state/territory planning standards

6. Challenges

For the citizen science project to be successful, strategic collaborations and partnerships with councils are very important. Getting people to contribute requires major effort. Therefore it is necessary to bring in the resources and participant base required to sustain projects over the long term. The primary challenges for most projects include maintaining funding for cyber infrastructure databases, and project leadership (Dickinson et al, 2012). Additionally, to have an effective program that can truly inform decision makers such as local governments, standardized monitoring protocols must be employed to ensure consistency and reliability among the data, regardless of the scale of the project.

A successful citizen science project needs to plan very carefully what outcomes it hopes to achieve, how it will attain and assess those outcomes, and how it will remain accountable to its citizen scientist participants so that citizen scientists get back at least as much as they put in. Druschke and Seltzer (2012) conducted a survey of participants before and after their citizen science project, Chicago Area Pollinator Study (CAPS), and discovered that even though the project was successful, they did not achieve the knowledge, attitudinal, and behavioural goals they had hoped for because of the failure to effectively engage citizen scientists and bring them into the collaborative research effort.

Citizen science is often most effective when the approach is simple. Too complex and demanding protocols can reduce participation. Simple projects with straightforward protocols can be rapidly completed by anyone in any location. However, complex and structured protocols can be suitable for citizen science especially if they appeal to a particular group of enthusiasts such as school children or others (Pocock et al., 2014). A significant investment in money, resources and time is usually needed to support citizen science. What researchers consider important may not interest a lay person, therefore tangible benefits need to be communicated to the citizens effectively.

7. Conclusion

Australia lacks a reliable, robust and up-to-date data, monitoring protocol and common reporting format for long term urban microclimate and local climate change measurement in comparison to many other countries despite the increased frequency and magnitude of heat waves. Such data is very important for assisting in urban risk management, and is the cornerstone for any smart-city implementation, aiding
more effective decision-making by multi-disciplinary teams. This paper gives an overview of a citizen science project that aims to engage local communities in urban microclimate research that involve urban heat island measurement. The various steps involved in the project ranging from engaging councils and citizens, identifying measurement locations, designing instrumentation, data collection and display of data using user friendly platforms are discussed and the main challenges are highlighted. Importantly through data collection and participation, public will be empowered to respond to extreme heat through an understanding of the influential factors.

**Acknowledgements**

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**References**

National Climate Centre (2009) Special Climate Statement 17 - The exceptional January-February 2009 heatwave in south-eastern Australia.
Field Study of Auckland Housing Winter Indoor Health Conditions Associated with Insulation, Heating and Energy

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Abstract: Common problems of winter indoor micro-climatic conditions of Auckland houses are low air temperature and high relative humidity. Winter indoor air temperature and relative humidity are mainly impacted by house design with different insulation in their envelopes, different space heating methods and how much energy is used for space heating. The three Auckland houses, with different insulation and glazing in their envelopes and different space heating methods (temporary heating and central heating), were selected for field studies of winter indoor microclimatic conditions. According to the field study data and energy data, the study identifies differences in indoor thermal and health conditions of local houses with different R-value building envelopes, investigates what type of space heating is suitable and how much space heating energy is needed to achieve the guidelines for indoor thermal comfort and healthy conditions for a local lightweight timber frame construction house with sufficient insulation and double glazed windows. To compare and identify differences of energy consumption between the house using central heating and the local houses using different temporary space heating, this study randomly collected the energy data of 131 Auckland sample houses using different temporary heating methods, with or without sufficient insulation and double glazed windows.

Keywords: Housing Energy; Indoor health; insulation; space heating.

1. Introduction

Auckland's climate is temperate, with summers being comfortable, warm and dry, and winters being mild and wet, which requires only limited winter heating and does not require summer cooling. Auckland has around 1,150 heating degree days (the base temperature used is 18 °C) [NZMS, 1978]. Previous studies show that indoor air temperatures of New Zealand homes are quite low compared with the guidelines for thermal comfort and healthy conditions during winter time [Boulic et al., 2008; Lloyd et al., 2008]. Only about 5% New Zealand houses use a central heating system [French et al., 2007]. The World Health Organisation (WHO) recommends a healthy minimum indoor temperature of 18°C for houses; and 20-21°C for more vulnerable occupants, such as older people and young children [WHO, 1987].
High winter indoor relative humidity is a major issue for Auckland housing indoor health conditions. New Zealand has some of the highest levels of house dust mite allergens in the world [Siebers, 2006]. Visible mould growth on indoor surfaces is a common problem in over 30% of New Zealand houses [Howden-Chapman et al., 2005]. The abundance of two major causes of allergy, mites and mould in New Zealand housing, increase proportionately with average indoor relative humidity. One option to prevent mould growth on indoor surfaces is to control the indoor humidity level under the threshold (80%) of mould gemmation. If the mould spores never start gemmation then mould will not grow on indoor surfaces [Su, 2006; ASHRAE, 1993]. According to international and national standards, the indoor relative humidity should be lower than 60% for indoor air quality [ASHRAE, 1992; ASHRAE, 1993; ASHRAE, 2001; SNZ, 1990; DBH, 2001]. Most of the health effects such as bacteria, viruses, fungi, mites, etc. have increases associate with very high indoor relative humidity. Maintaining indoor relative humidity between 40% and 60% can minimize the indirect health effects [Arundel, 1986] (see Figure 1).

![Figure 1: Health effects and indoor relative humidity (Source: Arundel, et al. 1986)](image)

Since 1978, continuously increasing R-value of building envelope of Auckland houses in accordance with the updated building standards mainly focus on improving energy efficiency [SNZ, 1977; BIA, 1992]. Houses without sufficient insulation are not energy efficient and it is expensive to heat up indoor space. Government funded Warm up New Zealand: Healthy Homes projects, administrated by the Energy Efficiency Conservation Authority (EECA), provide free ceiling and underfloor insulation to low-income households with people who have health needs related to cold and damp housing. Previous studies of retrofitting New Zealand housing projects show that increased insulation in the building envelopes can only increase 1°C or less than 1°C of indoor mean air temperatures [Isaacs, 2006; Lloyd, 2008]. Increasing insulation without tackling the lack of space heating is not a good idea [Gustafsson, 2000]. The study investigates what type of space heating is suitable for the local house with lightweight timber frame construction and identifies how much space heating energy is needed for the local houses to achieve the guideline of winter indoor thermal comfort and healthy conditions [WHO, 1987; Arundel, 1986].

New Zealand housing energy efficiency should include insulating the complete building fabric and using energy efficient space heating [Verebeek, 2005]. The New Zealand government continuously publishes New Zealand’s energy strategy and policy every 5 years for improving New Zealander’s health related to living conditions, saving housing energy and reducing greenhouse gas emissions. Inadequate insulation combined with ineffective space and water heating systems are found in many New Zealand
homes [MED, 2011; EECA, 2011]. If a household spends more than 10% of its income on heating merely to maintain adequate warmth it is deemed to be in “fuel poverty” [Boardman, 1991; Clinch and Healy, 2001]. It is thought that approximately 25% of New Zealand homes are living in fuel poverty [Howden-Chapman et al., 2012]. Recent studies related to New Zealand fuel poverty issues are based on existing New Zealand designs, space heating methods, hot water systems and housing energy [O’Sullivan et al.; Lawson et al., 2015]. The Household Energy End-use Project (HEEP) found that the main use of energy across all types of fuel in a New Zealand household was for space (34%) and water (29%) heating. New Zealand houses have the highest percentage (77%) of electric hot water systems in the Western world. It is anticipated that a move to mains pressure gas hot water systems would significantly affect both energy and water usage [Isaacs et al., 2006].

2. Methodology

To investigate winter indoor thermal comfort and healthy conditions of Auckland houses with different R-values of building envelopes and different space heating methods (temporary and permeant heating), three Auckland houses with lightweight timber frame construction were selected for the field studies of winter indoor micro-climatic conditions. House 1 was built in 2000 (R-values for Roof: 1.9, Wall: 1.5, Floor: 1.3, Single Glazing: 0.13). House 1 had 2 occupants and used an electronic cylinder hot water system and an electronic oil heater in the master bedroom only for the evening time during the field study. House 2 was built in 2012 (R-values for Roof: 2.9, Wall: 1.9, Floor: 1.3, Double Glazing: 0.26). House 2 had 2 occupants and used a gas instant hot water system but did not use any space heating during the field study, although there is a heat pump. House 3 was built in 2012 (R-values for Roof: 2.9, Wall: 1.9, Floor: 1.3, Double Glazing: 0.26). House 3 had 2 occupants and used a gas instant hot water system and a gas central heating system during the field study. Indoor air temperature of House 3 was set at 20°C in the downstairs living room during the field study. Monthly electricity and gas consumption data for the three houses were collected for this study. The air temperature and relative humidity adjacent to floors and ceilings of indoor spaces in three houses and under shaded outdoor space were continuously measured at 5-minute intervals 24 hours a day for about 56 days during the winter months from June to August 2014 (16382 air temperature measurements for each data logger or each test point), by Lascar Humidity Data Logger.

The study not only identifies the difference of indoor mean air temperature and relative humidity of the sample houses but also difference of percentage of winter time, when indoor air temperature and relative humidity meets or does not meet the guidelines of thermal comfort and healthy conditions. To compare differences in the 24-hour mean indoor air temperature in winter and investigate the 24-hour mean variations of indoor air temperatures in winter of the three houses all field study data of indoor air temperatures (16382 air temperature measurements for each data logger or each test point) of the three houses in winter have been converted into the winter hourly mean air temperature (about 682 air temperature measurements within a particular hour in winter are averaged for the hourly mean air temperature). Monthly energy data and building plans of 70 Auckland sample houses built after 2007 with sufficient insulation and double glazing windows and 61 Auckland sample houses built after 2000 with insufficient insulation and single glazing windows were randomly collected for this study.
3. Results and Discussion

3.1. Winter indoor thermal and health conditions of the three houses

Although House 1 used an electronic heater in the master bedroom during the field study, indoor mean air temperature of House 2 is 1.1°C higher than House 1 and the percentage of winter time in House 2, when indoor air temperatures are higher than or equate to 18°C, is 17.6% higher than House 1 (see Table 1 and Table 2). Mean relative humidity of House 2 is 4.9% lower than House 1 and the percentage of winter time in House 2, when indoor relative humidity is between 40% and 60%, is 19.6% higher than House 1. Although upgrading insulation and using double glazing windows can significantly increase the percentage of winter time, when indoor air temperatures and relative humidity can meet the guidelines of health conditions, there is still 78.5% of winter time when indoor air temperatures are lower than 18°C and 71.6% of winter time when indoor relative humidity is higher than 60% compared with House 3. An Auckland house with sufficient insulation and double glazing windows needs space heating to achieve winter indoor thermal comfort and health conditions (18°C for the minimum indoor temperature and 40%-60% for indoor relative humidity).

Table 1 Percentages of winter time and mean indoor air temperature ranges of the three houses

<table>
<thead>
<tr>
<th></th>
<th>≥16°C</th>
<th>≥18°C</th>
<th>≥20°C</th>
<th>≥22°C</th>
<th>≥24°C</th>
<th>≥26°C</th>
<th>Mean</th>
<th>Max.</th>
<th>Min.</th>
<th>Fluctuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>House 1</td>
<td>35.3%</td>
<td>3.9%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>15.5</td>
<td>19.8</td>
<td>11.4</td>
<td>8.4</td>
</tr>
<tr>
<td>House 2</td>
<td>61.0%</td>
<td>21.5%</td>
<td>2.5%</td>
<td>0.01%</td>
<td>0%</td>
<td>0%</td>
<td>16.6</td>
<td>22.1</td>
<td>11.2</td>
<td>10.9</td>
</tr>
<tr>
<td>House 3</td>
<td>100%</td>
<td>100%</td>
<td>98.7%</td>
<td>44.50%</td>
<td>1.30%</td>
<td>0.01%</td>
<td>21.9</td>
<td>27.3</td>
<td>18.8</td>
<td>8.5</td>
</tr>
</tbody>
</table>

Table 2 Percentages of winter time and mean relative humidity ranges of the three houses

<table>
<thead>
<tr>
<th></th>
<th>≥40%</th>
<th>≥50%</th>
<th>≥60%</th>
<th>≥70%</th>
<th>≥80%</th>
<th>40% to 60%</th>
<th>Mean</th>
<th>Max.</th>
<th>Min.</th>
<th>Fluctuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>House 1</td>
<td>100%</td>
<td>100%</td>
<td>92.2%</td>
<td>37.6%</td>
<td>1.0%</td>
<td>8.8%</td>
<td>68.3%</td>
<td>82.9%</td>
<td>54.3%</td>
<td>28.6%</td>
</tr>
<tr>
<td>House 2</td>
<td>100%</td>
<td>100%</td>
<td>71.60%</td>
<td>11.90%</td>
<td>0%</td>
<td>28.4%</td>
<td>63.4%</td>
<td>81.0%</td>
<td>51.1%</td>
<td>29.9%</td>
</tr>
<tr>
<td>House 3</td>
<td>100%</td>
<td>28.8%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0%</td>
<td>100%</td>
<td>48.1%</td>
<td>56.7%</td>
<td>38.5%</td>
<td>18.2%</td>
</tr>
</tbody>
</table>

3.2. How much the space energy is needed to achieve indoor health conditions?

House 2 and House 3 have the same R-value in their envelopes. With a central heating system, House 3 has 100% of winter time when indoor air temperatures are higher 18 °C and indoor relative humidity is between 40% to 60% for all indoor spaces (see Table 1 and Table 2). Table 3 shows energy data of the three houses. As space heating energy is closely related to the volume of indoor space, the study uses daily mean energy consumption per cubic metre of indoor space (kWh/m³day) as a basic energy unit. House 3 used gas for the gas central heating system, gas instant hot water system and cooking during the space heating months. House 3 used gas for the gas instant hot water system and cooking during the no space heating months. The difference of daily mean gas usage per cubic metre of indoor space between the space heating months (May to September) and the no space heating months of House 3 can mainly represent its space heating energy. The difference of daily mean gas usage per cubic metre of indoor space between the space heating months and the no space heating months of House 3 is 0.0689 kWh/m³day, which can mainly represent the space heating energy needed to achieve the guideline of indoor thermal comfort and health conditions (for 20°C as the minimum indoor air temperature) of a local
house with lightweight timber frame construction with sufficient insulation in its envelope according to the current building code.

During no space heating months, daily mean energy of House 1 (0.03564 kWh/m³day) with an electronic hot water cylinder is significantly higher than house 2 (0.01630 kWh/m³day) and House 3 (0.02350 kWh/m³day) with gas instant hot water systems. During no heating month energy used for hot water is the major part of energy consumption. House 1 with an electronic cylinder hot water system could use more energy for hot water than House 2 and House 3 using gas instant hot water system. There is a short time for occupants to use hot water for a shower or other purposes during the 24-hour day. Current hot water cylinders continuously heat water and maintain water temperature at a temperature of 24 hours a day whether hot water is needed or not. During the winter night when occupants do not use hot water and internal air temperature is very low, especially for those houses without sufficient insulation, heat loss from a cylinder to the cold internal space can consume some extra energy for maintaining the water temperature.

Table 3 Energy data (kWh/m³day) of the three houses

<table>
<thead>
<tr>
<th></th>
<th>House 1</th>
<th>House 2</th>
<th>House 3</th>
<th>House 2</th>
<th>House 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total energy</td>
<td>Total energy</td>
<td>Total energy</td>
<td>Gas only</td>
<td>Gas only</td>
</tr>
<tr>
<td></td>
<td>Electricity</td>
<td>Electricity</td>
<td>Electricity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>only</td>
<td>and gas</td>
<td>and gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual</td>
<td>0.04878</td>
<td>0.01919</td>
<td>0.05286</td>
<td>0.00871</td>
<td>0.04593</td>
</tr>
<tr>
<td>Heating months</td>
<td>0.06699</td>
<td>0.02319</td>
<td>0.09354</td>
<td>0.01162</td>
<td>0.08595</td>
</tr>
<tr>
<td>Other months</td>
<td>0.03564</td>
<td>0.01630</td>
<td>0.02350</td>
<td>0.00661</td>
<td>0.01705</td>
</tr>
<tr>
<td>Difference</td>
<td>0.03135</td>
<td>0.00689</td>
<td>0.07004</td>
<td>0.00501</td>
<td>0.06890</td>
</tr>
</tbody>
</table>

3.3. Discussion of local housing energy consumption

Mean annual daily energy consumption (0.06367 kWh/m³day) of the 61 sample houses with insufficient insulation and single glazed windows is higher than the 70 sample houses with sufficient insulation and double glazed windows (0.05848 kWh/m³day) (see Table 4). The houses with higher R-value building envelope (higher insufficient insulation and double glazing window) are more energy efficient. The difference of daily mean energy usage per cubic metre of indoor space between heating and no heating months of House 3 (0.07004 kWh/m³day) is significantly higher than the 61 houses (0.03151 kWh/m³day) and the 70 sample houses (0.02588 kWh/m³day). The Auckland sample houses with temporary heating methods use less space heating energy than House 3. Generally, Auckland houses with temporary space heating do not heat up the whole house and only heat up some indoor spaces, such as living room or bedroom, mainly for winter evenings, nights and early mornings. For the no space heating months, daily mean energy consumption of the 61 sample houses (0.05046 kWh/m³day) and the 70 sample houses (0.04763 kWh/m³day) are significantly higher than House 3 (0.02350 kWh/m³day). 67% of the 61 sample house and 66% of the 70 sample house use electric hot water cylinders. As water heating is a major part of energy consumption during no space heating months, the energy used for hot water in the 131 Auckland sample houses could be more than for House 3. A further study should focus on what type of hot water system is energy efficiency for the local houses.
3.4. Major issues for local house thermal design

3.4.1. Low air temperature and high relative humidity in southern downstairs bedrooms

Winter indoor mean air temperatures of southern downstairs bedrooms are significantly lower than other spaces in both House 1 and House 2 with different R-value in their building envelopes (see Table 5), which can result in higher indoor relative humidity (Table 6). House 2 having higher R-value insulation in its envelope does not efficiently improve indoor thermal and health conditions of the southern downstairs bedroom. The southern downstairs indoor space is in cold side of house without direct sun light. Southern bedrooms are commonly smaller than the northern bedrooms and the other spaces; the floor area of the downstairs southern bedroom (10.3m²) of House 2 is smaller than the master bedroom (17.7m²) and the open living space (68.2m²). A southern bedroom with a smaller floor area could potentially result in big ratios of external wall area to indoor space volume or window area to floor of that room. The ratio of the external wall area to indoor space volume of the downstairs southern bedroom (0.65) is higher than the open living space (0.4) and master bedroom (0.49). Although the ratio of northern window area to northern wall (0.2) of House 2 is higher than southern window area to southern wall area, the ratio of window area to indoor space volume of the southern downstairs bedroom (0.09) is higher than the northern downstairs open living space (0.06). Windows are commonly a weak part of the building envelope for thermal resistance, even double glazed windows, compared with wall and roof with sufficient insulation. Negative impact of a big ratio of window to floor could overrule or degrade the positive impact of higher insulation levels and double glazed windows on indoor thermal comfort and health conditions of a southern indoor space conditions. A further study can focus on adding more insulation in the southern wall and limiting the ratio of window area to indoor space volume of the southern indoor space for improving indoor health conditions of southern indoor spaces.

Table 5 Percentages of winter time and air temperature ranges of different indoor spaces

<table>
<thead>
<tr>
<th>Location</th>
<th>≥16°C</th>
<th>≥18°C</th>
<th>≥20°C</th>
<th>≥22°C</th>
<th>≥24°C</th>
<th>≥26°C</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>House 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living</td>
<td>34.7%</td>
<td>4.6%</td>
<td>0.1%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>15.5</td>
</tr>
<tr>
<td>Downstairs bedroom</td>
<td>11.2%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>14.2</td>
</tr>
<tr>
<td>Upstairs master bedroom</td>
<td>69.2%</td>
<td>32.7%</td>
<td>6.7%</td>
<td>0.1%</td>
<td>0%</td>
<td>0%</td>
<td>16.9</td>
</tr>
<tr>
<td>Corridor</td>
<td>34.0%</td>
<td>2.9%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>15.3</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living</td>
<td>78.7%</td>
<td>21.8%</td>
<td>1.0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>16.8</td>
</tr>
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<td>28.3%</td>
<td>4.9%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>14.8</td>
</tr>
<tr>
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<td>71.1%</td>
<td>44.9%</td>
<td>18.7%</td>
<td>6.4%</td>
<td>0.9%</td>
<td>0.1%</td>
<td>17.9</td>
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<td>30.7%</td>
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<td>0.2%</td>
<td>0%</td>
<td>0%</td>
<td>17.0</td>
</tr>
<tr>
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<td></td>
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<tr>
<td>Downstairs</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>68.2%</td>
<td>1.1%</td>
<td>0%</td>
<td>22.2</td>
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<td>99.9%</td>
<td>98.6%</td>
<td>62.5%</td>
<td>13.3%</td>
<td>1.0%</td>
<td>22.6</td>
</tr>
<tr>
<td>Upstairs south bedroom</td>
<td>100%</td>
<td>100%</td>
<td>82.5%</td>
<td>19.4%</td>
<td>0.1%</td>
<td>0%</td>
<td>20.9</td>
</tr>
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<td>Corridor</td>
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<td>100%</td>
<td>84.7%</td>
<td>12.3%</td>
<td>0.1%</td>
<td>0%</td>
<td>20.8</td>
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</table>
Table 6 Percentages of winter time and relative humidity ranges of different indoor spaces

<table>
<thead>
<tr>
<th>Indoor spaces</th>
<th>≥40%</th>
<th>≥50%</th>
<th>≥60%</th>
<th>≥70%</th>
<th>≥80%</th>
<th>40% - 60%</th>
<th>Mean</th>
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<tr>
<td><strong>House 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living</td>
<td>100%</td>
<td>100%</td>
<td>90.8%</td>
<td>34.7%</td>
<td>0%</td>
<td>9.2%</td>
<td>67.7%</td>
</tr>
<tr>
<td>Downstairs bedroom</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>71.4%</td>
<td>13.4%</td>
<td>0%</td>
<td>73.4%</td>
</tr>
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<td>100%</td>
<td>69.7%</td>
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<td>0%</td>
<td>30.3%</td>
<td>64.3%</td>
</tr>
<tr>
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<td>100%</td>
<td>90.4%</td>
<td>35.8%</td>
<td>1.5%</td>
<td>9.6%</td>
<td>67.9%</td>
</tr>
<tr>
<td><strong>House 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living</td>
<td>100%</td>
<td>99.4%</td>
<td>69.2%</td>
<td>11.8%</td>
<td>0%</td>
<td>30.8%</td>
<td>62.8%</td>
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<tr>
<td>Downstairs bedroom</td>
<td>100%</td>
<td>100%</td>
<td>95.7%</td>
<td>41.4%</td>
<td>2.5%</td>
<td>4.3%</td>
<td>68.6%</td>
</tr>
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<td>Upstairs master bedroom</td>
<td>100%</td>
<td>97.5%</td>
<td>58.6%</td>
<td>8.0%</td>
<td>0%</td>
<td>41.4%</td>
<td>61.1%</td>
</tr>
<tr>
<td>Corridor mean</td>
<td>100%</td>
<td>100%</td>
<td>69.7%</td>
<td>10.8%</td>
<td>0.0%</td>
<td>30.3%</td>
<td>63%</td>
</tr>
<tr>
<td><strong>House 3</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downstairs Living</td>
<td>100%</td>
<td>40.6%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
<td>49.1%</td>
</tr>
<tr>
<td>Upstairs master bedroom</td>
<td>99.8%</td>
<td>24.3%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
<td>47.5%</td>
</tr>
<tr>
<td>Upstairs south bedroom</td>
<td>100%</td>
<td>66.8%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
<td>51.6%</td>
</tr>
<tr>
<td>Corridor</td>
<td>100%</td>
<td>24.3%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
<td>47.6%</td>
</tr>
<tr>
<td><strong>Outdoor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outdoor</td>
<td>100%</td>
<td>99.9%</td>
<td>97.4%</td>
<td>86.8%</td>
<td>68.4%</td>
<td>2.6%</td>
<td>85%</td>
</tr>
</tbody>
</table>

3.4.2. Large fluctuations of indoor air temperature and discussion of space heating method

Fluctuations in indoor air temperatures and relative humidity of House 1 and House 2 are both large (see Figure 1 and Figure 2). Large fluctuations of winter indoor air temperature can result in large fluctuations of indoor relative humidity (Figure 2), which can negatively impact winter indoor health conditions. In common with most Auckland houses, House 1 and House 2 are lightweight timber frame construction with internal insulation and external cladding, of brick veneer in this instance. Wall insulation materials are located at the internal surface of the wall as thermal designs of House 1 and House 2 are for temporary heating, not for permanent heating. As the internal surface of the wall does not have thermal mass, the space can be heated quickly, rather than heating the building envelope first and then heating the space. For this type of lightweight building envelope without sufficient thermal mass on the internal surface of the wall, the indoor space air temperature is heated up quickly by solar radiation and rising outdoor air temperatures during winter daytime and also cooled down quickly during winter night time. Figure 3 shows winter indoor hourly mean air temperatures of House 1, House 2 and House 3. Indoor minimum air temperatures in winter of House 1 and House 2 occur during early morning. Minimum winter indoor hourly mean air temperatures of House 1 (14.1°C) and House 2 (14.8°C) occur at 6:45 to 8:30 for House 1 and at 7:45 to 8:05 for House 2. Large fluctuations in indoor air temperatures can result in very low indoor air temperatures during early morning and night time in winter, negatively impacting indoor thermal comfort and health conditions and costing more in energy for space heating to achieve the indoor thermal and health conditions.

Reducing the fluctuation of winter indoor air temperature can improve indoor health conditions and housing energy efficiency. Suitable space heating can not only raise indoor mean air temperature but also fill variable gaps or differences between indoor air temperature and the minimum indoor air temperature required for thermal comfort and healthy conditions during the 24 hours of winter time. Space heating needs to be automatically controlled to achieve and maintain winter indoor thermal comfort and health conditions of a local house with lightweight timber frame construction.
Figure 1: Partial winter air temperatures in the living rooms of House 1 and House 2

Figure 2: Partial winter relative humidity in the living rooms of House 1 and House 2

Figure 3: Winter indoor and outdoor hourly mean air temperature of the three houses
4. Conclusion

According the field study data of House 1 and House 2, increasing R-value of building envelope from 1.9 for roof, 1.5 for wall, 1.3 for floor and 0.13 for glazing, as required by the New Zealand building standards in 1996, to the 2009 requirements of 2.9 for roof, 1.9 for wall, 1.3 for floor and 0.26 for glazing can increase 17.6% of winter time, when indoor air temperatures are higher than or equate to 18°C (the minimum indoor air temperature required for health conditions) and 19.6% of winter time, when indoor relative humidity is between 40% and 60% (minimizing indirect health effects). Although sufficient insulation and double glazed windows significantly improves indoor thermal and health conditions of House 2 compared with House 1, 78.5% of winter time the indoor air temperatures are lower than 18°C and 71.6% of winter time when indoor relative humidity is higher than 60%. Auckland houses with sufficient insulation and double glazing windows need space heating to achieve winter indoor thermal comfort and healthy conditions.

An Auckland lightweight timber frame construction house has large fluctuations of indoor air temperatures during the 24 hours of winter time. To achieve indoor thermal comfort and healthy conditions, suitable space heating can not only raise indoor mean air temperature but also fill variable gaps or differences between indoor air temperature and the minimum air temperature required for thermal comfort and healthy conditions during the 24 hours of winter time. Space heating has to be controlled according to different needs during 24 hours of winter time, which can not only make indoor thermal comfort and healthy conditions stable, but also save heating energy. Based on House 3 energy consumption data, 0.06890 kWh/m3day daily mean energy per cubic metre volume of indoor space is needed to achieve the guideline for thermal comfort and healthy conditions (for 20°C as the minimum indoor air temperature) in an Auckland house with sufficient insulation and double glazed windows in their lightweight timber frame construction envelopes. If indoor air temperature of House 3 is set at 18°C (not 20°C) in the downstairs living room during the winter, the space heating energy can be lower than 0.0689 kWh/m3day.

Based on energy data of the 131 Auckland sample houses with temporary space heating, the houses with higher R-value building envelope are more energy efficient. On average, the Auckland sample houses with temporary space heating use less space heating energy than the space energy needed to achieve the guidelines for thermal comfort and healthy conditions. For the no space heating months, daily mean energy consumption of the 131 Auckland sample houses is significantly higher than House 3 with gas instant hot water system. Over 66% of the Auckland sample house use electric hot water cylinders. During the no space heating months, the energy used for hot water becomes a major part of energy consumption. Increasing R-value of building envelope and increasing space heating energy for achieving indoor health conditions without tackling inefficient hot water system is not good idea for local housing energy efficiency. Reducing energy used for hot water and increasing space heating energy for occupants’ health could be the future housing energy strategy for housing energy efficiency and reducing the fuel poverty of New Zealand households.

References


Thermal Comfort Analyses of Elementary School Students in the Tropical Region

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Abstract: This study aimed to analyse the thermal comfort level of students in primary school classrooms in the tropical region with the case studies done in Makassar, Indonesia. The data collection was done through a survey in the six selected primary schools in Makassar. The study involved 1,111 students from 33 classrooms. The recorded data includes personal data and the thermal environments, i.e. air temperature, air humidity, mean radiant temperature (MRT), and airflow velocity. At the same time, students were asked to fill out questionnaires asking their comfort level perceived at the time of measurements. The results showed that Temperatures range from 28.33°C in the morning (8:00 am) to 34.29°C in the afternoon (2:20 pm). Air humidity ranges from 53% to 89% with an average of 68%. Students experienced relatively stagnant airflow conditions characterised by a minimum 0m/s, an average 0.1m/s, and a maximum 1.45m/s of air velocity. The elementary school students are quite tolerant to high temperatures. Even though only a small percentage of respondents (28%) feel neutral in comparison with respondents who feel warm and hot (43%), 86% of them accepted these conditions. However, more than 72% of respondents preferred to decrease the air temperature in the classrooms.

Keywords: Air temperature; elementary schools; neutral temperature; thermal comfort.

1. Introduction

Thermal comfort is one of the requirements for workers that enable them to work well and more productively. Sensharma et al. (1998) found that there was a positive correlation between room environment and the productivities of workers in the office building. This thermal comfort is not just requirement for office buildings but also for educational buildings. A quite old study back in 1968 revealed that there was a positive effect on the thermal quality of classrooms on students’ performances (Pepler and Warner, 1968). An extensive literature review by Mendell and Heath (2005) showed a good correlation between indoor school environments (which include thermal comfort) and the performance and attendance of children.

Thermal comfort standards such as ASHRAE Standard 55 (ASHRAE, 2004) has been widely used as a reference for designing thermal comfort in many countries, including Indonesia. To examine the performance of thermal comfort experienced by users, then according to this specification, a survey using a questionnaire should be carried out. This questionnaire asks the thermal sensation votes (TSV) of
respondents in seven scales, namely: hot (+3), warm (+2), slightly warm (+1), neutral (0), slightly cool (-1), cool (-2), and cold (-3). However, long before, Bedford (1936) has also proposed a method for evaluating thermal comfort which also consists of seven scales. They are: much too warm (+3), too warm (+2), comfortably warm (+1), comfortable (0), comfortably cool (-1), too cool (-2), and much too cool (-3). In this research, The Bedford scale was named thermal comfort vote (TCV). Besides measuring the thermal comfort using questionnaire method, the thermal comfort can also be estimated using the Predicted Mean Vote (PMV) developed by Fanger (1970). According to Fanger (1970), the PMV can be calculated by using two personal parameters (clothing and the activity of respondents), and for environmental parameters (air temperature, MRT, relative humidity, and air velocity).

Most schools in Indonesia were built as a prototype building, with no consideration based on the local climatic conditions. The schools have been constructed to the same standards regardless of the user's comfort, in this case, the students of the primary school, which are young (6-12 years). During daytime, the classrooms are excessively dependent on the natural ventilation system, which is not enough to make classrooms comfortable. The condition of the classrooms is still very far from comfortable conditions. The number of classrooms equipped with fans. Since the morning of the classroom has been assisted by the airflow from the fan to make the students comfortable in participating in learning in their classrooms. It is what lies behind the author to conduct this study in elementary schools in the city of Makassar. Specifically, the authors will discuss two issues in this article, as follows:

- Thermal environmental conditions of elementary school classrooms in Makassar.
- Users’ responses (students) to the thermal environmental conditions of the classrooms.

2. Research Method

2.1. Data Collection

This research is a preliminary study of thermal comfort analyses of naturally ventilated classroom carried out in six primary schools in Makassar. The study was conducted at the 33 classrooms, which is used for teaching and learning process. The buildings consisted of one and two-storey buildings. The buildings should provide comfortable indoor environments including thermal comfort for occupants.

The data collection has been carried out using several instruments. The LSI-Lastem Thermal Comfort Multi Logger (LSI TC) is a set of instrument, which consists of several sensors and data logger. The arrangements of LSI TC applied in this survey including one data logger and four sensors. The sensors including a globe thermometric probe (BST131) for measuring mean radiant temperature (MRT), a portable psychometric forced ventilation probe (BSU102) for measuring air temperature and relative humidity, and a wet bulb temperature probe (BSU121) for measuring wet bulb temperature. The instruments were placed in the classrooms. In addition to LSI TC, the measurement also recorded by six Hobo Loggers. Two types of loggers were used, i.e. the Hobo temp/RH logger and the HOBO temp/RH/Light/External. Four Hobo temp/RH loggers (Hobo-1) were used for measuring air temperature, and relative humidity, and two Hobo temp/RH/Light/External loggers (Hobo-2) were used for measuring air temperature, relative humidity, and air velocity.

The collection of data was carried out as follows:

- Survey on objective measurement was conducted to collect the personal and the thermal environment data. Personal data was gathered by collecting the clothing and the activity of each respondent. The thermal environmental variables, i.e. air temperature, mean radiant temperature
(MRT), relative humidity, and air velocity were recorded by using instruments as mentioned before. The instruments and their position in the measured classrooms are shown in Figure 3. The sensors were attached at 100 cm above the floor level (Wong and Khoo, 2003). Because of the limitation of equipment, the MRT only recorded at one point that was at point A, while the air velocity recorded at two points (A and B).

Figure 3: The arrangement of instruments in the typical classroom

- Survey on subjective measurement, which was conducted to measure the level of thermal comfort of respondents. The study carried out by using questionnaire technique, which was adapted from Wong and Khoo (2003). The modified questionnaire has been used for research in the naturally ventilated classrooms in Makassar (Hamzah et al., 2016). For this study, the questionnaire has been adapted to accommodate seven questions, four questions related to the thermal aspect which captured the thermal sensation vote (TSV), thermal comfort vote (TCV), thermal preference and thermal acceptance of respondents. Two questions related to the air velocity votes and the air velocity preference. Lastly, one question related to the respondents votes on the humidity of classrooms.

2.2. Data Processing and Analyses

Data analyses were carried out by spreadsheet software MS Excel. The spreadsheet has been used to calculate the mean value of environmental variables and to generate tables showing the percentage of TSV, TCV, and PMV. For the statistical analyses, a statistical software SPSS version 16 has been used to show graphical of respondents’ votes and the calculation of regression analyses. To calculate the PMV for each defendant, the availability of four corresponding environmental variables as well as two personal variables for each respondent is essential. The calculation was done using spreadsheet template developed by Tanabe (Farina, 2015).

Research results were analysed based on the statistical analyses using SPSS version 16. The statistical analysis employed in this study were graphical and regression analysis. The regression analyses were
determined by two criteria, i.e. test of linearity of regression and the significance of equation coefficient. Before analysing the data using statistical analysis, the data have been verified. One method of verification is to check their normality and reliability. The checking required making sure that the results are valid for concluding. All data have been checked for their normality and reliability.

3. Results and Discussion

3.1 Research Sample

Surveys and measurements of thermal comfort and thermal environments have been carried out in six primary schools in the city of Makassar, which represent the six sub-districts. The locations of schools are spread out from the city centre to the suburbs (Figure 4).

![Figure 4 Location of surveyed elementary schools in Makassar](image)

The following part explains the particular area of each school. SD Inpres Nipa-nipa located in a suburban area with a location farther away from the concentration of settlements. SDN Sudirman 1 located in the city centre near to the town square, along with three other primary schools in the same location. SD Inpres Tamalanrea 4 established in a dense residential area bordering the road environment. SD Inpres Daya positioned near the local commercial area, 13 Km away from the city centre, and it is adjacent to arterial roads. SD Inpres Hartaco Indah located in residential areas with medium density. SD Unggulan Toddopuli found in the medium density residential and commercial areas.

Table 2 lists the characterisations of the samples.
Table 2: Characteristic of samples

<table>
<thead>
<tr>
<th>No.</th>
<th>Name of school</th>
<th>Location (sub-district)</th>
<th>Number of classes</th>
<th>Number of students</th>
<th>Date of survey/measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SD Inpres Nipa-nipa</td>
<td>Manggala</td>
<td>5</td>
<td>157</td>
<td>21 April 2016</td>
</tr>
<tr>
<td>2</td>
<td>SDN Sudirman 1</td>
<td>Ujung Pandang</td>
<td>6</td>
<td>205</td>
<td>29 April 2016</td>
</tr>
<tr>
<td>3</td>
<td>SD Inpres Tamalanrea 4</td>
<td>Tamalanrea</td>
<td>5</td>
<td>160</td>
<td>30 April 2016</td>
</tr>
<tr>
<td>4</td>
<td>SD Inpres Daya</td>
<td>Biringkanaya</td>
<td>6</td>
<td>239</td>
<td>3 May 2016</td>
</tr>
<tr>
<td>5</td>
<td>SD Inpres Hartaco Indah</td>
<td>Tamalate</td>
<td>5</td>
<td>126</td>
<td>7 May 2016</td>
</tr>
<tr>
<td>6</td>
<td>SD Unggulan Toddopuli</td>
<td>Panakkukang</td>
<td>6</td>
<td>224</td>
<td>12 May 2016</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>33</td>
<td>1,111</td>
<td></td>
</tr>
</tbody>
</table>

3.2. Microclimate Conditions

In general, micro-climatic conditions in the classrooms at the time of measurement in 33 classes from six elementary schools can be seen in Table 3, which shows the minimum air temperature in the morning (08:00) 28.33°C and the maximum during the daytime (14:20) of 34.29°C. The temperature shows that classrooms in the surveyed primary schools experiencing excessive heat. The air temperature is outside the comfort zone as specified in the national standard (BSN, 2011). Air humidity is ranging from 53% - 89% with an average of 68%, indicating that the air humidity is within the comfort zone. Most of the classes have the average airflow rate is low, which is less than 0.5 m/s.

Table 3: Microclimatic conditions recorded at the surveyed classrooms

<table>
<thead>
<tr>
<th>Schools name</th>
<th>Time of Measurements</th>
<th>Statistic</th>
<th>Air Temp (°C)</th>
<th>RH (%)</th>
<th>MRT (°C)</th>
<th>Air Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD Inpres Nipa-Nipa</td>
<td>08.00-14.00</td>
<td>Average</td>
<td>30.87</td>
<td>66.50</td>
<td>30.86</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Min</td>
<td>28.33</td>
<td>54.55</td>
<td>28.78</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max</td>
<td>33.18</td>
<td>75.90</td>
<td>32.85</td>
<td>1.29</td>
</tr>
<tr>
<td>SD Negeri Sudirman</td>
<td>08.00-11.00</td>
<td>Average</td>
<td>30.00</td>
<td>71.35</td>
<td>29.72</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Min</td>
<td>29.32</td>
<td>63.69</td>
<td>29.24</td>
<td>0.00</td>
</tr>
<tr>
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<td></td>
<td>Max</td>
<td>30.78</td>
<td>77.50</td>
<td>30.32</td>
<td>0.53</td>
</tr>
<tr>
<td>SD Inpres Tamalanrea 4</td>
<td>08.00-10.50</td>
<td>Average</td>
<td>30.91</td>
<td>70.48</td>
<td>30.65</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
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<td>Min</td>
<td>28.87</td>
<td>58.86</td>
<td>29.02</td>
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<tr>
<td></td>
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<td>Max</td>
<td>32.90</td>
<td>78.30</td>
<td>32.39</td>
<td>1.25</td>
</tr>
<tr>
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<td>56.10</td>
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<td></td>
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<td>35.26</td>
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<td>Max</td>
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<td>88.79</td>
<td>35.26</td>
<td>1.45</td>
</tr>
</tbody>
</table>
3.3. Students’ Responses to the Air Temperature

Figure 5 illustrates the students’ responses to the air temperature in the classrooms based on indicators of Thermal Sensation Vote (TSV), Thermal Comfort Vote (TCV), and also the Predicted Mean Vote (PMV). Based on the TSV, about 43% of respondents voted the hot regions (+1 to +3) and only 29% voted the cold region (-1 up to -3). The percentage of respondents who felt ‘neutral’ is less than 30%. These indicate that most of the students in the surveyed classrooms felt hot (uncomfortable).

![Figure 5: Thermal Sensation Votes (TSV) and Thermal Comfort Votes (TCV) of students](image)

More than 38% of respondents voted the hot regions (+1 to +3) and only 12% in the cold region (-1 to -3) in the Bedford scale (TCV). Interestingly, about 50% of respondents felt comfortable in the classrooms. This figure quite different with the ASHRAE level (TSV) was less than 30% of respondents voted neutral. These suggest that both of these indicators, despite using the same size but gave a different result. It looks more respondents understand the word ‘comfortable’ than ‘neutral’.

Very different figure have resulted from the calculated of PMV. In the PMV model, all respondents were predicted to have voted in the hot region (1 to 3). This figure indicates that the PMV model overestimated the actual votes of those surveyed. According to this PMV model, no students will feel ‘neutral’ or ‘comfortable’ in these surveyed classrooms. The results gathered using PMV method were very different with the actual votes either by TSV or TCV, where about 28% and 50% respondents felt ‘neutral’ and ‘comfortable’, respectively. This indication might not be appropriate to use PMV to estimate the thermal comfort of respondents in naturally ventilated rooms in the tropic. Feriadi and Wong (2004), and Wong and Khoo (2003) have suggested similar results.

Figure 6 presents students’ response to the air temperature in the classrooms based on indicators of Thermal Preference and Thermal Acceptance. The left part of the figure shows that the majority of respondents (72%) want to decrease the air temperature in the classrooms and only very few (0.7%) of those want to increase the air temperature. Less than a third of respondents (27%) feel the temperature is right so do not want to increase or decrease the air temperature. These responses imply that most of the students feel that the air temperatures were not within their thermal preferences.
As seen in right part of Figure 6 the majority of respondents (86%) accepted the thermal conditions of the classrooms and only a small proportion of them (14%) did not accept thermal conditions of the classrooms. These may indicate that students, even though more than 40% respondents felt hot (+1 to +3) they still can accept the condition of classrooms for learning process.

3.4. Students’ Response to Air Velocity

Students' response to the airflow in classrooms based on indicators Air velocity votes and the Air velocity preference can be seen in Figure 7. The figure shows that the majority of respondents (70%) had no or only very few feel the airflow in classrooms and only about 28 % who felt the presence of sufficient air flow, as well as about 2%, feel disturbed by the movement of air in classrooms. These may indicate that the existing ventilation system was not able to supply enough airflow into the classrooms.

Figure 7: Students’ response on air velocity

Regarding Air velocity preference, the majority of respondents (58%) preferred to increase the air velocity in the classrooms, and only about 8% wanted a decrease in the speed of air. When compared with the choice of the condition of the air velocity, there is a difference, where only about 2% who feel
disturbed by airflow there, but there were about 8% who want the reduction in air velocity. There is also a difference between choosing airflow 'enough' (just right) that as much as 28% compared with those not wanting an increase or decrease in airflow (34%).

3.5 Students’ Response to Air Humidity

Students’ response to humidity conditions in the classroom based on the indicators Humidity votes can be seen in Figure 8. It is regarded that more than a third of respondents (37%) feel the humidity enough (just right), almost the same as choosing indoor air moisture (39%). The respondents’ votes of the humidity in the classrooms were mostly influenced by the humidity of classes as seen in Table 3.

![Figure 8: Students’ response to the air humidity](image)

As shown in Table 3, the humidity of classrooms was minimum 54%, average 68% and maximum 88%. These mostly lay in a comfortable zone as mentioned in the national standard (SNI Standard No. 6390:2011) (BSN, 2011). These values indicate that most of the classes were humid and no classrooms were dry. In contrast, about 24% of respondents voted that the classrooms were drained. This figure indicates that students of elementary schools were hard to determine the humidity of classrooms.

3.6. Neutral Temperature ($T_n$)

Figure 9 demonstrates the relationship between the operative temperature ($T_{op}$) with a value of PMV, TSV and TCV. The following part describes the relationship between these three couples in producing neutral temperature values. Regarding PMV, Figure 9 shows most of PMV values lay in the hot regions (+1 to +3). With operative temperature is ranging from 28,5°C to 34°C the regression equation ($R^2 0.91$) gives the relationship equation as follows:

$$PMV = 0.37T_{op} - 9.37$$ (1)

By using equation (1), then the value of $PMV = 0$ ($T_n$) obtained when the operating temperature 25,50°C. This value means that the respondents would feel neutral (neither hot nor too cold) at 25,50°C ($T_{op}$). This value must be minimal if compared with an average temperature of classrooms ranging from 28,5°C up to 34°C. So if we use this PMV formula to predict the thermal comfort of the respondent, then there will be no respondents who feel neutral (comfortable).
The very different number is found in the relation between \( T_{op} \) and TSV. With the \( R^2 \) 0.08 the linear regression analysis between \( T_{op} \) and the TSV is shown in the following equation relationship:

\[
TSV = 0.22T_{op} - 6.64 \tag{2}
\]

The \( T_n \) obtained from this equation is 30.20°C, which means that the respondents would feel neutral at a temperature of 30.20°C (\( T_{op} \)). This temperature value is higher than the temperature of the neutral using the PMV.

There is a similarity of the relationship between the \( T_{op} \) and TCV and the \( T_{op} \) and TSV. With \( R^2 \) 0.08 gives the relationship equation as follows:

\[
TCV = 0.2T_{op} - 5.91 \tag{3}
\]

The \( T_n \) obtained from this equation is 29.40°C, which means that the respondents would feel neutral at a temperature of 29.40°C (\( T_{op} \)). This temperature value is higher than the temperature of the neutral using the PMV and slightly lower than the neutral temperature using TSV.

4. Conclusion

The condition of classrooms in selected primary schools in Makassar showed hot situation. It is characterised by high temperatures, high relative humidity and very low air velocity during the daytime. The thermal comfort survey results show that the elementary school students are quite tolerant to high temperatures. Even though only a small percentage of respondents (28%) feel neutral in comparison with respondents who feel warm and hot (43%), 86% of them accepted these conditions. However, more than 72% of respondents preferred to decrease the air temperature in the classrooms. Most respondents did not feel the airflow in the classrooms so that most of them want the increase in airflow velocity. The result of the calculation of neutral temperature (\( T_n \)) using a model Predicted mean vote (PMV) produces the value 25.5°C which is very low when compared with the air temperature in the room. This result is less...
than the value of the neutral temperature (Tn) obtained from the questionnaire either by using Thermal sensation vote (TSV) for 30.2°C or Thermal comfort vote (TCV) of 29.4°C.

**Acknowledgements**

The author would like to thank the Ministry of Research, Technology and Higher Education and the Hasanuddin University for providing the fund for this research. The authors would also like to thank the headmasters/headmistress of the surveyed schools who given permission to carried out measurements in their schools. Finally, the authors would like to show appreciation to doctor and master students who involved in the data collection and data analysis.

**References**


Moisture Production and Extraction in New Zealand Homes

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\textbf{Abstract:} The effect of moisture in New Zealand homes is a topic which has been studied intensely, yet problems still arise from excess moisture. The effects that moisture can have in homes is well documented; however very few studies exists on sources of moisture created by occupants. Typically, studies have focused on removing moisture after its production, rather than focusing on its source. This paper examines both the moisture produced in bathrooms in New Zealand homes and the effectiveness of extraction fans found in these bathrooms. A literature review was conducted on the amount of moisture produced in bathrooms and the common factors that make extraction fans ineffective. From this, a survey was conducted and experiments performed to measure the amount of moisture produced in a typical New Zealand home and the effectiveness of commercially available fan and duct systems. The main findings from this study were that commercially available ventilation systems for removing moisture from homes are performing well below the requirements of the New Zealand building code.

\textbf{Keywords:} Ventilation; moisture; bathroom; extraction fans.

\section{1. Introduction}

Despite advances in building technology and material performance, problems relating to excess moisture in the home are still occurring. A 2010 house condition survey conducted by the Building Research Association of New Zealand (BRANZ) found that at the time of the study, 53\% of owner-occupied houses and 73\% of rental properties had problems relating to mould (Buckett, et al., 2010). The reasons behind this included poor ventilation, excessive subfloor moisture, use of unflued gas heaters and inadequate levels of insulation. Typically, with poor ventilation and lack of infiltration, a cycle occurs where moisture condenses on the windows and surfaces overnight. When the air temperature increases during the day this moisture evaporates into the air and the cycle repeats (Cox-Smith, 2015). Numerous studies have been undertaken by BRANZ focusing on the effects of moisture and removing moisture from the home (McNeil, et al., 2015). However, little data exists on moisture created by occupants and how their behaviour around moisture-generating activities impacts the total moisture load in the home. To design ventilation systems that mitigate issues relating to mould, an understanding of the total moisture load in the building is needed.
This study aims to understand how much moisture is produced in a typical New Zealand bathroom and whether typical ventilation systems are capable of removing this moisture. With new construction methods resulting in houses becoming more airtight, it is important to install effective ventilation systems to remove moisture (Larson, 2004). The most effective way to remove moisture is through the use of an extraction fan that vents directly to the exterior (Elkink, 2012). Extraction fans installed in New Zealand homes are typically noisy and inefficient and vent into the roof cavity (Rosemaier, 2014). Knowledge gaps relating to duct installation also exist with little guidance from manufacturers on factors that could affect the extraction fan performance.

2. Literature Review

A wide range of moisture-generating activities have been documented in literature, covering activities such as cooking, showering and cleaning. However, the data generated for each of these activities tends to vary between studies with very wide gaps in the data. Reasons for this include different methodologies, measuring conditions and occupant behaviour. Apart from construction moisture and subfloor moisture, moisture generation relates strongly to occupant behaviour. For this, it is crucial to understand how occupants behave in their environment. The most comprehensive data set was published by the International Energy Agency in the IEA Annex XIV and has been widely used throughout the literature quoted by several different studies including TenWolde (2001). Another popular, although older study, was Hite and Bray’s study, Research in Home Humidity Control (1949).

The range of literature reviewed consisted of documentation of experiments and methods relating to a ‘typical’ family of four comprised of two adults and two children. On average across the literature, 12,400g of moisture is predicted to be released into the typical home per day. Clothes washing and drying was determined to have a significant impact in the home, with one source stating potential extreme days could generate up to 40,000g (40kg) of moisture (Straube & Burnett, 2005; Hanssen, 1984). Moisture released from bathing and showering varied between studies ranging from 200 – 2,400g per day from a combination of the events (Trechsel, 2001; Hanssen, 1984). From this literature, there is no consistency between studies and no studies relating to a New Zealand context. This shows that these activities could be performed again with the moisture release measured in a New Zealand context. To do this an understanding of the activities duration and occurrence was needed. This, like the literature reviewed, was performed through a survey.

The second part of the literature review conducted was to analyse the existing literature on the performance of extraction fans. NZS4303:1990 Ventilation for acceptable indoor air quality, states for extraction of air that bathrooms and toilets need 25l/s intermittent or 10l/s continuous air exchange. A number of common practices in residential households leading to poor performance of extraction fans, are due to a lack of knowledge regarding extraction fans and ducts. For example, installing an oversized fan will remove moisture effectively, but could also have negative impact on the house causing depressurisation. This can also lead to other issues such as an increase in the noise produced, as well as high energy consumption (Fuoss, 2004). By installing undersized fans, moisture will not be adequately removed due to limited power efficiency (Kim & Yang, 2016). Therefore, it is vital that correct extraction fan and ducts are assembled and installed in order to effectively deal with the moisture caused by the occupants.

Another crucial element in the performance of extraction fan systems is the connected duct. A study conducted by Abushakra, Walker and Sherman (2004) evaluated the pressure drop in flexible ducts caused by compression of flexible ducts in residential and light commercial applications (Abushakra, et al., 2004).
It was observed that the pressure drops in flexible duct systems were higher than expected based on design calculations. The flexible ducts are often found to be compressed to varying degrees which leads to excessive pressure drop, increase in fan power, flow restriction and increase in noise (Abushakra, et al., 2004). The results in the study showed that moderate compression in flexible ducts could increase the pressure drop by a factor of four (often seen in field installations), while further compression could increase the pressure drop by factors close to ten (Abushakra, et al., 2004). Another study by Weaver (2011), resulted in similar findings in relation to residential flexible ductwork. The study suggested that the configuration of flexible ducts has a significant impact on the performance of extraction fans. The set of experiments that were conducted demonstrated the static pressure drop for various percentages of compression. Unnecessary compression causing bends in the flexible duct can raise the static pressure loss by as much as a factor of ten (Weaver, 2011). Weaver (2011) stated that installation of the ductwork plays a very crucial role in the performance of extraction fans. Therefore, it is important that designers and contractors are aware about how important it is to install flexible ducts properly and avoid any static pressure losses. Other effects that increase the pressure drop in the duct are caused by changes in the geometry of the airflow path, bending of the duct, and significant sagging of the duct between supports.

A study done in Korea on bathroom extraction fans by Kim and Yang (2016) showed that performance of the extraction fans failed to meet manufacture regulations. Suggesting that changes in construction and design methods can effectively improve the extraction fan performance. This study also raised an interesting point about the technical proficiency of the installer of the fan connecting components. Skills of the installer had a significant influence on the performance of the extraction fan (Kim & Yang, 2016). It is therefore necessary to have a skilled installer who has an understanding of the impact that poor installation of the ducting has on the performance of the extract fans.

Another notable factor that plays a role in the performance of the extraction fans is the location of the extraction fan. It is important to carefully locate the extraction fan to allow it to remove the moisture effectively and ensure maximum air-flow through the bathroom. The fan should not be located beside a window where fresh air comes in (Simx, 2013). Poor installation of the extract fans will lead to performance well below the anticipated level of operation. Currently, numerous commercially available extraction fans do not include a moisture sensor. It is vital to pair an extraction fan system with a sensor to ensure the system is turned on and kept on at appropriate times to help remove moisture.

**2.1. Performance of commercially available extraction fans**

A primary aim of this study is to investigate the effectiveness of current commercially available extraction fans and to test if they meet the building code requirements. As part of this literature review, the manufacturing company Simx Limited was contacted regarding their commercially available Manrose extraction fans. Simx tests their fans on a double chamber Static Pressure Rig and then calculate free air performance and airflows along six different Pascal resistances. The manufacturing company does not consider the duct a factor and how it could affect the airflow rate of the extraction fan and whether it will still meet minimum building code requirements.

The free air flow performance of extraction fans studied the claim that the fans meet and exceed the minimum Building Code requirements. It is also assumed by the manufacturer that once the duct is connected to the fan the completed installation will meet also meet Building Code requirements. There was no information available on the relationship between the extraction fan and duct, or how it will affect the performance in terms of air flow rate and pressure drop. The manufacturing company test the airflow
rate without a connected duct, which means that they are assuming that after installing the duct and fan, it will have the same airflow.

2. Survey

To determine how occupants behave in their own homes a survey was created and sent to the Faculty of Architecture at Victoria University of Wellington and BRANZ employees, receiving 99 responses. From the survey responses, it was found that occupants favoured showers over bathing in a bathtub with 100% of respondents having showers and only 13% taking both. The duration of these were 8.7 and 20.5 minutes respectively. Hand washing at home was around seven times per day per person. Use of a towel after showering and bathing is assumed to be 2.7 times per day per household based off the daily number of showers and baths taken by the respondents. 64% of respondents had a clothes dryer that was used in the home. 30% of these respondents had dryers that were vented to the outside and 10% had a condenser dryer. The remaining respondents stated either their dryer was vented to the outside or the respondent did not know if it had a vent. Typically, dryers were used more frequently in the winter at 2.9 times per household per week and in summer 1.4 times.

3. Experiments

3.1 Moisture generating experiments

The following experiments were either conducted in the home or in a controlled workshop. Each experiment was carried out using a similar method; the process of measuring the weight before and after an event. This would determine the amount of moisture that has or will eventually be released into the air via evaporation. Experiments were conducted several times to determine an average amount of moisture released. Methods from Yik, et al. (2004) for a majority of experiments were followed closely where possible.

After a person washes their hands and after showering/bathing, towels are used to dry themselves. For this experiment the moisture released into the air is assumed to be the water that is absorbed by the towel. The towel was placed on the scale before use and then weighed again after. It was found that from hand washing 3.9g of moisture is absorbed per wash or 27.5g/person.day. From showering 89.3g is absorbed per shower. However, this will vary depending on the person.

Mopping floors contributes to moisture in homes via evaporation from water that remains on the floor area. Mopping floors in New Zealand is typically completed using a mop but can also be done by hand using a sponge, rag or similar. Both methods were tested for this experiment where an area of vinyl floor was marked out and mopped five times for each method. This resulted in an average moisture release of 13.7g/m². Assuming a kitchen of 3m x 4m and a bathroom of 2.4m x 3.5m gives a total area of 20.4m². This is an estimate which will not relate directly to every household, therefore a m² rate is presented. A household that mops 20.4m² will release 289.8g of moisture on days where floors are mopped.

Leaving washing to dry indoors or using an unvented clothes dryer is assumed to release large amounts of moisture into the air. Data from the survey and Yik, et al. (2004) were used to create a typical washing load and the quantities of the items being washed. The dry clothes were weighed individually on the scale before being placed in a top loader washing machine. These clothes were then weighed again after being washed to determine the amount of moisture that would be released from drying the item. For a typical household of 2.7 occupants, a rate of 2,478g/load is estimated with a total of 4.5 loads of washing washed.
per week. It is assumed that an unvented clothes dryer releases all the clothes moisture into the air and none remains in the machine.

Evaporation of water from showering is assumed to add significant amounts of moisture to the air because of the high temperature of the shower water and the warm poorly ventilated environment. This moisture evaporates into the air and once the air is saturated will begin to condense on surfaces within the bathroom. To calculate an estimate for moisture release from showering a model derived by Shair, et al., 1979 was used taking into account ventilation, infiltration, vaporisation from the shower and water vapour condensation onto the bathroom surfaces (Yik, et al., 2004).

\[ w(t) = \frac{(b/a)}{1 - \exp(-at)} \]  
\[ a = \frac{(S + Q + kA)}{V} \]  
\[ b = \frac{(Sw_s + Qw_o + kAw_o)}{V} \]

Where: \( w(t) \) = Moisture content in the bathroom air at time in kg.kg⁻¹; \( t \); \( w_o \) = moisture content in the air entering the bathroom due to ventilation in kg.kg⁻¹; \( w_s \) = saturated moisture content of the air in equilibrium with the water droplets in kg.kg⁻¹; \( S \) = coefficient of moisture transfer from the shower water to bathroom air in m³.s⁻¹; \( k \) = Coefficient of moisture transfer between the bathroom air and surfaces enclosing the bathroom in m.s⁻¹; \( Q \) = ventilation flow rate due to mechanical ventilation in m³.s⁻¹; \( A \) = total area of surfaces enclosing the bathroom in m²; \( t \) = time in s; \( p \) = air density in kg.m³.

Using this model (1), for a shower lasting 8.7 minutes, a total moisture release of 401.4g per person is estimated, equating to 46.1g/minute. Moisture released from bathing in a bathtub was also calculated resulting in 174.2g/event, but from the survey results very few people bathed in a bathtub compared with showering.

From the experiments it is found that many of the events that contribute to moisture in bathrooms release moisture over a long period depending on the indoor climate. Towel use and floor mopping have a slow release rate compared to activities like showering and unvented clothes drying where moisture is released quickly over a short period. For a typical shower and clothes drying event based on the survey findings and experiments these activities release 401.4g/person and 2,478g/event respectively. Measures to reduce the amount of moisture released into the air from the two largest contributors would include reducing the length of showers and the total amount of clothes left to dry indoors. However, this may not always be achievable. With the amount of moisture released into the air known, this raises the question of whether this moisture will contribute to problems like mold and mildew in the home. Ventilation is key to prevention of these types of issues, so typical bathroom ventilation systems that are able to cope with this much moisture are vital.

### 3.2 Extraction fan performance

To establish whether current bathroom extraction fans can cope with the moisture released in bathroom, methods from Abushakra, et al., 2004 study and Weaver, 2011 were adapted to determine the extraction fan performance. Since the study was conducted overseas, alterations were made in the equipment used for measuring the airflow and size of duct in the experiment due to the availability.

All experiments concerning extraction fans were conducted in a laboratory. Two different testing procedures were conducted with each setup consisting of different equipment and interpretation software for measuring the 100mm and 150mm extraction fans’ airflow performance. First the airflow performance of the fan is measured using the hot wire method to find out if it met the performance that
is quoted by the manufacturer. The second method uses Laminar Flow Element (LFE), LFE Pressure gauge (measured pressure difference) and MKS Transducer (Airflow rate) all used in the experiment to ensure the reliability and accuracy of the result.

Both methods demonstrated that the 150mm fan did not meet the company specifications giving a different rate of air flow. However, the last test with the laminar flow element provided a more reliable result because the variables could be more easily controlled.

**Hot Wire Anemometer**

The Hot wire anemometer experiments resulted in the extraction fans performing well below their quoted performance shown in Table 4. The 100mm fan does not meet the building code requirement of 25l/s intermittent or 10l/s continuous air exchange, because it was only able to achieve 8.6l/s airflow rate, whereas the 150mm extraction fan met the building code requirement on its own, but failed after adding 1m of duct.

<table>
<thead>
<tr>
<th>Axial fan</th>
<th>NZBC requirement (l/s)</th>
<th>Quoted performance (l/s)</th>
<th>Airflow – no duct (l/s)</th>
<th>Airflow – 1m duct (l/s)</th>
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</thead>
<tbody>
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<td>6.7</td>
</tr>
<tr>
<td>150mm extraction fan</td>
<td>25 intermittent or 10 continuous</td>
<td>94</td>
<td>73.6</td>
<td>60.1</td>
</tr>
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</table>

**Laminar Flow Element (LFE) and Extraction Fan**

The airflow performance of the extraction fan was measured by the LFE shown in Figure 10. The LFE measures the airflow and the MKS measures the pressure on the other side of the extract fan.

![Laminar Flow Element (FLE) experiment setup](image)

**Figure 10: Laminar Flow Element (FLE) experiment set up (Authors image)**

Testing of the extraction fan using the LFE method resulted in the fan not meeting the minimum Building Code requirements of 25/s nor its quoted performance of 23/s shown in Table 5. The 150mm fan meets the Building Code requirement, however when 1m of duct is added the airflow rate drops from 26.3 to 22.8l/sec and thus fails to meet the Building Code requirements.

<table>
<thead>
<tr>
<th>Extraction Fan</th>
<th>Duct</th>
<th>MKS Pressure Gauge</th>
<th>LFE Gauge</th>
<th>Extraction Fan Duct</th>
</tr>
</thead>
</table>

**Table 5: Comparison of extraction fans and New Zealand Building Code**
Laminar Flow Element (LFE), 150mm Extraction Fan and PVC Duct

This aim of the experiment was to measure the airflow of different lengths of ducts. Table 6 shows the difference in airflow between PVC and a rigid duct at different lengths with the 150mm extraction fan connected. In both types of ducts airflow reduces as the length of duct increases. By increasing the length of the duct, the pressure drop will increase and the airflow will decrease. Both the experiment and literature review show that flexible (PVC) ducts are less effective and play a significant effect on the extraction fan performance. Flexible ducts are popular to install in residential dwellings because of their low cost, easy installation and ability to navigate around tight corners.

<table>
<thead>
<tr>
<th>Axial fan</th>
<th>NZBC requirement (l/s)</th>
<th>Quoted performance (l/s)</th>
<th>Airflow – no duct (l/s)</th>
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<td>6.8</td>
<td>3.6</td>
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<tr>
<td>150mm fan extraction</td>
<td>25 intermittent or 10 continuous</td>
<td>94</td>
<td>26.3</td>
<td>22.8</td>
</tr>
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</table>

Table 6: PVC and rigid airflow ducts

<table>
<thead>
<tr>
<th>150mm axial fan</th>
<th>Length (m)</th>
<th>PVC airflow (l/sec)</th>
<th>Rigid airflow (l/sec)</th>
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<tr>
<td></td>
<td>1</td>
<td>22.8</td>
<td>n/a</td>
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<td></td>
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<td></td>
<td>3</td>
<td>22.5</td>
<td>23</td>
</tr>
</tbody>
</table>

This third experiment involved a 3m flexible duct which was compressed down into 0.15, 1 and 2m lengths. The findings in Table 7 show that a slight compression can result in a large pressure drop and result in lower airflow rate. When the duct has no compression (fully stretched) this results in a higher airflow compared to compressed. This is because the flexible duct had a spiral helix construction, therefore it has the highest friction loss. The inner surface of the flexible duct changes shape with compression which increases turbulence and friction loss. The flexible duct is soft and flexible therefore it is easy to squeeze through tight places and compress excessive lengths to fit between connections.

<table>
<thead>
<tr>
<th>150mm axial fan</th>
<th>Compression scenario (m)</th>
<th>PVC airflow (l/sec)</th>
<th>Pressure drop (Pa/m)</th>
<th>Compression (%)</th>
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<tr>
<td></td>
<td>(Compression)</td>
<td></td>
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<tr>
<td></td>
<td>0.15</td>
<td>20.8</td>
<td>95.3</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>20.8</td>
<td>18.4</td>
<td>80</td>
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<tr>
<td></td>
<td>2</td>
<td>20.6</td>
<td>8.8</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>(Fully stretched)</td>
<td>22.5</td>
<td>4.8</td>
<td>40</td>
</tr>
</tbody>
</table>

The final experiment performed involved adding a number of bends ranging from 60 – 90° to a 3m PVC flexible duct with the 150mm fan. This resulted in the airflow reducing dramatically to 1.23l/s with one bend compared to no bends which had an airflow of 22.5l/s shown in Table 8. The reasoning behind
this dramatic increase may be attributed to the degree of the bend. Further testing is required with bends of smaller angles to understand whether this data can be fully trusted.

<table>
<thead>
<tr>
<th>150mm axial fan</th>
<th>No of bends on 3m</th>
<th>PVC airflow (l/sec)</th>
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<tr>
<td></td>
<td>0</td>
<td>22.5</td>
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<td></td>
<td>1</td>
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<tr>
<td></td>
<td>2</td>
<td>1.24</td>
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<td></td>
<td>3</td>
<td>1.21</td>
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</tbody>
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4. Conclusion

The aim of this study was to investigate how much moisture is produced from day to day activities and what effect extraction fans have in New Zealand households. With 53% of owner-occupied houses and 73% of rental properties having mould, an understanding of the sources of moisture caused by occupants within the home is needed (Buckett, et al., 2010). Typically, literature tends to focus on removing moisture from the home rather than managing it at its source (McNeil, et al., 2015). By undertaking experiments relating to a typical New Zealand household, it was found that an estimate of 3,831g of moisture could be released into the air on a day where high moisture generating activities are performed like showering and use of an unvented clothes dryer. To minimise the amount of moisture released into homes, duration of moisture generating events like showering and the quantity of clothes left to dry indoors could be reduced. These measures alone are not able to prevent moisture being released into the air, which is where extraction fans should be used to remove moisture.

Overall, the research conducted indicated that the size of the fan, location of the fan, excessive length, number of bends and various compression on the duct all contribute to the failure of residential fan systems and duct systems. The manufacturer’s claims for the performance of their 100mm fans may meet the minimum requirements on paper, but the research demonstrates that as typically installed in practice, the completed fan installation does not meet the ventilation requirements of the NZBC Clause G4.

Both designers and contractors need to be made aware that the following recommendations will help to meet Clause G4.

- Use rigid duct wherever possible.
- If using flexible duct, ensure it is stretched out which will avoid bends and slight compression.
- Specify timers and sensors of the extractions fans.
- Use 150mm fans instead of 100mm.
- Avoid angled corners in ducts
- Have a maximum of 2m of duct connected to the exterior
- Allow fresh air into the room, to supplement the air being extracted

To reduce the impact of moisture in homes, testing of different types of fans and a wider range of duct sizes is needed to determine the most efficient fan and duct system for residential dwellings. Testing of manufacturers claimed performance and actual performance is also key to ensure consumers are purchasing a system that meets its claims.
Acknowledgements

This paper presents the findings of two summer research projects. The authors would like to thank the Building Research Association of New Zealand and Victoria University of Wellington.

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Responsive Systems and Electronic Spatial Interfaces

Outcomes in Architectural Design Studios

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Abstract: This conference paper is the first of two papers that discuss the outcomes of a long-term pedagogical research project into the integration of interdisciplinary design-research, and making practices into the content of second-year architecture studios. This paper focuses specifically upon one studio involved in the design of responsive systems and electronic spatial interfaces. The studio introduces students to technologies associated with “The Internet of Things” and encourages them to consider how their use in design might impact a range of different social and spatial systems. Through the design, prototyping, and testing of these systems students are encouraged to learn through practice, developing their projects iteratively while being critical of the implications of their actions. Through a discussion of the studio aims, structure, project examples, and outcomes, this paper outlines an initial approach to the teaching of programming and electronics within a design studio context. Along with the paper on Biological Systems these works highlight the importance of critical engagement with materials and processes and of opening up future architectural pedagogy to new fields of exploration.

Keywords: Architectural education, critical design, responsive systems, spatial computing

1. Introduction

The architecture that I have studied, that I have practiced with other architects, with my professors... It is over. Eduardo Souto de Moura (2016)

Architecture consumes earth’s limited resources, it is long lasting and expensive, and it can significantly alter the quality of living of its users. We live in a fully explored, finite, over populated world and so it is imperative that we do not think of and produce architecture in the same ways that we have in the past. It is essential that we understand humans, non-humans, objects, buildings, cities and regions not as isolated entities, but as parts of systems of increasing complexity and uncertainty. As humans, it is important that we understand our place in these systems, not an overwhelmingly important position but only as part of it. Climate related natural disasters, over population, uncontrolled consumption, disregard
for non-humans and non-humans environments, food and water supply constraints, artificial intelligence, massive migrations, cultural tensions, raising inequalities, extremist groups and unannounced acts of random violence are unprecedented challenges that are all connected. It is important to recognize that actions have consequences and that there is no such thing as designing an isolated entity. As a part of this system, architects need to understand the world that they live in, in order to raise awareness about the consequences of their designs.

Starting from these foundations, a long-term pedagogical and research project was implemented at the University of Western Australia under the Integrated Design ethos. During their second year, architecture students are given the opportunity to take a 13 week studio called Making. As a part of the school’s design stream, students are invited to develop solutions to design problems that may or may not include architecture. During the semester, students are required to submit both prototypes and finished products at their real scale as opposed to drawings and models. This encourages design development through experimentation, and the production of multiple prototypes that are critically examined and iteratively improved. Through this process, students are expected to develop a better understanding of the difficulties faced in producing built objects, and to consider the relations between projects that only exist in print, on screen, as models and those that exist in the built environment, leading to careful and thoughtful future designs.

The majority of studio coordinators of Making are not architects, and those that are have specific skills that are unusual within architectural practice. Some of the most recent specialized skills ranged from: ceramics, eco-activism, responsive electronic interfaces, biological systems, ecological systems, traditional carpentry, graphic design and conceptual art. By opening the design studios to coordinators with diverse backgrounds, students can focus on different underlying design systems. By offering the opportunity for students to work with diverse specialists, we are expanding their fields of action. By opening up the discipline to new fields of action – biological, electronic, multispecies, conceptual arts, we enable students to collaborate in trans-disciplinary approaches and complex environments where outputs are unpredictable, through design. We empower students to become independent thinkers, to have the desire to run their own practices. We accept unexpected, ambitious, and unfinished projects that can be more interesting than expected, finished, and predictable outcomes. To do that, we ask students to redefine what success means, to seek alternative uses for design knowledge other than in the production of commodities. To use making as a means of interrogating the world to better appreciate and understand the impacts of design decisions and to allow students to pose their own questions instead of reacting to defined problems. It is important to assume that by doing this we are no longer in an expert/apprentice position; we are together with our students in an experimental research journey with unpredictable outcomes. We do not know exactly what students will produce and we do not know how it will be applied in future architecture. It is precisely this, the acceptance of uncertainty, the program’s greatest strength. Together we lay the foundations for a future that we cannot foresee. Our world is rapidly changing. Architecture education and practice have to adapt, to open up new fields of exploration and to prepare students for uncertainty.

This conference paper is first in a series of conference papers from our long term pedagogical and research project.

2. Responsive Systems and Electronic Spatial Interfaces

In architectural discourse the idea of a responsive environment has its roots in the 1960’s with the Cybernetics movement and scientists, engineers and mathematicians such as Norbert Weiner, Gordon
Pask, and Ross Ashby. The field was concerned with how processes of self-regulation and feedback could underpin an understanding of systems within the natural world, which could then be applied to the creation of adaptive computational systems (Yiannoudes, 2016). The concept of a ‘responsive architecture’ was first explored by Cedric Price and Nicholas Negroponte (among others) who were interested in applying ideas that were emerging in the field of Cybernetics to architectural design (Mathews, 2006; Negroponte, 1975). Since this time these ideas have evolved in a number of directions, with the concept of responsive spatial systems seeing growing prevalence within a number of fields such as art, architecture, urban design, computer science, and interaction design.

Over the last decade, the increased availability of cheap, programmable microcontrollers, sensors, and actuators, as well as free access to programming platforms and information about their use has provided an opportunity for designers to engage with the production of digital systems and interfaces, not just on a conceptual level, but through engagement with the technology itself. Technologies of these kinds, sometimes referred to as “The Internet of Things”, are changing the ways that we understand and operate within the physical world as spatial computing is increasingly becoming (for better or worse) a part of our everyday lives. While the increased volume of data available to us presents the dystopian possibility of authoritative control of our actions, it also opens up new possibilities for how we interact with and perceive the world around us. For students of architecture, the accessibility of electronics and programming technologies provides an exciting opportunity to complement their practice with interdisciplinary skills.

3. The Studio Format

In the design of responsive systems, interactions and interfaces are of central importance. In relation to the understanding of ‘interaction’, the architect Norbert-Schulz (2000) suggests that qualitative teaching demands that a manual grasp - hands on training - should contribute to qualitative comprehension. This is a sentiment echoed by Kreuger (2011) who suggests that it is cognitively economical to use the ability to recognize the possibility within something rather than to invent those possibilities oneself. In this design studio, this kind of ‘hands-on’ training was necessary for the students to be able to engage with a range of unknown quantities within a limited space of time.

In the Making studio, the intent was not to teach students the practice of interaction design, which as Lane and Tegtmeyer (2014) identify is a field that is more concerned with the practical and pragmatic application of digital technologies in the creation of products and services. The pedagogical technique employed shares more similarity with Meta-design, which is a design process focused on the lessons learned by making mistakes (Fischer and Giaccardi, 2006) and Critical Making (Ratto, 2011). Critical Making consists of three main processes: research into existing literature to establish themes and provoke questions, prototype development to develop skills and establish design parameters, and a third stage of communication, critical reflection, and revision. Production of designs in collaborative groups of teachers, students, and stakeholders is also emphasized in order to provide greater feedback within the making process.

The question posed to students at the outset of the studio was “How can electronic hardware and software be incorporated into the design of a responsive spatial system?” Students were expected to be able to identify and engage with a system (spatial, social, physical, imagined etc.) within a chosen site, identified through self-directed processes of mapping and research, and then propose design interventions that they would later prototype and test. Before beginning the studio, students were given access to a small amount of reference material. Each reading was focused on a different topic; mapping,
cybernetics, interactive art, and responsive architecture (Corner, 1999; Jones, 2006; Krueger, 2011; Mathews, 2006). The first stage of the studio was an individual assignment worth 30% of the overall grade which lasted two weeks. Students were asked to identify a potential site within the campus, document their spatial experience, and begin to imagine possibilities for intervention. Through various processes of mapping, some of which were introduced in studio presentations and readings (Corner, 1999), students identified existing systems within their site that they could engage with (Figure 1). They were also asked to complement these investigations with research into literature and precedents. The outcomes of this initial research were then presented and discussed within the studio to direct and develop ideas for the second part of the assignment, and identify technical skills that needed to be learned.

The second assignment was also an individual exercise worth 50% of the overall grade. From a developed conceptual standpoint students were given four weeks to imagine, design, and prototype an artifact that responded to their identified system. The submitted artifact could be considered as a modular component of a larger assemblage, or as a single agent in a network of distributed agents. In producing their designs, students were encouraged to experiment and develop multiple prototypes. The process of experimentation and prototyping was also to be documented in a short film to communicate the intent of the project and the process of design experimentation.

Students were expected to develop technical skills independently and as required to be able to produce their responsive system. The basics of electronics and programming were established in a couple of workshops and after this, direction was given to students only in response to particular problems that emerged in each project. In this case, validating or developing a design intervention could not simply be a formal or speculative exercise – development necessarily had to occur through a continual process of design, testing, evaluation and revision to identify the scope of potentials in their project and also to refine and direct the behaviour of their responsive system. This could not just be done through traditional methods of speculation and representation through drawing. Instead, making was encouraged as the primary means of design development.
4. Outcomes

Given the relative openness of the brief there were a large number of different approaches to the idea of a responsive system. The following is a list of projects and their identified typologies. This framework is based on Schwartzman’s categories for design and art that involve technology and embodiment (2011) with the addition of the category of ‘Reactors’ to describe projects that were concerned with patterns of motion in the animated reactions of objects and how they can evoke an emotional response within a viewer.

4.1. Reframers

Challenging the relationship of the body to space/ recasting the role of objects in spatial rituals

- *Periscopes*, transmitting light from larger context within an enclosed external site
- A ‘Functional’ Intervention, collapsing chair - reframing the expected role of furniture through détournement
- *Claustrophobia Module*, inflatable wall in corridor triggered by presence (Figure 2)
- *Remote Viewer*, viewfinders that switch user perspectives through telepresence
- *A Priori*, lit wireframe sculpture connected to users heartbeat
- *Vibro Chair*, chair that invites user to sit by vibrating when in proximity

![Figure 12: Claustrophobia Module, Chelsea Smith, An inflatable wall that restricts corridor movement.](image)

4.2. Environments

Altering or generating spaces through sensory effects.

- *Soundmites*, sonic responsive network
- *Synthesis*, sound feedback loops in spaces
- *Lightbox*, interior space with light sculpture that changes colour based on external activity
- *Chromosaturation*, reactive generation of spatial volumes through primary colours (Figure 3)
- *Atmo-Sphere*, sonic telepresence module for your head
• Reflective Traces, patterns of motion represented through reflecting light from vibrating pools of water onto building

![Image](image.png)

Figure 13: Chromosaturation, Haley Harrison, Colour volumes that shift based on nearby activity

4.3. Tools

Extending or augmenting spatial systems through the representation of quantitative information

• Windcopy Machine, representing external wind conditions using interior kinetic sculpture
• Heatmap Chair, Public benches that react to patterns of use through changing colours
• Flow Counter, counter system for stair and ramp
• Mood Lamp, representing user mood on building columns through patterns of colour derived through skin temperature
• Level Representation, communicating activity levels on different floors of building through light sculpture

4.4. Mediators

Interacting with the threshold between systems natural/physical

• Leaf Catcher, net sculpture that changes form as it collects tree leaves (Figure 4)
• Coloured Shadows, prismatic glass installation in stairwell that changes patterns of light and colour in reaction to changing interior light conditions
• Skylophone, ambient installation that converts sky colour into xylophone melodies
Figure 14: *Leaf Catcher*, Riley Omelczuk, A series of nets that intervene with natural processes of decay.

### 4.4. Reactors

Generating object behaviours through patterns of motion

- *ALVA Pets*, small machines with reactive ‘personalities’
- *Systema Medusozoa*, mimicking undulating Jellyfish motion through reactive, inflatable sculpture (Figure 5)
- *Japanese Fans*, mechanical fans in corridor that actuate based on direction of motion

Figure 15: *Systema Medusozoa*, Nadya Haryanto, A study of systems of motion in jellyfish.

From the prototypes that were produced in this stage, the students were asked to decide on a single project to develop further as a group for the final assignment (worth 20% of the final grade and assessed as an entire class). The entire studio was asked to work together to produce the final product with smaller groups being assigned to specific tasks (ie. design team, project management, construction detailing, system design, programming, electronics, filming, drawing etc.). Soundmites was the project that was
chosen for the final assignment. The concept of the project was for a system of reactive machines to be attached to the metal downpipes around the architecture campus (Figure 6). These units would respond to the movement of people around the space by striking the downpipes with various intensities and tempos. Each module consisted of an internal enclosure made of 3d printed ABS plastic that would contain an ultrasonic proximity sensor, a battery pack, a small motor and striking armature, and an Arduino microcontroller. This internal enclosure was designed to sit within a timber case that would waterproof the electronics and provide a clamping mechanism, enabling the Soundmite to be attached to a range of different downpipes. The aim of the project was to generate an altered sonic environment outside the architecture school through a network of these units – programmed with a simple reactive logic to strike the downpipes when they detected a person moving within a certain proximity. While the behaviour of each object was simple, the combination of a dozen units created a chaotic and unpredictable soundscape that changed in response to the activity within the monitored space.

Figure 16: Soundmite building pipes, map of system installation, Emiline Elangovan
Figure 17: Soundmite Internals and final object installed on site

5. Conclusion

In the 1990’s Mark Weiser (1991) predicted that invisible and ubiquitous computing would produce a state of “embodied virtuality” enabled by the development and integration of wireless networks, sensors, and actuators into the built environment”. For design students, the accessibility of contextual information derived from technology is now taken for granted as a natural part of everyday rituals. Davies and Thrift (2015; 2004) have both noted that this naturalisation of technologically mediated experience comes for most at a price; in order to benefit from the increased efficiencies provided by quantitative organisation of spatial activity we have to be willing to submit a degree of agency to the control of these new organising systems. Just as in the use of a computer operating system, an understanding of the underlying structure is not required for the efficient use of the system (and in the case of commercial systems it is often not desired). However, knowledge of the inner workings of the program provides a much greater scope for interaction and control of that system. As computational logics become applied to the design of everyday objects we are faced with the same dilemma – we can operate within the parameters set out by the original programmer, or we can open ourselves to the possibilities inherent in the technology through a deeper knowledge of the design of its underlying systems. Marc Tuters (2004) has noted that as computation becomes an increasingly prevalent component of the physical environment “the imagination of programmer, with her coded control of the virtual’s interface with the real” will increasingly determine the shared, consensual reality of digitally mediated existence. For design students, being able to engage with electronics and programming provides them with the opportunity to navigate an interdisciplinary field that is rapidly transitioning from a specialisation to a core component of the design of environments and everyday objects. As such, it will be important for future architecture students to understand how these systems operate. In the case of this studio, engaging students in experimentation with an unknown
quantity forced them to negotiate the balance between conceptualisation and pragmatic application. The use of Critical Making as a design methodology enabled students to develop research and technical skills through their application in specific projects. Moving from individual work to group work during the progression of assignments allowed the complexity of the project to scale alongside the development of their skills, and provided a forum for critical reflection through discussion with the whole class. However, this also introduced a number of issues with relation to the fairness of applying a single grade to the final assessment and the impact of this upon overall grades which could be improved by reducing groups to smaller teams of 4-6 students.

In the immanent future, responsive systems will become (for better or worse) a part of our everyday lives. As the internet of things develops, the design of responsive spatial systems will become increasingly important, not just in the way that it can control spatial effects and the actuation of objects and buildings, but also in the way that blockchain and other emerging technologies (such as Ethereum and IOTA) will connect spatial activities to economic systems of exchange. In this context the design of responsive systems will have major impacts upon social, economic, and political spheres and not just the aesthetics of the built environment. Teaching at least some degree of literacy in electronics and programming will prepare students of architecture for future uncertainty and enable them to engage in an increasingly mediated world.

References

A Comprehensive Review of Literature on the Importance of Windowscapes

Evaluation and Suggestion for Improvement of New Zealand Building Code

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Abstract: Rapid intensification of Auckland has made our visual awareness of the outdoor environment (windowscapes) more confined and restricted. The recent changes of Auckland’s windowscapes have made the shortcomings of New Zealand Building Code more apparent. This paper aims to demonstrate the importance of windowscapes in urban dwellers’ life and to suggest some changes to current building code to provide healthier and liveable indoor environments. Hence, evidence from the literature on the impact of views on building occupants’ wellbeing will be first reviewed. Then, New Zealand Code Clause (G7 Natural light) and its Acceptable Solution will be critically analysed to identify areas that require improvement. Our literature review indicates that private views are more relevant for health and wellbeing than building and planning legislation in New Zealand currently considers them to be. Hence, this paper suggests that windowscapes should become an essential part of future building codes and standards. This paper concludes that providing strict requirements regarding windowscapes is essential to building a healthier indoor environment.

Keywords: Windowscapes; building code clause G7; health and well-being; outdoor visual awareness

1. Introduction

The importance of windowscapes has been neglected in urban dwellers’ life particularly in Auckland. Rapid intensification has made Auckland’s windowscapes more confined and restricted.

Windows have many roles: providing views, daylight, and ventilation. With the advent of buildings with large areas of glazing, increased time spent in buildings and increased awareness of the benefits of improved working environments, the importance of windows for building occupants has shifted in favour of windowscape. The provision of permanent supplementary artificial lighting and ventilation reduced the role of the window as the only source of daylight and fresh air, while the concept of transparency in architecture introduced a new type of relationship with the landscape outside. This was coincident, and
possibly the result of, changes in the lifestyle of modern urban dwellers who spend the majority of their time indoors (Shoemaker, 2002, p. 141). In agreement with this, McLain and Rogers (1981) say that despite fresh air and natural light remaining the major functions of windows, people are more interested in window as a way of contact with the outside world.

The importance of having a view for urban dwellers is confirmed in most studies on windows. Wells (1965) found that 89% of surveyed office workers stressed the importance of having access to the window even when there was abundant artificial light in the interior. An analysis (Nichols, 1977) of sixty questionnaires from volunteer participants working in an urban high-rise office building revealed that respondents without window views made more non-job-related trips away from their workstations – presumably looking for a view to the outside – than respondents with views. Nagy et al. (1995) found that respondents from an underground office rated the importance of having a view much higher than those from aboveground offices. Both groups considered the view as the most important function of a window, followed by fresh air and natural light. According to the literature review by Farley and Veitch (2001, p. 8) “of all the benefits and psychological functions provided by windows the provision of a view appears to be most valued by building occupants.” In Bodart and Deneyer’s (2004) survey, sunlight and visual contact with the outside were found to be the two most positive functions of windows for building users. Cooper-Marcus (1982) argued that attractiveness of neighbourhoods mainly depended on what residents could see from their windows. These results can be explained by the theory that humans have evolved to crave visual information about their environmental surroundings (Verderber, 1986).

2. Literature Review on Preferred Windowscapes

Windowscape plays a crucial role in modern life for urban dwellers as the majority of their time is spent indoors. The visual quality of urban windowscapes can, consequently, have a great influence on the quality of life. But what factors can influence windowscape preferences and what are the most and least visually preferred features of urban windowscapes? Answering these questions are important as preferences reflect how given environments support well-being (e.g. Van den Berg et al. (2003)).

Research shows that two main factors influence preferences for urban windowscapes: environmental characteristics and attributes of observers. This section only summarises key environmental factors, for more comprehensive literature review refer to Mirza (2015) and Lothian (2000). Environmental characteristics can be divided further into concrete features of urban landscape (e.g. water, greenery, sky, buildings) and psychological landscape descriptors (e.g. complexity and mystery).

**Buildings:** Since buildings are an inevitable component of urban windowscapes, two key questions for designers and developers are: how can buildings be incorporated in an urban scene to positively increase the visual quality of the views? And what characteristics of buildings are more highly valued by viewers? Kfir et al. (2002) found the presence of residential buildings in the near distance were the most influential factor in negative assessments of the view. However, if the buildings were more than 500 meters away or if the window outlook included a view of the sea, buildings had no effect on view preference. Tuaycharoen (2006) asked 20 students to assess how interesting they found the views of ten rooms in different buildings; a concrete wall with little colour variation was chosen as the least interesting view. Similarly, in a hospital context, rooms with large windows towards a concrete building were disliked (Verderber, 1986).

Low preference for obscuring buildings might be related to the associated loss of occupants’ privacy. For instance, Markus & Gray (1973) found the satisfaction with windows in residential dwellings depends on the number of buildings visible and their infringements upon privacy. In line with these
findings, Mirza (2015) noted that blocking buildings were more negatively assessed in home views than office views. This result is due to different levels of visual privacy needed in these two contexts. **Cityscapes:** 88% of the office workers (n=348) in Markus’ study (1967) preferred to see the distant city and landscape from their windows. A cityscape was rated higher than views showing close natural features (Tuaycharoen, 2006).

**Landmarks:** Landmarks to be the most preferred built feature of urban windowscapes. In some cases, even a silhouette of a landmark on the horizon has the power to positively influence the observers (Mirza, 2015).

**Roading:** Roading (e.g. streets, highways, and parking lots) can negatively influence assessment of a scene. Parking lots and traffic were identified as two prominent disliked features of urban landscapes and windowscapes (Nasar, 1998; Hellinga, 2013). Weber et al. (2008) found streetscapes were considered more beautiful if the street is broad and laterally bounded by trees with only a few buildings visible.

**Sky:** The ability to see the sky from the window can keep observers in touch with information such as seasonal changes, time of day and the weather (Markus, 1967, p. 103) and was found to be a main reason behind a desire for windows. Butler and Biner’s (1989) research reported a view of outside for temporal information (weather and time of day) to be the strongest predictor of window size preferences. Office workers who could see the sky, were less likely to report fatigue, headache and eye strain problems (Heschong Mahone Group, 2003). While it has been found that a view dominated by sky is more satisfying than a view without this feature (Lottrup, Stigsdotter, Meilby, & Claudi, 2013), the sky alone cannot evoke positive feelings in observers (Markus, 1967).

**Greenery:** Greenery was found by a significant number of researchers to be the most effective addition to a view for improving the visual quality of: commercial highway strips (Lambe & Smardon, 1986; Smardon & Goukas, 1984), residential areas (R. Kaplan, 1985; Hussain & Byrd, 2012) and streetscapes (Stamps, 1997; Weber et al., 2008). However, it is not the case that all kinds of vegetation are equally preferred. Lottrup et al.’s (2013) research on workplace window views found that flowers, trees and park-like environments increased the odds of being satisfied with the views, while no significant relationship was found for mowed lawns and wild self-seeded natural environment. Participants in Gorman’s survey study (2004) identified “trees block visibility” as one of the negative attribute of street trees. Results from Mirza’s study (2015) adds to these findings by demonstrating that positive influence of greenery is more effective in blocked and semi-blocked views than long open views. Such results are important for application: if a view to a blocking building is inevitable when designing a new building, the architect should try to minimize the negative influence of a blocked view by providing greenery.

**Water:** The positive effect of water on preferences has been consistently reported (White et al., 2010; Mirza, 2014). White et al. (2010) found that the extent of aquatic features in a built environment might be less important in influencing preferences than their mere presence. Vecchiato (2012) asked experts and lay people to express their opinion about a list of landscape features; bodies of water were found to be the most important feature to increase the visual quality of a landscape. Zhao et al. (2013) found that natural landscapes with approximately 45% of water body cover were preferred. Howley and O’Donoghue (2011) found water bodies as the most liked landscape attribute, followed by mountains and greenery, respectively.

**Complexity:** Complexity is a positive and influential predictor of preferences for urban window views (Collins, 1975). Wolf (2003) found that the increase of complexity of urban scenes by disliked features (e.g. buildings, and overhead wires) could negatively affect preferences. S. Kaplan (1987) reported that
natural landscapes were preferred over urban scenes regardless of the level of complexity. Mirza (2015) found that the effect of complexity on preferences depends on the context of the views. While the complexity was a significant predictor of preferences for office windowscapes, no relationship was found for home views. The researcher explained her result by suggesting that observers in their office are more likely to be mentally fatigued due to the need of staying engaged with their everyday tasks and fighting off distractions compared to when they are at home. As a complex scene can effectively contribute to restoration, the higher preferences for complex views in offices is the result of observers’ greater need to recover from mental fatigue.

**Openness:** Openness is a key driver of preferences (Kaplan & Kaplan, 1989). Openness of an urban view depends on the density and configurations of buildings (Hur, Nasar, & Chun, 2010), as well as the storey level where the window is located (Kfir et al., 2002). Hellinga and Hordijk, (2008) asked their respondents to choose which of six pictures they preferred most and least as a view from their offices. A wide view from a high floor was the most appreciated and a view from the ground floor to a close building was preferred the least. Ozdemir (2010) found identical offices to be experienced differently, depending on their views. Office workers with open expanded views perceived their rooms to be larger and lighter, and thus more satisfying, than those with closed views.

**2.2. The benefits of preferred windowscapes**

Research has shown that windowscapes can have economic value depending on their content. For instance, a pleasant view can lead to a considerable increase in house price (e.g. Luttik (2000)); while an unpleasant view could be expected to lead to a decrease in the house price. Factors that increase the value of a property include (in descending order of importance) view to the sea, view to urban parks, view from high-rise apartments and view to sparsely populated regions (Damigos & Anyfantis, 2011). Full views to the ocean could increase the market price of single-family homes in Washington by almost 60% (Benson, et al. 1998). Similarly, a wide water view could increase the mean sale price of residential properties in Auckland as much as 44% (Samarasinghe & Sharp, 2008). In Singapore, an unobstructed sea view from a high-rise building could add an average of 15% to the property price (Yu, Han, & Chai, 2007).

Windowscapes have different beneficial values depending on their content. R. Kaplan (1993) reported that employee3s with desk jobs with a window to natural features (i.e., trees, vegetation, plants and foliage) had fewer ailments, were less frustrated and more satisfied with their jobs. Window views of green vegetation or water, rather than of other buildings or a brick wall, were found to have a positive effect on attention capacity (Tennessen & Cimprich, 1995). Leather et al. (1998) added to this finding by demonstrating that natural features within a view can buffer the negative effect of job stress on intention to quit and a marginal positive effect on general well-being.

The Heschong Mahone Group (2003) found a significant correlation between the content of the views and reports of fatigue, headache, difficulty concentrating and influenza. The study also found office workers with interesting views performed 10% to 25% better on tests of mental function and memory recall than those with no view. Shin (2007) documented positive self-rated health effects of viewing forests through a window on office workers in Seoul, South Korea. A cross-sectional survey on office workers in the Netherlands showed that attractive window views reduced discomfort (e.g. concentration problems and headache) (Aries, Veitch, & Newsham, 2010). A recent study by Lottrup et al. (2013) showed that a view of natural elements was related to high view satisfaction, which then contributes to high work ability and high job satisfaction. Research in this area shows that an attractive windowscape is more than
an amenity and underpinning this preference is a fundamental issue of psychological well-being and physical comfort (Tuaycharoen & Tregenza, 2007).

Heerwagen and Orions (1986) investigated whether employees who work in windowless offices use visual decoration to compensate for the lack of having access to a window. Those who worked in windowless offices used more visual materials for decoration than occupants of windowed spaces. The content of the décor in windowless offices was dominated by nature themes. Bringslimark et al. (2011) reported similar results. Bringslimark et al. (2011) noted that workers in windowless offices were more likely to bring plants and pictures of nature into their workspaces than workers with windows. Radikovic, (2005) argued that an artificial window video would be an excellent replacement for a window in an all single-person spaces with a limited view of nature, such as underground, underwater, outer space, or just strictly urban areas. However, a research conducted by Kahn Jr. et al. (2008) showed that a plasma window was no more restorative than a blank wall.

The physiological effect of windowscape is not limited to workplaces. Patients with a view to stands of trees were found to recover faster and required less pain medication than patients facing a brick wall (Ulrich, 1984). Prison inmates whose view consisted of adjacent farmlands had lower rates of sick call than those looking out upon the prison yard (Moore, 1981). An archival study of past residents of a nursing home revealed a significant negative correlation between people view (view to parking lots, the front entrance, or a yard) and length of stay, while view of greenery had no effect on this matter (O’Connor, Davidson, & Gifford, 1991).

Having natural elements in the home window views contributes substantially to residents’ satisfaction with their neighbourhood and their sense of well-being (R. Kaplan, 2001). Taylor, Kuo, and Sullivan (2002) found concentration and self-discipline of inner-city girls (but not boys) were positively affected by the naturalness of the view from their high-rise urban homes. The authors explained their results by suggesting that boys typically spent less time indoors. Residents living in greener surroundings reported to have a lower level of fear, fewer incivilities and less aggressive and violent behaviour (Kuo & Sullivan, 2001). Residents of a large metropolitan area in the U.S. rated the potential of trees for helping people feel calmer as one of the key benefits of this natural feature (Lohr et al. 2004). Having a view over gardens has been shown to have a strong contribution to neighbourhood satisfaction (R. Kaplan, 2001; Kearney, 2006); moreover, those whose homes had access to their own garden or to shared gardens had significantly better health (Macintyre et al., 2003). Surprisingly, R. Kaplan (1985) noted that urban parks and large grassy open spaces played a minor role, at best, in residents’ ratings of satisfaction with various aspects of the neighbourhood; while the availability of nearby trees and well-landscaped grounds were the two most important factors. Although, from these studies, it can be concluded that viewing natural features through windows has positive psychological effects, it is still not clear which features have contributed most (Velarde, Fry, & Tveit, 2007).

College students living on higher floor levels with open views found their dormitory rooms less crowded and got along better with their roommates (Schiffenbauer, 1979). Undergraduate university students who had views to a lake and trees from their dormitory windows were better able to concentrate than those students with views to city streets, buildings or a brick wall (Tennessee & Cimprich, 1995). Students who were asked to imagine themselves cognitively fatigued, rated settings with views of large natural murals with water more restorative than settings with window views of real, but mundane nature with built structures present (Felsten, 2009).

There is a series of laboratory studies that adds to our understanding of the psychological value of viewing attractive scenes. For instance, experimental research by Tuaycharoen and Tregenza (2007) found
less discomfort to be caused by glare from a window when the window offered an interesting view than from a window of the same mean luminance but with a view of less interest. The authors previously conducted a similar study in a laboratory condition with images of scenes, which led to similar findings (Tuaycharoen & Trenzena, 2005). Purcell et al. (2001) found nature scenes with water were rated higher in restorativeness than nature scenes without water. Karmanov and Hamel (2008) study added to this finding by showing urban environments with an outlook onto water could have the same stress-reducing and mood-enhancing power as a natural environment. This may suggest that water bodies can compensate for the lack of greenery in urban environments.

3. Critiques of NZBC G7

In light of previous finding on the importance of windowscapes on urban dwellers’ life, this section critically reviews the current New Zealand Building Code (NZBC) G7 Natural light and its Acceptable Solution.

As a performance-based regulation, the Building Code sets the standards that all building work must meet to protect health and safety of building occupants. In practice, ‘performance-based’ means that any design and construction methods can be used as long as they can prove that the requirements of the Building Code have been met. This flexibility encourages the construction industry to develop innovative and cost-effective solutions. Most clauses in The Building Code have Acceptable Solutions or Verification Methods describing how to meet the performance requirements of the particular clause. Although Acceptable Solutions and Verification Methods are not mandatory, designs based on them must be accepted by Building Consent Authorities.

G7 Natural Light is aimed to ensure that there is sufficient natural light and visual awareness of the outside environment for building occupants. Like other NZBC technical clauses, G7 contains three main sections: objective, functional requirement, and performance criteria. Stating its objective is to “safeguard people from illness or loss of amenity due to isolation from natural light and the outside environment”, G7 appreciates the importance of windowscape on health and wellbeing of building occupants (Brooker’s Building Law Handbook, 2012, p. 355).

The functional requirement specifies that “habitable spaces shall provide adequate openings for natural light and for visual awareness of the outside environment” (ibid. p. 355). However, G7 puts limits on this requirement making it only mandatory for ‘habitable spaces’ within ‘housing’, ‘old people’s homes’ and ‘early childhood centers’. In other words, offices or student accommodation can be built with no or limited access to the outside views. That is while our literature review showed the significance of window views on the health and productivity of office workers and students. Moreover, functional requirement of G7 (G7.2) appears equivocal as there is no clear definition for ‘adequate opening’: “adequate to achieve the objectives of the Building Codes”. This is also the case for ‘visual awareness’, leaving it open to any interpretation. For instance, it can be easily interpreted that G7 does not require a habitable space to have a street or landscape view and as long as one can differentiate between day and night, and diverse weather conditions, the requirement of the code are met. In other words, a view to a brick wall a few meters away from an observer can comply with the building code; however, if such views can safeguard people from ‘illness or loss of amenity’ is most certainly in question.

Two performance criteria are used to fulfil the requirements of NZBC G7. As this research is only dealing with the visual awareness of the outside requirement (G7.3.2) of Clause G7, there will be no mention of the illuminance requirements (G7.3.1) unless it is deemed required. G7.3.2 performance
criteria explain that “openings to give awareness of the outside shall be transparent and provided in suitable locations” (ibid p. 355). The code does not define any criteria to determine a suitable location for a window. It can be argued that the best practice is to ensure that the visual privacy of the occupants is secured while a desirable view is achieved. However, the lack of knowledge on influence of windowscapes preferences on wellbeing made architects to become more concerned with how the building looks from the outside and hence give the location of the window from inside less priority.

Using the guides in acceptable solution in G7 to design new buildings can be counted as a one of the main reasons for current lack of sufficient visual awareness in most habitable spaces. The Acceptable Solution (G7/AS1) is divided into two parts: vertical windows in external walls and awareness of the outside environment. However, the emphasis has been more put on natural lighting, while the importance of window views is overlooked. For instance, G7/AS1 suggests overcoming the impact of obstruction in a view on the amount of natural light entering a building by using high reflectance surfaces. That is while no comments have been made on the impact of obstruction on the quality of the windowscape or how to compensate this. Moreover, G7/AS1 allows visual awareness of the outside environment through another space making this issue even more critical.

Although this section only focuses on G7 but the following shortcomings in current building and planning regulations have been noted that deserves further investigations in future work: 1) The possible impact of future development on windowscapes of adjacent properties hasn’t been considered in the Building Act and the Building Code. This particularly becomes more important in mixed zoning areas, as a new office building can get constructed on the boundary and block an exterior view of an existing next-door apartment building; 2) The fact that views from a private domain are not considered important under the current Resource Management Act (2017); 3) The openness of windowscapes hasn’t been considered important in Auckland’s new planning rule book. Based on the new unitary plan, a minimum net site area for the mixed housing suburban zone is 400m² and for the mixed housing urban zone is only 300m². Only one-meter setbacks from the side and rear boundaries are required. These rules are changing Auckland’s windowscapes and soon a building within a short distance becomes a common feature within all residential windows.

4. Conclusions

Windowscape is an aspect of health and safety that is at risk of being compromised due to insufficient regulation. Our literature review indicates that private views are more relevant for health and wellbeing than building and planning legislation in New Zealand currently considers. Hence, this paper suggests that windowscape should become an essential part of future building codes and standards. In particular, G7 needs to extend to include buildings that are occupied on a regular basis and for extended periods of time such as working environment, offices and student accommodation. Moreover, it is important that G7 enforces remediation where there is an obstruction in the view. This is because our literature review shows that an attractive windowscape is more than an amenity and underpinning this preference is a fundamental issue of psychological well-being and physical comfort. For instance, if a view to a building is blocked when designing a new building, the architect should try to minimize the negative influence of a blocked view using developing technologies such as green walls. The fact that the NZBC is performance-based and not prescriptive, can make profit-driven property developers lean more towards ‘liberal interpretation’. This paper believes that providing strict requirements regarding windowscapes is essential to building a healthier indoor environment. For instance, strict requirements can make designers
to consider windowscapes in their initial designs rather than adding component retrospectively to compensate the lack of such amenity.

References


A Pilot Study of Design Evaluation of Three Memory Support Residential Facilities in Victoria

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Abstract: There are over 400,000 persons with dementia in Australia. This figure is projected to increase by 90% to more than 760,000 in the next 20 years and exceed 1.1 million by 2056. Due to the significant increase in the number of people with dementia, the demand for memory support residential facilities is expected to increase. People with dementia are vulnerable to environmental impacts, so the design of such facilities has a significant impact on the quality of life and well-being of the residents. In this pilot study, three memory support facilities in Victoria are selected for evaluation: Rathdowne Place in Carlton, Peninsula Grange in Mornington and Campbell Place in Glen Waverley. Through design analysis and fieldwork observation, the aim of this study is to identify key factors of the built environment for residents with dementia, compare building layouts and provide design recommendations.

Keywords: Design for dementia; memory support facilities; residential care; design evaluation

1. Introduction

According to the latest statistics available from the World Health Organisation, around 47 million people have dementia with 9.9 million new cases being diagnosed every year. The total number of people with dementia is projected to near 75 million in 2030 and almost triple to 132 million by 2050 (WTO, 2017). Over 400,000 persons with dementia were living in Australia in 2016 and the figure will exceed 1.1 million by 2056. In 2016, over 23% of people with dementia were living in care accommodation (Brown et al., 2017, p.23). Due to the significant increase in the number of people with dementia in Australia, the demand for memory support residential facilities is expected to increase. How to provide a living environment for residents with dementia which can cater for their specific needs is crucial.

In this pilot study, three memory support facilities in Victoria are selected for evaluation: Rathdowne Place in Carlton, Peninsula Grange in Mornington and Campbell Place in Glen Waverley. Through design analysis and fieldwork observation, the aim of this study is to identify key factors of the built environment for residents with dementia, compare building layouts and provide design recommendations.
2. Characteristics of People with Dementia

For designing an appropriate memory support facility, it is important to understand the characteristics of people with dementia. Dementia is a broad term to describe a collection of symptoms that are caused by disorders affecting the brain. The most common type of dementia is Alzheimer’s disease, which affects up to 70% of all people with dementia (Alzheimer’s Australia, 2017).

According to the report, Dementia in Australia published by the Australian Institute of Health and Welfare (AIHW, 2012), residents with dementia showed problematic verbal behaviours (such as being verbally disruptive and having paranoid ideation that disturbs others), problematic physical behaviours (including physically threatening or harmful behaviour and constant physical agitation), severe cognitive skills impairment, wandering behaviour and depression (Table 1).

<table>
<thead>
<tr>
<th>Behaviour characteristics</th>
<th>Percentage of residents with dementia showing the behaviours twice a day or more</th>
</tr>
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<tbody>
<tr>
<td>(1) Problematic verbal behaviours</td>
<td>55%</td>
</tr>
<tr>
<td>(2) Problematic physical behaviours</td>
<td>50%</td>
</tr>
<tr>
<td>(3) Severe cognitive skills</td>
<td>48%</td>
</tr>
<tr>
<td>(4) Wandering behaviour</td>
<td>27%</td>
</tr>
<tr>
<td>(5) Depression</td>
<td>10%</td>
</tr>
</tbody>
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Besides behavioural issues, people with dementia may also encounter difficulties in handling the activities of daily living including mobility, personal hygiene, toileting and continence depending on different stages. Currently, there is no cure for dementia, however, medications are available to ameliorate symptoms such as agitation and paranoia.

Due to various impairments of people with dementia, they are vulnerable to environmental impacts. Therefore, the design of memory support facilities has a significant impact on the quality of life and well-being of the residents. As mentioned by Weisman et al. (1990), ‘even modest changes in the environments of people of reduced competence may have significant positive consequences.’ (pp. 14-15).

3. Evidence-based Strategies for Design for Dementia

Evidence of the impact of design for people with dementia continues to evolve with patterns becoming ‘visible and potentially reliable when we collate and sift through the results of multiple, small, non-randomised research projects undertaken over the past twenty years’ (van Hoof & O’Brien, 2014, p. 2). Encouraging residents, carers, health professionals and families to participate in design processes is helping to shift design away from a medical model with residents as passive care recipients to more homelike environments in which residents remain engaged in life in meaningful ways (Davis, Byers, Nay, & Koch, 2009).

In recent years, design for dementia has shifted from focusing on solving behavioural problems to a more positive approach on design for remaining capabilities. Six principles for quality aged-care environments have been summarised as: 1] facilitating orientation, 2] promoting independence, 3] providing for intellectual and sensory stimulation, 4] supporting safety and security, 5] developing a homelike and familiar atmosphere and 6] balancing private and social spaces (van Hoof & O’Brien, 2014,
People with dementia have varying and changing capabilities and so architecture which is able to evolve and respond according to need is a useful approach.

4. Design Evaluation of Three Memory Support Facilities

4.1. General Layout

The three selected memory support facilities in Victoria were recently built: Rathdowne Place in 2014, Peninsula Grange in 2015 and Campbell Place in 2017. All of them provide single bedrooms with ensuite. The scenario of spaces for couples is not available. Shared rooms are more common in the UK, Asia and Europe and less so in Australia and the US. Among them, Peninsula Grange has the largest memory support facility which can accommodate 34 residents. The 34 bedrooms are grouped into four wings, with eight bedrooms in two wings, seven and nine bedrooms in the remaining two wings. Bedrooms are located on both sides of the corridors, with a maximum length of five bedrooms. Communal spaces at the central portion link the four corridors together. On the north-east side of the facility, there is an outdoor garden (Figure 1 left).

Figure 18: Floor plans of memory support facility at Peninsula Grange (left) and Rathdowne Place (right)

The memory support facility at Rathdowne Place is the smallest within these three facilities catering for 13 residents. Its size makes it less economical to staff (author conversation with Australian Unity architect on 02.08.17) with seven bedrooms on one side (House 1) and six bedrooms on the other side (House 2). Bedrooms are in L-shaped configuration in House 1 and in linear arrangement in House 2 with a corridor of three bedrooms in length. House 1 and House 2 are separated by an activity room, but are open to the same covered terrace outside. (Figure 1 right). The memory support facility at Campbell Place...
is slightly larger than the one in Rathdowne Place and can cater for 17 residents. It has eight bedrooms on one side (House 1) and nine bedrooms on the other side (House 2). Corridors in each house are in T-shape configuration. House 1 and House 2 are connected by a service corridor for staff access. Each House opens to an outdoor terraced garden. (Figure 2 left).

The original layout of the memory support facility at Campbell Place (Figure 2 right) shows the bedroom arrangement in L-shaped configuration, which is similar to the layout of House 1 at Rathdowne Place. In contrast to the final design outcome (Figure 2 left), the original layout shortens the length of corridors and enables better visual access between bedrooms, communal spaces and terraced gardens outside. Having said that, the final layout supported by the operation offers a designated service corridor leading to the pantry, which can directly connect to the respective domestic kitchen of each House. This can facilitate the delivery of meals from the central kitchen via the service corridor and enables the staff at the domestic kitchen to have the ease of access to the pantry during meal preparation process (Figure 3). However, by providing such pantry, the original calm/ activity room has been deleted (Figure 4).
From the perspective of operational efficiency in terms of meal delivery and preparation, the final layout is favoured by staff, but the provision of calm/activity room is beneficial to residents with dementia. As mentioned previously, at least half of people with dementia exhibit problematic verbal and physical behaviours twice a day or more according to the statistics, it is highly preferable to provide a space for solitude for some residents (Weisman et al., 1990, p.60). If the folding partition has adequate sound proofing performance, the subdivision of the room can allow residents to have a quiet room on one side and an activity room for small group interaction on the other side. Folding partitions allow spatial flexibility and enable residents living in both House 1 and House 2 to share the same space for other social events.

The provision of the multi-purpose room between the two Houses at Rathdowne Place shares a similar idea with the original layout of the Campbell Place (Figure 5). However, due to its limited size, spatial subdivision by folding partitions is no longer feasible. The room can be used as an activity room or a calm room only at different times. Contrary to the Campbell Place, there is no designated service access at
Rathdowne Place. The staff working at the Campbell Place may have better communication and collaboration as they share the same pantry and the domestic kitchens are connected to each other, whereas the staff at Rathdowne Place may need to work more independently. At Rathdowne Place, the main entrance for visitors and staff access for daily operation share the corridor for the services rooms, which may bring inconvenience to visitors and may also cause disturbance to the residents as a source of over stimulation (Fleming and Bennett, 2017, p.20).

![Enlargement plan of the memory support facility at Rathdowne Place](image)

Although there is no designated service corridor for the memory support facility at Peninsula Grange, kitchen entrances and service entrances are provided for staff access which are separated from the main entrances to minimise the disturbance to dining areas. Similar to Campbell Place, a pantry is provided adjacent to one of the domestic kitchens to facilitate daily operation. However, the service entrances are close to bedrooms nearby which may cause distraction and disturbance to the residents unless the service doors are well camouflaged with silent locks (Zeisel et al., 2003, p.708).

### 4.2. Dining Area and Domestic Kitchen

The dining hall at Peninsula Grange can be divided into halves by sliding partitions, resulting in two smaller dining areas to cater for 17 residents on one side. This offers adaptive spatial usage to cope with the needs of the residents. Since the gathering of 34 people together at the same place may create too much noise resulting in overstimulation, agitation and confusion to some residents, the flexibility of spatial subdivision can reduce the possibility of disruptive behaviours during mealtimes (Schwarz et al., 2004, p.174). The dining hall offers visual and physical access to gardens on both sides which can be orientational cues and helpful stimulation to residents. Windows at both south-eastern side and north-western side can also allow natural light to enter to the interior (Figure 6).

At Peninsula Grange, the domestic kitchen is the focal point of the dining area. It does not replace the full-service kitchen, but breakfast preparation, beverage making and dessert baking can contribute to the domestic ambience of the space, reducing the image of the overall institutional setting (Figure 7 left). The distinctive smell of food during meal preparation provides olfactory sensitivity to residents. The kitchen
next to the dining area also facilitates the staff to cater for personal dietary requirements and allows residents to make choices, especially during breakfasts, so that they feel more in control of their lives, which has positive implications for the sense of competence and self-esteem of people with dementia. The kitchen is not merely a food preparation area, but also ‘a practical and non-institutional alternative to the traditional nurses’ station’ (Weisman et al., 1990, p.61). Staff at the kitchen enjoy an unobstructed view of the dining area, adjacent living areas and the outdoor garden beyond, which offers informal surveillance and ease of monitoring of the residents (Figure 6). Similar domestic kitchen arrangement is also provided at Campbell Place (Figure 7 right).

Figure 6: Enlargement plan of the memory support facility at Peninsula Grange

Figure 7: Domestic kitchen at Peninsula Grange (left) and Campbell Place (right)

Fleming and Kirsty (2007, pp.217-218) do not recommend open plan kitchen as residents with dementia may present a danger to themselves or to others in the kitchen. The unrestricted access to appliances (including a toaster, an oven, a microwave, a kettle and a fringe) can be dangerous, so the provision of a domestic kitchen relies on proper staff supervision and effective measures to keep residents out of the kitchen without causing frustration and agitation to them.
Compared to the open plan kitchens at Peninsula Grange and Campbell Place, the domestic kitchen at Rathdowne Place is more enclosed with glass doors to prevent any unauthorised entry in compliance with the recommendation of Fleming and Kirsty (Figure 8). The original idea of having a domestic kitchen at the centre of the communal area at Campbell Place (Figure 2 right) has been realised at Rathdowne Place (Figure 1 right), but the kitchen at Rathdowne Place has full-height partitions which affect the sight lines within the memory support facility.

![Figure 8: Domestic kitchen at Rathdowne Place](image)

### 4.3. Outdoor Gardens

Among the three memory support facilities, the outdoor garden at Peninsula Grange is the biggest. Doors opening to the garden are unlocked during the daytime enabling residents to go outside as one of their choices. This can lead to the decrease in negative aggressive behaviours of the residents (Namazi and Johnson, 1992, p.20). In fact, a well-designed garden is a therapeutic environment for people with dementia as it can provide visual, tactile, olfactory and auditory stimulation through the combination of natural landscape, fragrance, sunlight, wind and birds. The timber trellis at the entrance of the garden serves as an iconic structure for residents’ spatial orientation (Figure 9 left). If more interest points can be provided along the looped path and appropriate shelters can be erected to protect seating areas from excessive sun and strong wind, this may attract more residents to use the garden. Wheelchair-accessible raised planting beds can also be provided to allow residents with remaining abilities to participate in gardening. Although the open terraced garden at Campbell Place is relatively small and there was not much planting at the time of visit before the move-in of any resident, it can still be a source of sensory stimulation to residents if it is properly landscaped (Figure 9 right). Gardens at Peninsula Grange and Campbell Place face north-east and south-east respectively. Both of them can capture favourable morning sunlight, encouraging residents to go outside (Figures 1 & 2).

The outdoor activity area at Rathdowne Place is the smallest with a covered terrace and limited planting (Figure 10 left). It faces north, but due to its openings on one side and its close proximity to the adjacent building, solar exposure is unavoidably affected. Solar penetration to the communal space behind the covered terrace is further reduced due to the set-back from the façade (Figure 1 right).
4.4. Memory Boxes

The memory support facility at Rathdowne Place is the only one among these three facilities to have memory boxes outside residents’ rooms (Figure 10 right). The inclusion of personal objects in the memory boxes, such as photos and other artifacts, can provide opportunities for people with dementia to reinforce their long-term memory and reflect upon their past experiences within their remaining capabilities. This can personalise the institutional setting and enhance the sense of identity by creating a familiar environment and serve as an effective orientation cue for wayfinding than displaying distinctive but non-personal items (Namazi et al., 1991, p.14). Displaying personal objects along the corridor may also stimulate social interaction and conversation among residents and enable the staff to have better understanding of the residents about their stories and preferences (Kovach et al., 1997, p.108).

5. Conclusions and Recommendations

Through this pilot study, the general building layouts of the three selected memory support facilities at Rathdowne Place, Peninsula Grange and Campbell Place are compared. Key design factors are identified and appropriate provisions within the facilities are discussed, including:
1. visual access and clear sight line within the domestic ambience of the space
2. separate access for staff to minimize disturbance and avoid overstimulation to residents
3. orientation cues for wayfinding
4. choices to residents for their sense of self-esteem
5. outdoor activity space for connection to nature
6. sense of identity and familiarity by displaying personal objects

The impact of the built environment of memory support facilities on the quality of life and well-being of residents with dementia requires ongoing research. We propose further ethnographic research including observation, photo elicitation, a questionnaire survey and focus groups to collect and collate feedback from the staff and family members of the residents. Collected data can inform the future design approach of similar memory support facilities to suit the specific needs of people with dementia.

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References


Outdoor Wind Environment Study of High-rise Residential Buildings in Urban Areas

A Literature Review

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Abstract: As wind environment is one of the key elements in the sustainable and environmental design, there is a need to study local wind environments of modern cities. In urban areas, especially when the density of city is increasing, the influence from buildings to wind environment is becoming higher and higher. This paper presents a literature review for outdoor wind environment study of high-rise residential buildings in urban areas. First, the previous wind environment research is reviewed. It not only helps to understand the fundamentals of interaction of how wind flows around objects such as buildings on the earth’s surface, but also present the gap between the formal study and the nowadays contemporary residential buildings in urban areas. Second, as there are two methods of wind tunnel and computational fluid dynamics (CFD) for simulating the wind environment, this paper focuses in summarizing the existing CFD tools and setting up the fundamentals for developing future workflow. Third, the evaluation criteria of wind environment from different standards is compared. In the end, a possible framework to evaluate wind environment is discussed. The literature review is intended to highlight the limitations of previous research of novel high-rise residential buildings and current adaptation analysis methods. In particular, for the hot-summer and cold-winter climate, and with the development of architecture, novel forms and arrangements of residential buildings have been developed, wind environment design strategy response to this kind of climate and forms is insufficient. The review helps to set up the fundamentals for our following research to explore the optimization of outdoor wind environment of residential buildings in urban areas by establishing early-stage design principles.

Keywords: Wind environment; high-rise residential building; CFD; design principles
1. Introduction

As sustainable design has received more and more attention in recent years, environmental analysis is sometime needed in the early stage in design process. To be one of the key elements in the sustainable and environmental design, local wind environment of modern cities is needed to evaluate.

This paper reviews the wind environment studies, CFD simulation tools. It is finished on the focus to the discussion of the research gaps. The literature review responses to the seeking for good early design principles that generate favourable outdoor wind conditions for residential buildings, especially in hot-summer and cold-winter urban areas.

2. The Development of Wind Environment Study

The definition of natural ventilation can be described as using the natural forces of wind and buoyancy to introduce fresh air and distribute it effectively surround or inside buildings. For natural ventilation to be effective, there has to be a close relationship between the wind and the built forms, the site environment in a particular location, and the layout within the buildings (Loftness and Haase, 2013). In this section, a literature review on wind environment studies is provided. First, the development of wind environment study is introduced. Second, it presents the interaction of wind flow and buildings based on the building aerodynamics. Third, it reviews the studies around the world.

In 1960s, with the rapid development in the field of materials science building and construction technology, the height of the building is also on the rise. However, due to lack of awareness and preventive measures at the time, high-rise buildings have negative effects, leading to a deterioration in the wind environment and other related issues. As the frequency of wind environmental problems was growing, with some even directly affect the safety of users, making it getting attention by engineers and researchers.

At first, people started to study wind because it can generate loads on high-rise buildings. Starting from the 1960’s, building aerodynamics has secured its place in scientific literature thanks to the construction and use of improved boundary layer wind tunnel facilities, which made it possible to accurately simulate the flow around buildings (Blocken and Carmeliet, 2004). At that time, a vague standard says if the distance between two buildings is more than about six to eight times the average of the horizontal size of the building, their mutual influence can be ignored (Simiu, 1985). But the reality is not the case, because the city’s land area is restricted very limited land resources. As building density is becoming higher, large space in urban areas is basically impossible. Recognizing the importance of the outdoor wind climate, many urban authorities nowadays require studies of the pedestrian wind environment for large construction projects.

The majority of studies in the past have been conducted with wind tunnel modelling. In the last three decades, CFD (Computational Fluid Dynamics) has become available as an additional tool (Blocken and Carmeliet, 2004). Study in building wind environment using CFD method began in the middle of 1980s last century. To study the air flow, the Reynolds Equation (Dowson, 1962) and the Smagorinsky Model (Scotti, 1997) are usually used. Using Cartesian grid and simulation method are generally based on the standard k-ε turbulence model. But the lack of standards and defects of k-ε model in the early nineties made the simulation difficult to implement.

In 1990s, researchers began establishing relevant research model to make the studies closer to the actual situation, including the modification of turbulence models. A large part of the research work is a
combination of wind tunnel tests, aimed at solving practical engineering applications are issues involved. The CFD simulation analysis of rectangular-shaped buildings was made at that time. In 1996, scholar Mingde Su and his colleagues did the research about wind velocity field and wind pressure in cuboid-shaped high-rise building under different wind directions. Simulation studies and the data obtained were calculated with the experimental achievements and then compared (Su, 1996). To study the results of the peak factor of the wind pressure on building surfaces, wind tunnel experiments for high-rise buildings were operated by Wu Taicheng and other researchers. They used a dynamic pressure model for analysis (Wu and Chen, 2007). The researchers of Launder and Kato proposed an improved turbulence model (Launder and Kato Model) on the turbulent energy equation (Launder and Kato, 1993; Selvam, 1996). The model was further amended on the basis. Murakami and other researchers set up the CFD simulation using the LES method (Kondo, Murakami and Mochida, 1997). It was found that the results from using LES Method is closer to the wind tunnel test data than using the Reynolds Equation Method (Murakami, 1998). A solution of similar model is suggested (Kawamoto, 2000).

3. The Interaction of Wind Flow and Building

Wind environment study requires fundamental knowledge of wind engineering principles (Stathopoulus, 2007). The construction of a building inevitably changes the outdoor climate at the building site (microclimate). Wind speed, wind direction, air pollution, driving rain, radiation and daylight are all examples of physical aspects that constitute the outdoor climate and that are changed by the presence of the building. The change of these quantities depends on the shape, size and orientation of the building and on the interaction of the building with the surrounding buildings and other obstacles (Blocken and Carmeliet, 2004).

3.1. Pressure and Force

Wind pressures on building surfaces are expressed as coefficients relative to the dynamic pressure of the approaching wind. By convention, positive pressure coefficients indicate pressure acting toward a surface while negative pressure coefficients indicate suctions or pressures acting away from a surface (Aynsley, 1999).

![Figure 1. The figure shows the wind speed profile of podium layer, urban canopy layer (UCL), roughness sublayer (RSL) and urban boundary layer (UBL). Vp, Vc, Vs are the wind speeds of these layers (Oke, 2006; Ng et al., 2011).](image-url)
Force on buildings generated by wind is somehow closely related to pressures. There are lift force and drag force. As air flows around a solid body, it exerts varying degrees of air pressure around the surfaces of the object. If the total effect of surface pressures normal to the direction of the flow on either side of the object are not equal and opposite in direction, then the resulting force, normal to the direction of the airflow, is referred to as the lift force. Drag forces act in the direction of flow on a body in a steady air flow. Drag force is the sum of viscous skin friction force and pressure drag which results from net differences in surface pressures on the windward and leeward sides of the body (Aynsley, 1999).

3.2. The Influence of Roughness Properties of Urban Areas

For modern cities as shown in the figure (Figure 1.), the velocities and flow paths of wind, the scales and intensity of turbulence are influenced by the roughness properties of the urban areas (Landsberg, 1981). The total drag on a roughness surface includes both a pressure drag on the roughness elements and a skin drag on the underlying surface, and a skin-drag on the ground surface (Raupach, 1992; Shao and Yang, 2005). Because the skin drag is relatively small and is not a factor controlled at the urban scale, only the pressure drag is usually considered in most studies (Ng, 2011). A logarithmic function is developed to set up a semi-empirical relationship by taking two aerodynamic characteristics of roughness length and the zero-plane displacement height into consideration (Oke, 1987). It is reliable for evaluating such aerodynamic characteristics of urban areas for depicting and predicting urban wind behaviours (Grimmond and Oke, 1999). Currently, there are three classes of methods for estimating the surface roughness: Davenport roughness classification (Davenport et al., 2000), morphometric and micrometeorological methods (Grimmond and Oke, 1999).

3.3. The Influenced Air Flows

Most buildings with flat surfaces and sharp corners are referred to as "bluff" bodies. The air flow separates from their surface at the sharp corners when its momentum overcomes the weaker cohesive forces of attached objects such buildings. Shear layer is generated along the lines of separation of turbulent wake beside and behind the bluff body. The predictable separation of flow at sharp edges and corners of bluff bodies results in constant flow pattern characteristics and pressure distributions for a given wind direction over a wide range of wind speeds (Aynsley, 1999) (Figure 2.).

Figure 2. Left - Typical air flow features around a building (Aynsley, 1999). Right - Interaction of air flow and a normal rectilinear floor plan building. It explains the mechanism of downwash and high-speed wind areas may be expected at the pedestrian-level corners (Cochran, 2004).
Generally, buildings will induce high wind speeds at lower levels if a significant part of them is exposed to direct wind flows. Building is often designed in a rectilinear floor plan with curtainwall to ground level. High-rise buildings may aggravate pedestrian-level winds by allowing the high-elevation, faster winds to flow down the face of itself, which is called downwash mechanism (Figures 2.). As the air flow reaches the ground it is then accelerated around the pedestrian-level corners.

4. Wind Environment Studies around World

In this section, the wind environment study around world is introduced briefly. In recent years, lots of scientific studies dealing with the wind environment and modelling have been established quickly (Oke, 1987; Cermak, 2003). Though many countries have relevant codes and design guidelines for gust and strong wind problems, few has touched on the issue of urban air stagnation and city air ventilation problems (Ng, 2009). The research about outdoor climate has received relatively little attention in the building physics community (Blocken and Carmeliet, 2004), except some dealing with air pollution and dispersion.

4.1. Studies in America and Europe

In America and Europe, study in this field started early. Researchers studied a statistical procedure for a performing air quality simulation model (Cox et al., 1989). In relative research, researchers did the evaluation of CFD data with experimental data (Gromke et al., 2008). Influence of avenue-trees on air quality at the urban neighbourhood scale was studied (Gromke and Blocken, 2015). Researchers have done a lot of study for indoor environment. In the indoor environment quality (IEQ) section of many standards in different European countries, the establishment of relative rules aims to improve indoor air quality (Dimitroulopoulou, 2012). Researchers studied in the validation and optimization for the turbulence model (Yu, 2016). A comparison was made between ENVI-met and Autal2000 to study their modelling performance (Paas and Schneider, 2016). In Germany, developments are required not worsen the climatic conditions of the site. Urban climatic maps have been produced to guide planning and development decisions. Take the city of Kassel as an example, a planning evaluation map has been translated from the climatic map to factor the dynamic characteristics of the wind environment in the urban area for planners to decide future development (Katzschner, 2000).

4.2. Studies in Asia

As it has been discussed in the above section of development of wind environment study, relevant research started early in Japan. Some calculation models have been set up since 1980s. Researchers used wind tunnel tests to study the pedestrian wind environment in residential neighbourhoods in major cities in Japan (Kubota, 2008). A CFD study was conducted to study the climate in the Greater Tokyo area (Murakami et al., 1999). The CFD method was also used to study air pollution issue in cities in Japan (Kondo, 2006).

In Singapore, a parametric study is done to understand the gross building coverage ratio variation on outdoor ventilation in high-rise residential estates. In the study of building geometry on outdoor ventilation for high-rise residential estate, guidelines and algorithm have been reviewed (Lee, Jusuf and Wong, 2015). Researchers have done the study of outdoor ventilation of high-rise residential housing estates for a deeper understanding of wind flow with respect to different levels of height variation (Lee, Jusuf and Wong, 2015).
In Hong Kong, high-rise residential buildings are found blocking the sea breeze “fresh air” which is important for air ventilation and pollutant dispersion in the street canyon (Ng, 2009). The air ventilation impacts of the “wall effect” caused by the alignment of high-rise buildings in complex building clusters is investigated (Yim et al., 2009). The researchers try to improve the wind environment in high-density cities by understanding urban morphology and surface roughness (Ng et al., 2011). Then they have done a practical application of CFD on environmentally sensitive architectural design in Hong Kong (Yuan and Ng, 2014).

In China, Tang Yi, Meng Qinglin and other researchers did the study of the summer monsoon CFD simulation in Guangzhou Jiangnan Garden residential district in 2001. The ventilation openings of different situations and different simulated wind speed were set. Various modifications of the program were made to be compared. The distribution of wind velocity of residential areas was illustrated as a qualitative basis for planning and design for the construction of residential district (Tang and Meng, 2001). In 2002, Prof. W. K. Chow and other scholars used CFD simulation and a wind tunnel to study a financial high-rise building in Beijing. The CFD software they used is the Phoenic. The results from the CFD simulation and the wind tunnel tests were analysed to obtain the specific distribution of dynamic analysis diagram of the high-rise building (Chow and Gao, 2002). In 2003, Chen Jianguo and other researchers from Tsinghua set up the 2D and 3D models to analyse the Lanqi Ying residential building groups in Beijing. Understanding of stroke case load and environmental impact were deepened through CFD numerical simulation of wind environment for users and residential high-rise building designers (Chen, 2007). Zhang Aishe and other researchers did the CFD simulation of wind environment of two adjacent buildings, taking into account of the spacing ratio and building height and other conditions. The CFD simulation results reveal the areas of renewable wind load of high-rise buildings. The mechanism was formed to provide a theoretical basis for high-rise residential buildings and urban planning which has a certain reference value (Zhang, 2008). The researchers from Tongji University explore climatic adaptability of high-rise buildings from the wind environment (Chen, 2008). For the hot-summers and cold-winters area, a study was done on grand urban windway planning (Hong, Yu and Li, 2011). The strategy of climate adapt design of the existing building was studied in a practical project in Wuhan (Gan et al., 2013). Researchers have begun using surface roughness evaluation to study urban wind environment, as in the research of GIS-based surface roughness evaluation in the urban planning system to improve the wind environment for Wuhan (Yuan, Ren and Ng, 2014).

5. Discussion of Research Gaps

Wind environment is an important topic for sustainable design. Though researchers from different countries have done lots of studies in this field, gaps can still be found which leads to our future research.

Compare to American and European countries, the local climates, urban forms and residential building types are largely different from the Asian cities in hot-summer and cold-winter areas. As types of high-rise residential building are similar to mainland China, researches in Hong Kong and Singapore can be very good references. However, those researches in Hong Kong and Singapore response to the hot and humid climate in the tropical cities instead of the hot-summer and cold-winter climate in the temperate zone. The outdoor wind environment of residential buildings in the hot-summer and cold-winter climate is rarely considered. In addition, previous researches are focusing on urban scale or indoor ventilation. The influence from the forms and arrangements of architecture, especially novel residential buildings, is not clear yet.
According to their different forms, the buildings can be categorized into regular forms such as cuboid shapes, or irregular forms such as arc-shapes. Analogously, the arrangement of building groups can be categorized into regular types such as linear arrangements, or irregular types such as curvilinear types (Zhang, 2012). The increase in the number of tall residential buildings and the more or less arbitrary, with respect to wind, installation of large structures have frequently demonstrated the lack of adaptation of the structural environment to wind phenomena. Manifestations at ground level, such as zone of high speeds or eddies, make the approach to buildings uncomfortable, sometimes even dangerous for the pedestrian (Gandemer, 1978).

![Image of residential building layouts](image)

Figure 3. Left - Samples of residential building groups with curved layouts in Wuhan, Beijing, Shanghai and Hong Kong respectively (Google Map, 2016). Right - Previous studies which are generally regular-shaped layout buildings (Du, 2009).

The non-standard curvilinear residential buildings that don’t follow conventional rectilinear block structures are becoming increasingly more popular recently. Curved layouts are becoming increasingly popular because of their elegant expressions (Figure 3.). Compared to conventional, rectangular layouts, curved-layout ones have superiority in their innate aesthetic functions and their flexibility of arrangements (He and Schnabel, 2016). Also, circular shapes typically do not cause flows of the type that generated by the ones with rectilinear floor plan (Cochran, 2004). It has been stated that, curved buildings generally promote lateral flow, so they behave better as far as effects of pedestrian-level winds are concerned (Stathopoulos and Baniotopoulos, 2011). However, though various studies of ventilation conditions of conventionally design buildings have been made, research of the novel irregular buildings with curved-layout is still limited. It is said that: ‘Most people, and includes architects, without a sound grounding in the science of fluid dynamics, frequently reach wrong conclusions regarding the relationship between the shape of an object and its interaction with the surrounding airflow (Aynsley, 1999).’

6. Conclusion

The review has identified ad-hoc studies in urban areas dealing with the wind environment from different countries. But for the hot-summer and cold-winter climate zone and novel forms of high-rise residential buildings, wind environment studies are still rare. In sum, the conclusion can be summarized as follows.
1. Future Research: There is a need to study the mechanism behind for developing early design principles that generate favourable outdoor wind conditions for residential buildings in urban areas response to hot-summer and cold winter climate.

2. Theoretical Framework: There are several green building evaluation criteria around the world. In these evaluation criteria, the standards from various manuals are different. Some are indistinct or even primitive for outdoor wind environment among buildings. According to the themes of evaluation criteria of wind speed probability and statistics, the balance of wind velocity is proportional to human sense of comfort. Combined with the research methodology, the theoretical framework for our future research can be founded considering the rate of aeration which depends on wind flow velocity, distribution of the flow velocity and wind velocity transition of different areas, on the basis of the requirements from the ‘Green Building Evaluation Standard’.

3. The Methodology: For our future research, to do the research, as the conventional in-depth simulation is time-consuming, a practical integrated workflow to immediately evaluate the performance for each design alternative is needed.

In the future, by bridging the parametric modelling and CFD simulation, we intend to develop an advanced workflow that is capable to optimize design through iteration analysis. Accordingly, our future study will contribute to this field in both expanding the study of categorized subjects of novel forms response to certain climate and analysing methodology creatively, which would help practical architecture projects.

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Implications for the Design of Rental Housing for the Elderly that Improves their Quality of Life

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Abstract: As the population ages, the demand for suitable rental housing will increase. Suitable housing means housing that can accommodate those impairments that typically correspond with ageing. This paper explores the quality of life (QoL) requirements of the elderly with high-care needs who live in rental housing. It identifies important design considerations through a qualitative case study of three elderly people who need assistance and are living in local-authority rental housing in New Zealand. The themes of QoL were identified from the literature and related to the larger themes of; 1. Activities and independence, 2. Sense of control, 3. Privacy, 4. Relationships, 5. Quality of care and 6. Other. The survey consisted of a detailed documentation of the physical environment, followed by interviews with and full-day observations of the residents and their caregivers. The study finds that the design of housing that improves their QoL requires solutions to accommodate the various conflicting needs for their QoL which include those derived from the diversity in user’s preferences and impairments. In the design of rental housing, there is greater need for additional or reorganized space to accommodate caregivers and visitors; maintain residents’ independence, privacy and other aspects important for their QoL.

Keywords: Elderly; quality of life; rental housing; qualitative method.

1. Introduction

As people age, they have greater propensity for impairment and difficulty performing everyday tasks, as well as a higher prevalence of psychological concerns such as insecurity and loneliness (Hale et al., 2010; Jaye et al., 2015). At some point, typically in their 70s or later, these experiences induce them to seek a more suitable dwelling (Statistics New Zealand, 2002). Some consider moving closer to their children; but most New Zealanders prefer to avoid ‘being a burden’ (Davey, 2006). Along with the projected rapid growth in the older people with high care needs (LiLACS NZ, 2017), there is an increasing need for housing that supports those who require assistance to live independently.

The demand for rental housing in New Zealand is projected to increase rapidly (Matthews and Koh, 2017), and as the levels of homeownership continue to fall (Statistics New Zealand, 2014) the demand for rental housing is considered to rise even faster in the future. Shortages are already reported in rental housing for the elderly in Auckland (Seniorline, 2016). In response, recent government initiatives are
seeking to address this situation, encouraging community housing sectors to grow (New Zealand Government, 2015).

Rental housing tends to be less suitable for those elderly with disabilities, in terms of the provision of care and support, and access and facilities for the disabled when compared with housing in retirement villages (Kuboshima et al., 2017a). However, a high proportion of residents receive personal care in rental housing, yet the current rental housing generally fails to accommodate those with higher levels of dependency (Kuboshima et al., 2017b). There is a growing demand to provide the physical environments that facilitate the high-dependency elderly to live independently in rental housing.

The quality of life (QoL) of dependent older people has been studied by many researchers (Tester et al., 2004; Murphy et al., 2007). Common themes include; independence, activities, relationships, identity and quality of care. Nord, a Swedish researcher focused on privacy and the delivery of care in the assisted living. She found that the changing relationships between space and activity which accompanied assistance often compromised privacy (2011). It has also been suggested that privacy could be at stake in an ordinary home, as caregivers enter the home (Hale et al., 2010). Similarly, a New Zealand study reported a reduced QoL for residents in supported-living units in retirement villages (Hayward, 2012). These examples, examined privacy and QoL in owned dwellings; however, there is limited literature on the experiences of rental housing for the elderly in New Zealand.

This paper explores themes of QoL for the elderly who live in rental housing and require assistance from others to identify the design considerations for rental housing required for the elderly to maintain QoL as they age. This study focuses on housing provided by local authorities in the Wellington region of New Zealand. The features of the typical local-authority housing include; complexes with less than 40 units; the inclusion of adjacent communal facilities; common unit types of bed-sit and one-bedroom units in semi-detached or apartment-styles. Some local authorities provide additional social support for residents, such as organising recreational activities and visiting elderly regularly. However, none provide assistance in household task or personal care, which is provided by external care providers through district health boards.

3. Method

An ethnographic case study was conducted for three elderly who need assistance in daily life and are living in local-authority rental housing in New Zealand. Ethnography is a qualitative method which has a great deal of potential in post-occupancy studies and which has many uses in architecture and built environment (Lucas, 2016). Inclusion criteria were: those who receive personal care; were more than 70 years of age; and were interested in the survey. They were selected through a questionnaire for the elderly which formed part of a previous study of housing options for those with high care needs. The survey consisted of: 1. documentation of the physical environment of the house; 2. semi-structured interviews with the elderly residents and their caregivers; and 3. Personal observation of the residents during a full day including unstructured interviews and informal conversation. Three cases of elderly people with different levels of dependency and living in different types of unit were selected for analysis (Table 10). Transcribed interviews and the observation notes were imported into the qualitative data management software, NVivo. The themes that emerged were coded in relation to broader QoL themes. For each theme, similarities and differences between the three cases and the reasons of them were analysed, and the relevant design themes were identified. Integrating the results, the implications for the design of housing for the elderly that improves their QoL are discussed.
Table 10: Basic information on residents and settings of the selected cases

<table>
<thead>
<tr>
<th>Resident</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>81</td>
<td>73</td>
<td>75</td>
</tr>
<tr>
<td>Gender</td>
<td>Female</td>
<td>Male</td>
<td>Male</td>
</tr>
<tr>
<td>Levels of dependency</td>
<td>High (DS* = 7)</td>
<td>High (DS = 4)</td>
<td>Low (DS = 2)</td>
</tr>
<tr>
<td>Required personal care</td>
<td>Bathing, Dressing Personal hygiene Put on/off compression stockings</td>
<td>Bathing Personal hygiene Put on/off compression stockings</td>
<td>Bathing Personal hygiene</td>
</tr>
<tr>
<td>Unit type</td>
<td>Bed-sit</td>
<td>Bed-sit (Bed-space and lounge can be separated by a curtain)</td>
<td>One-bedroom</td>
</tr>
<tr>
<td>Suitability for the disabled</td>
<td>Not suitable (Steps in access, Bath-tub)</td>
<td>Not suitable (A gap in the shower)</td>
<td>Not suitable (A gap in the shower)</td>
</tr>
<tr>
<td>Unit size</td>
<td>32m²</td>
<td>35m²</td>
<td>41m²</td>
</tr>
</tbody>
</table>

Setting

Unit plan

L=lounge, BR=bedroom, BS=bed-sit, K=kitchen, B=bathroom

*DS ('Dependency Score'): For each person, six activities (bathing, dressing, personal hygiene, moving indoors, moving from bed to wheelchair/chair and eating) were given the scores of 0-2 or 0-3, according to the degree of assistance they receive. They were given a ‘Dependency Score,’ the total of six scores for each activity.

4. Themes for QoL

Through analysis, sub-themes were identified and related to the larger themes of; 1. activities and independence, 2. sense of control, 3. privacy, 4. relationships, 5. quality of care and 6. other, which is described in this section. For each sub-theme, similarities and differences for three cases were analysed qualitatively and the relevant design issues for each of the themes for QoL were distilled (Table 11).

4.1. Activities and Independence

Circulation and space for movement

All residents wanted barrier-free environments; for example, the bathtubs, a threshold to the shower stall and the steps for access to the unit could be removed. They had difficulties in moving with their walker frame (1) and experienced pain (3) when going up and down the steps.
Resident 1, who rarely used an aid indoors, needed to hold walls and fixtures to keep their balance while walking. Resident 2, who was dependent on a trolley which provide support with walking, had to be most careful when moving with his tea or soup on it over the threshold between different floor materials, which had less than a centimetre level difference. Resident 3 had no requirements in walking.

For outdoor mobility, Resident 1 had trouble going down three steps with a walker frame to the roadway to get on a taxi. Resident 2 had a difficulty passing through the exterior swing door with a threshold while holding the trolley. He used a mobility scooter, which was stored in his unit, because it had access by using the trolley, as well as space for transferring from the trolley and turning around the vehicle. Resident 3, who used a bicycle, wished for storage space for it under cover, preferably accessible nearby such as in shared storage.

There were differences in the suitability of the physical environment by types/levels of impairment, which relate to requirements for aids/vehicles for moving indoors and outdoors. The differences included; the need to hold walls when walking and the extent to which barrier-free interventions were needed. The corridor and passageway widths should be considered in terms of walls and furniture required to support walking. Barrier free design should be considered in the door design, as well as floor design in both interior and outdoor spaces.

Spaces for sitting and various activities

All participants sat most of the time on an adjustable armchair in their lounge/bed-sit space. This space, while allowing them to rest in their most comfortable posture and to adjust their leg and back position, also facilitated many activities. Activities gave them something to do and the feeling of being occupied which was important for them. Within their reach there were level surfaces such as a table or a kitchen bench or shelves (including those under a kitchen bench and those of a trolley) to accommodate various things such as glasses, phones, remote controls, medicine, cups of tea, mail, pens and papers.

There were also differences in activities in the sitting space, depending on the level/type of impairment; Resident 2 often sat at the table while playing PC games, which required special posture due to his impairment, whereas Resident 3, who could adjust his position, put his PC on the arm of the armchair while playing PC games. While there were common activities for all such as watching TV and reading, other activities varied depending on preferences. For example, Residents 2 and 3 liked operating PCs, and Resident 1 liked knitting and crosswords, for which the space was used differently.

The spatial organization of sitting spaces should allow the layout of an armchair with immediately adjacent tables and shelves to put on things within reach. The design of these spaces should also facilitate residents various activities including watching TV. In particular, space that accommodates a table as well as an armchair, is necessary for high-dependency elderly with limited posture options.

4.2. Sense of Control

Ease of maintenance, keeping space clean and tidy

It was important for residents to keep their spaces clean and tidy to maintain their sense of control. Resident 1 had many shelves at various heights within reach, which were very useful for her. Resident 3, who had shelves near his sitting space, also found that he could keep the space tidy. However Resident 2, did not have enough shelves and who put things on a table in a less organised way, wanted more shelves at an appropriate height. The higher shelves were rarely used by those with higher levels of impairment, because they could only reach the front of the shelf and could not use a step ladder to reach the rear area
of the shelf. Resident 2, whose hands shook, often spilt liquids (tea/soup) and didn’t like carpet, which stained easily and was never cleaned even by the home-helper.

Difficulties in keeping the space clean and tidy varied depending on the types/levels of impairment. There should be consideration with regard to interior elevation that provide shelves of appropriate height and depth, in the design of storage spaces. Greater consideration of maintenance and cleaning with respect to floor materials is also required.

*Control over visitors*

All three participants experienced a sense of control when they knew visitors were coming before they actually arrived. Each had a view of the doorway from their sitting space; however, there were differences in the extent to which the view of the visitors was restricted before they actually arrived depending on the spatial layout. Resident 2 and 3 had lounge spaces facing the front of the dwelling with a view to a long driveway and liked that they could see who was coming. However, Resident 1, whose lounge did not face the front, could only see who was coming through the window next to the front door just before they arrived. To improve the sense of control over visitors, there should be consideration given to the spatial organisation of interior spaces so as to allow residents to see the arrival of visitors from their armchair.

### 4.3. Privacy

*Space for privacy against passers-by*

When there was insufficient space between the dwelling unit and pathway, some residents felt a loss of privacy (1) and would shut the curtain (2) because ‘people can easily look inside’. This was not a worry of others such as Resident 3 who had no path nearby where many people could pass by. Privacy concerns are particularly important in small dwellings where many people can pass by in close proximity.

*High privacy needs for incontinence*

Resident 2 had high privacy needs which relates to incontinence. He kept a piddle bottle in the trolley at all times. When the lead researcher was situated near the sitting space for the observation part of the survey, the resident tried to hide and pass water in the kitchen (approx. 3m away); however, he was unable to reach the privacy of the kitchen, passing water near the armchair because he had insufficient time to move. Resident 3 also mentioned his frequent toileting at night (every 2 hours); however, this did not impact on privacy. There should be consideration in the spatial design of spaces for highly dependent people that meet the special needs for privacy related to issues such as incontinence.

### 4.4. Relationships

*Socialising through communal activities*

Resident 1 was fond of socializing and maintaining relationships with others; she was engaged in various kinds of social activities such as singing groups and social gatherings in other council housing complexes. She wished for a community room in her own site. In contrast, Resident 2 did not attend any communal activities organized for residents because of his concerns with incontinence. Resident 3, who had no organized activities nor any communal space in the complex where he lived, did not wish for them, because he preferred to keep in touch with other residents more personally. Differences in the manner of socialising with others can be affected by impairment and influence the preferences for socialising.
Space for welcoming visitors

Resident 1 and 2, who had limited mobility, often invited visitors in while remaining seated, calling out a greeting and invitation to ‘Come in.’ All participants preferred the separation of the lounge from the bedroom. Resident 1, who had only a bed-sit space, wished for a separate lounge in which to entertain guests. Resident 2 wished for a wall rather than a curtain between the sitting space and the bed space for improved privacy through hard separation of spaces. Resident 3 living in a one-bedroom unit liked the layout of their space with a dedicated private bedroom.

The requirements in the spatial organisation to welcome visitors varied by the level of impairment. For those with mobility issues, there should be a clear sight line from the sitting space to the door, as well as sufficient proximity for a visitor to hear their greeting and welcome through the door.

4.5. Quality of Care

Space for assisted showering

None of the residents had an accessible bathroom. Resident 1 had a bathtub with an overhead shower attached to the wall. This both increased the caregiver’s labour when assisting the mobility-impaired resident to bend forward and draw water with a bucket, as well as increasing the resident’s risk of falling. Resident 3 had a small, enclosed shower booth (940mmx890mm). This was not preferred by the caregiver because it was not big enough for her to go in to assist with washing. Bathroom size was also problematic for Resident 1 as it did not have enough space for drying with her caregiver’s assistance. For assisted showering, sufficient space is required for a caregiver for both washing and for drying off.

Independence and privacy in assisted showering

The amount of assistance required for showering varied by level of impairment. All residents wanted to do as much as possible themselves during showering to keep their independence and privacy. Resident 3, who only needed assistance in washing his legs and back and in drying, undressed himself by his armchair before the caregiver arrived, then washed himself in the shower with the curtain closed before he requested assistance, to maintain his privacy with her. Resident 1, who required assistance in every activity associated with showering except for undressing, could have had greater independence and privacy if the shower type was not the one attached to the wall. A detached hose-type shower could have allowed her to wash her private areas by herself.

Special consideration of the fittings, furnishings and fixtures in shower area is required for elderly people with mobility impairments. In addition, consideration should be given to the design of showering areas so as to allow the caregiver to keep out of the sight of residents for their privacy. The proximity of the space used for undressing to the bathroom is also important for improving privacy.

4.6. Other

Sunlight

All residents enjoyed natural lighting and sunshine; however, the access to sunlight varied due to both issues related to their impairment as well as spatial design. Resident 1 sat by the window to enjoy both the additional warmth as well as the natural light. Resident 2 opened the curtains only when it’s sunny, because of his high privacy needs resulting from health concerns. Glare and reflection on the TV and PC screens limited access to natural light for Resident 3, who found it necessary to shut one of the curtains
during the daytime. In the design and placement of windows, there is a need to meet both enhanced requirements for privacy as well as controlled access to sunlight to limit glare on TV/computer screens.

Table 11: Analysis of themes for QoL and relevant design themes

<table>
<thead>
<tr>
<th>Themes for QoL</th>
<th>Similarities</th>
<th>Differences*</th>
<th>Design themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independence and activities</td>
<td>Desire for environments with no level changes</td>
<td>(I) Assistance requirements for walking (I) Suitable storage space for mobility vehicles</td>
<td>Spatial organisation (interior/exterior) Floor design Door design</td>
</tr>
<tr>
<td>Circulation and space for movement</td>
<td>Preference for spending most of the time sitting in an adjustable armchair</td>
<td>(P) Kinds of space required for varied activities (I) Required seating configuration for activities</td>
<td>Spatial organisation (interior)</td>
</tr>
<tr>
<td>Spaces for sitting and various activities</td>
<td>Preference for a view to the door from their sitting space</td>
<td>(PE) views of visitors coming to the door</td>
<td>Spatial organisation (interior/exterior) Exterior elevation design</td>
</tr>
<tr>
<td>Sense of control</td>
<td>Preference for shelves of appropriate height and depth</td>
<td>(I) Preferences for floor finishes (floors to be cleaned easily). (I) Ability to access to storage</td>
<td>Flooring design Storage design</td>
</tr>
<tr>
<td>Ease of maintenance, keeping space clean and tidy</td>
<td>Preference for a view to the door from their sitting space</td>
<td>(PE) views of visitors coming to the door</td>
<td>Spatial organisation (interior/exterior) Exterior elevation design</td>
</tr>
<tr>
<td>Control over visitors</td>
<td>Preference for a view to the door from their sitting space</td>
<td>(PE) views of visitors coming to the door</td>
<td>Spatial organisation (interior/exterior) Exterior elevation design</td>
</tr>
<tr>
<td>Privacy</td>
<td>Preference for walls of appropriate height and depth</td>
<td>(I) Degrees of privacy needs depending on the health issue</td>
<td>Spatial organisation (interior/exterior)</td>
</tr>
<tr>
<td>Space for privacy against passers-by</td>
<td>-</td>
<td>(PE) Degrees of concerns in privacy depending on oversight and distance between unit and path</td>
<td>Spatial organisation (interior/exterior) Exterior elevation design</td>
</tr>
<tr>
<td>High privacy needs for incontinence</td>
<td>-</td>
<td>(I) Degrees of privacy needs depending on the health issue</td>
<td>Spatial organisation (interior/exterior)</td>
</tr>
<tr>
<td>Relationships</td>
<td>Preference for the separation of bedroom from the lounge</td>
<td>(I) Ways to welcome guests</td>
<td>Spatial organisation (interior)</td>
</tr>
<tr>
<td>Socialising through communal activities</td>
<td>-</td>
<td>(I)(P) Ways of socialising with others</td>
<td>Communal space</td>
</tr>
<tr>
<td>Space for welcoming visitors</td>
<td>Preference for the separation of bedroom from the lounge</td>
<td>(I) Ways to welcome guests</td>
<td>Spatial organisation (interior)</td>
</tr>
<tr>
<td>Quality of care</td>
<td>Need for an accessible shower area and space for caregivers to assist washing and drying</td>
<td>(PE) Types of shower and the area</td>
<td>Size of space (shower area)</td>
</tr>
<tr>
<td>Space for assisted showering</td>
<td>Wish to do as much as they could by themselves</td>
<td>(I) (PE) The amount of the assistance required</td>
<td>Equipment/fixture Spatial organisation (shower area)</td>
</tr>
<tr>
<td>Independence and privacy in assisted showering</td>
<td>Wish to do as much as they could by themselves</td>
<td>(I) (PE) The amount of the assistance required</td>
<td>Equipment/fixture Spatial organisation (shower area)</td>
</tr>
<tr>
<td>Other</td>
<td>Preference for sitting in the sunlight</td>
<td>(I) (PE) the degree of sunlight enjoyed</td>
<td>Spatial organisation (interior/exterior) Exterior elevation design</td>
</tr>
</tbody>
</table>

(I): differences by types/levels of impairments, (P): by preferences, (PE): by physical environments.
5. Design Consideration

Considerate design of interior space in individual units and adjacent facilities with regards to exterior space can improve the QoL for older people with restricted mobility. Important design considerations are discussed for each design theme, integrating the information obtained through the analysis.

5.1. Consideration for accommodating various levels/types of impairments and preferences

The design requirements for greater QoL are affected by type and level of impairments. There were also differences in the design requirements to accommodate individual preferences. Accordingly, it is necessary to provide different types of units that residents can choose from or increased flexibility in the design of housing units or complexes to accommodate the diversity in preferences. Alternatively, given that the level and type of impairments may change as people age, a universal design that meets different requirements could best support ageing-in-place and thereby enhance QoL.

5.2. Consideration for the design of rental housing for the elderly that improves QoL

Spatial organisation surrounding the sitting area and the sequential space (interior/exterior)

In the design of the space for people with restricted mobility, there should be careful consideration of the micro environment surrounding their sitting area. In particular, the sequence of space from the sitting area to the outside must be designed for access and control. The spatial organization should allow the layout of an adjustable armchair and adjacent tables and/or shelves to ensure things are within the reach to enhance control of their environment. Consideration of preferred activities can ensure that the space can accommodate intended use. For example, given that watching TV is a common activity, layouts should permit location and proximity of TV options with respect to armchair location and in addition, the adjacency of any windows to avoid glare on the screen. There should be enough space for visitors in the quasi-public areas of the unit and a separation of the lounge from the bedroom. The spatial organisation that allows residents to view visitors coming while the resident is seated improves their sense of control. The front door should be within sight of the sitting space as well as close enough for the voice to reach through the door. Windows should also be positioned to provide the resident outside views, but limit views from the outside to the inside.

Incontinence is a common problem for elderly people, the concerns of which can be worsened by restricted mobility. Locating a toilet as close to the sitting space or the bed as possible (less than 3 meters) could address this issue for some people. However, those with severe mobility concerns, accommodation should be made for toileting to occur in the lounge as well as in the bedroom through the use of a commode, or other device. There should be enough consideration in the spatial organisation of exterior space and placement of windows to meet the conflicting needs for high levels of privacy and other desires such as looking outdoors, welcoming visitors or just enjoying the sunshine.

Storage

Consideration in the design of storage spaces with regard to interior elevation as well as necessary floor area is required for the common amount of objects and furniture. Built-in shelves of appropriate height are generally preferred particularly in the bathroom and the kitchen. The kitchens observed in local-authority housing generally had cupboards/shelves that were too high for ease of access by their intended user. In an attempt to provide enough storage in the limited space, often the space was unusable for those
with limited mobility. The kitchen should be redesigned or enlarged so that it ensures enough useable storage.

Floor

Strategies for floor design with no level difference indoors as well as at the external door is required to meet the requirements of those with the highest levels of impairment. Interior floor design with no threshold could be a solution. There should also be consideration in the flooring materials with respect to maintenance, as people have a higher propensity to dirty the floor and a lower ability to clean it as the level of impairment increases. One resident wished for a non-slip tile floor for the entire unit, which could be easily cleaned by a steam cleaner; however, there is common preference for carpet for warmth. There should be consideration for easily cleanable materials that are warm to the touch.

Door

Hinged doors, particularly when combined with a threshold with a level difference, are difficult for those walking with aids such as a trolley and a walker frame to manipulate. Sliding doors, that do not require much strength to open, can be better suited. The door serves to maintain privacy and to retain heat; however, they can be difficult to manoeuvre for those with limited mobility and can take up valuable space. For example, doors between the laundry room and the bathroom, or the kitchen and the lounge could be removed.

Shower area

Special consideration of the type of shower enclosure and the degree of fixture and flexibility of the shower head is required to enhance independence of elderly people with mobility impairments. There should be no change of level in shower area. For assisted showering, there should be enough space for drying as well as washing to accommodate both the resident and a caregiver. In addition, showering areas should have fittings that enable assistance out-of-sight of residents to maintain their privacy. The design of walls and fixtures that could be held by the elderly with both hands to support their balance increases their safety and thereby their independence and privacy.

Communal space

In the design of communal space, there should be spaces that accommodate residents’ preferred ways of socialising, such as meeting visitors in private common spaces as well as open organized activities. Flexible space and appropriate facilities as well as flexible operation should be provided to facilitate various preferred uses, such as personal potluck meals, mobile library visits, accommodating exercise machines as well as the organized activities. There should be consideration in the accessibility and distance between the communal space and the unit to suit those with limited mobility and those using mobility aids. In addition, location of toilets should be designed to meet the needs of those with incontinence and their guests.

6. Conclusion

As the population ages, there will be an increased demand for housing that can accommodate those impairments that typically correspond with ageing. This paper examined the challenges and the loss of QoL for three elderly people with impairments living in local-authority rental housing. Analysis found that
the design of housing that improves QoL requires solutions to accommodate a variety of conflicting needs derived from the diversity in user’s preferences and the characteristics of their impairment. In the design of individual housing units and adjacent facilities, there is greater need for additional or reorganized space to accommodate caregivers and visitors and maintain residents’ independence, privacy and other aspects important for their QoL.

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LiLACS NZ (2017) Intervals of care need: need for care and support in advanced age, University of Auckland, Auckland.


The Role of HVAC filter in Building Operation and Maintenance

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Abstract: The filter in Heating Ventilation and Air Conditioning (HVAC) system is the first line of defence to maintain a healthy indoor environment from airborne particle pollutants. The work focuses on the analysis of indoor/outdoor airborne particulate matter (PM) concentrations and materials accumulated on HVAC filters. We used optical particle counters/sizers to monitor the PM number concentrations in five indoor environments and one outdoor location. The filter samples from the corresponding HVAC systems were collected after monitoring period for biological contents analysis. Results from the mass balance model showed that the indoor/outdoor (I/O) particle ratios generally decreased with higher filter grades, indicating the filter effectiveness in removing PM from the outdoor and recirculating air. The total accumulated amounts of biological contents also suggested the similar trends. The pressure drops across the filters, however, provided some limiting factors for pursuing the highest filter efficiency in typical building operation. The results showed that the benefits of using higher quality filters will gradually decrease or even off-set by the increasing pressures drops that directly translated to the energy consumptions, highlighting the importance to obtain a balance between these design and operating conditions. In addition, we observed that the different indoor conditions such as occupancy level and the function of the indoor environment are highly associated with the amount of deposited biological contents on the filters.

Keywords: HVAC filter, indoor air quality, particulate matters, bioaerosols

1. Introduction

Modern buildings often come with tight building envelop with very minor leaks, thus outdoor particles transport into indoor environments mainly through the mechanical ventilation systems (Riley et al., 2002;
Chen et al., 2014; Chen et al., 2016). As people spent most of their time indoor, the Indoor PM exposure may account for a large proportion of total daily exposure, especially when the outdoor conditions are compromised (Zhou et al., 2014; 2015). Filters with higher filtration efficiency can provide better PM removal in a single pass, but they may also cause issues such as higher pressure drops and loud operation noise, thus compromise the suitability of using high-grade filters in certain conditions. In addition, high pressure drops may lead to elevated energy consumption for the whole system (Stephens et al., 2010a; Montgomery et al., 2012; Cao et al., 2016). As energy efficiency has attracted more attentions in building design and operation, understanding the energy impacts from filters is essential.

Biological contents in indoor environment also attract increasing concerns as more studies had suggested the microbial colonization and metabolites contribute to adverse consequences for occupants, such as malodors, allergic reactions, asthma or sick building syndrome (Emmanuel, 2000; Pope lii et al., 2002). Current building operation design and practice usually take no consideration on how the accumulation of biological material occurs in various parts of mechanical ventilation systems. The filter in Air Handling Unit (AHU) serves as the first line of defence to protect the building occupants. Due to the importance of ventilation system filters, researchers have begun to analyse the biological composition of particulate matter collected on these filters. For example, Tringe investigated two shopping centres in Singapore (Tringe et al., 2008), reporting the microbiota measured on filters was primarily bacterial. Some also studied the survivability of bacteria on HVAC filters (Pigeot-Remy et al., 2014; Luhung et al., 2015). There are also studies analysing bio-related signals including those from bacteria and fungi on AHU filters (Chen and Chang, 2012; Liu et al., 2015; Acerbi et al., 2017; Zhou et al., 2017). All those efforts highlighted the importance of obtaining a good understanding on the strengths and limitations of AHU filters as part of the mechanical ventilation system.

We designed and conduct this study aiming to answer the following questions: 1) Can we use the filter to protect the indoor occupants when the outdoor conditions are compromised?; 2) How can we choose a proper filter to achieve a balance of energy consumption and occupant protection?; and 3) How do the building operation characteristics affect the biological contents accumulated on the HVAC filter?

2. Materials and Methods

The experiment design engages a two-stage approach. The first stage aims to evaluate how the HVAC filters affect the indoor environmental quality, while the second stage makes an attempt to improve our knowledge on the characteristics and changes of pollutants deposited on the filters along with operation time.

In the first stage, five neighbouring classrooms with similar dimensions, furnishing and interior layouts were selected (denoted as room A-E) in Nayang Technological University in Singapore. Each room has a size of 8.5 m x 8.0 m x 3.0 m (L x W x H) and is equipped with two ceiling mounted cassette Fan-Coil Unit (FCU, Daikin model FWMJK8AV4). Fresh air intakes are available via the connected duct to the outdoor environment. The windows are all tightly closed and the rooms are slightly pressurized during the experimental period. Indoor air leaks to the outdoors mainly through door gaps. There is no obvious particle source in the rooms.

Room A, without FCU filter, served as the control case of this study. Four different grades of filters (dust-spot efficiencies at 25%, 65%, 85% and 95%, referring hereafter as F25, F65, F85 and F95) were installed in rooms B to E, respectively. Table 1 presents the approximate Minimum Efficiency Reporting
Value (MERV) ratings and also the reference particle removal efficiencies of these filters according to ASHRAE standard S2.2.

We used Optical Particle Counters (OPC, model 9306 and 8220, TSI Inc., USA) to measure indoor and outdoor particle number concentrations. During the 10-days monitoring campaign, all the FCUs are operated in the continuous operation mode and fixed the flow speed with the temperature setting at 24 °C. Our study focuses on the fine particles (0.3-2.5 micrometer µm) not only because their association with various health concerns, but also the fact of their domination in many metropolitan environments (Chen et al., 2016; Nea, 2016).

<table>
<thead>
<tr>
<th>Room ID</th>
<th>Filter Grade</th>
<th>Equivalent MERV rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>No filter</td>
<td>N/A</td>
</tr>
<tr>
<td>B</td>
<td>25% (F25)</td>
<td>MERV 7</td>
</tr>
<tr>
<td>C</td>
<td>65% (F65)</td>
<td>MERV 11</td>
</tr>
<tr>
<td>D</td>
<td>85% (F85)</td>
<td>MERV 13</td>
</tr>
<tr>
<td>E</td>
<td>95% (F95)</td>
<td>MERV 14</td>
</tr>
</tbody>
</table>

We calculated total energy consumption by combining the electricity and chilled water consumption. The Power Quality Analyzer directly measured electricity consumption (W) by the FCUs (mainly for the fan operation). Chilled water energy was calculated using Equation (1).

\[ e_c = Q \cdot \Delta t \cdot (T_r - T_s) \cdot \rho_w \cdot C_p \]

(1)

Where \( e_c \) represents the chilled water energy (kW h); \( Q \) is the instant flow rate of chilled water (m³s⁻¹); \( \Delta t \) is the measurement time interval (= 1 s); \( T_r \) is the temperature of return chilled water (°C); \( T_s \) is the temperature of supply chilled water (°C); \( \rho_w \) is the density of water (=999.8 kg m⁻³ at 10 °C); \( C_p \) is the specific heat capacity of water (=4.192 kJ (kg K)⁻¹ at 10 °C). Total chilled water energy was calculated hour by hour. Total energy consumption of each filter application scenario consists of total FCU electricity consumption and total chilled water energy.

Noise levels were measured by a Sound Level Meter (model SM-10, Amprobe, USA) using the average of eight measurements conducted at evenly distributed locations in each room. As the goal is to examine the noise increment contributed by the add-on filters, we intentionally choose the time period with no occupants in the room.

In the second stage, we collected the ventilation system filters from ten AHUs including five classrooms (classroom 1-5) and five libraries (Library 1-5). All filters were indoor secondary filters with pleated polyester at MERV 8 rating, where MERV denotes the standard for “minimum efficiency reporting value”. Based on the local practice, all filters were collected at the end of the customary three-month period of service.

Immediately after filters acquired during routine replacement, samples were obtained by cutting small pieces (~10 cm²) from the filter and transported to the lab on ice for DNA extraction. At least five filter pieces of the same size were collected from each location for quality control and replication. The DNA
extraction follows the standard process by MOBIO Power Water kit (MO BIO, Carlsbad, CA, USA). The Qubit high sensitivity (HS) dsDNA kit was used to measure the total DNA in each sample.

3. Results and Discussion

3.1. Building Protection Factors: Particle I/O Ratios

Figure 1 depicts size-resolved particle Indoor/Outdoor particle concentration ratios for all rooms over the sampling period. I/O ratios reflect the combined protection effects from the HVAC system, including cumulative filtration from both outdoor and recirculation air, building leakage effects and indoor removal and deposition. When the outdoor conditions are compromised in the haze events, the HVAC system provide the protection by filtering/removing the particulate matters from outdoors. The smaller the I/O ratio, the higher protection level buildings provide. As shown in Fig. 3, the ratios decreased with increasing filter grades (i.e. higher removal efficiencies) in all size bins. This is conceptually straight forward as the better filter can remove more particulate pollutants and lead to lower I/O ratios. However, two exceptions stood out from the data. There was no significant difference between rooms A and B, as well as in rooms D and E. Room A with no filter installed and room B with the low-efficient F25 filter had comparable and the highest average I/O ratios. From the particle removal mechanism point of view, this is interesting because the particles in room A were mainly removed by the deposition lost along the duct. Room B should have a lower I/O ratio due to the additional filter removal mechanism. In order to gain more insight on this phenomena, further investigation revealed that the low grade MERV 7 filter did provide additional particle removal, but also produced an unavoidable pressure drop across the filter. This pressure drop reduced the recirculation rates compared to the room with no filter installed (14.0 h⁻¹ vs. 8.8 h⁻¹). Although the particle deposition along the HVAC ducting and various elements are relatively low compared to the filter, more recirculation compensates this trade-off and achieves similar particle removal efficiency as the one equipped with MERV 7 filter, which is a low efficiency filter in industry practice.

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Figure 1. Particle I/O ratios for three size bins in different rooms. The p values denote one-way ANOVA test results and error bars show the standard deviations. Note: Room A - with no filter; Room B - with F25; Room C - with F65; Room D - with F85; Room E - with F95.
The rooms with highest quality of filters, room D and E, also provide similar I/O ratios with no statistically significant difference. The similarity of I/O ratios in the two rooms may result from the combined effect of Air Exchange Rate (AER) and recirculation rates. Room D had a higher recirculation rate and higher AER than room E, thus more outdoor air, which contains more particulate pollutants, were introduced into room D, thus led to the comparable I/O ratios in the two rooms. Comparing the data with other reported studies, these ratios are comparable with the exposure factors reported by Zhou et al., where the buildings were outfitted with MERV 13 filters during a haze episode in 2013 (Zhou et al., 2015).

3.2. Energy Consumption

On top of the investigation on the protection effect against outdoor pollutants, it is also important to understand the impacts on energy consumption due to the filter installations. There are probably two major factors for the energy, namely the power used by the fans and also the energy needed to condition the air. From the monitoring data, the continuous operation of fixed-speed recirculation fans provides a similar hourly electricity consumption at 0.3 (kWh) across all rooms. The filters did not lead to significant differences in the electricity consumption. The chilled water consumption showed a different trend. As the outdoor air is warmer than the indoor temperature setting, Figure 2 shows the hourly chilled water energy which generally decreased with increasing filter grades. The most likely reason for this may be due to decreasing amount of recirculation air with higher filter grades. It is worth noting that the room with highest filter grade (room E, F95) consumed about 13.5% more chilled water energy than the scenario with F85. Further analysis indicated that the F95 filter has the greatest pressure drop, leading to a very low air circulation rate. This low air circulation rate leads to a difficulty in providing enough conditioned cooled air in a short period of time, thus the longer duration of each cooling session is needed than those with F85 filter. This interesting phenomena might be able to answer some contradictory results that had also been reported by other related field studies. Zaatari et al. found that replacing MERV 8 filters with MERV 13 or 14 filters could either increase or decrease energy consumption depending on the operation and system features of the rooftop units (Zaatari et al., 2014). Stephens et al. reported negligible energy impacts of high-efficiency filters compared with low-efficiency filters in residential and light commercial buildings with forced air HVAC systems (Stephens et al., 2010a; Stephens et al., 2010b). It seems that the energy impacts of different grades of filters largely depend on the system and operation characteristics and can vary widely if these conditions differ.

![Figure 2. Hourly chilled water energy under different filter application scenarios. Error bars represent the standard deviations.](image-url)
3.3. Noise Levels

Another important consideration is the noise increment due to the add-on filters. Table 2 presents the noise levels for background, filter-equipped, and the derived contributions from the filters. We can see that most of the filter installations did increase the overall noise levels. However, only F95 case exceed the recommended indoor noise level of 45.0 dBA, which indicated that most of the installations did not significantly compromise the hearing comfort for a typical indoor environment. By calculating the differences from the mean levels of background and with filter, we can derive the noise contribution by the add-on filters, which range from 34.9 dBA to 45.6 dBA in this case. F95 filter again failed to demonstrate its suitability in a small indoor environment because the noise contribution from the filter along has exceed 45.0 dBA. The reason causing that challenge is due to the significant flow resistance from the filter medium itself. We would also want to highlight that the noise is highly sensitive to the environmental parameters, such as room geometry, number of occupants, indoor materials to name a few. Lower background noise level is beneficial if we want to incorporate high quality HVAC filter as a control measure for indoor particle level.

<table>
<thead>
<tr>
<th>Filter type</th>
<th>Background</th>
<th>With Filter</th>
<th>Filter contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (no filter)</td>
<td>40.7±0.8</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>F25</td>
<td>39.3±0.7</td>
<td>41.1±0.7</td>
<td>34.9</td>
</tr>
<tr>
<td>F65</td>
<td>40.2±0.9</td>
<td>44.1±1.1</td>
<td>41.9</td>
</tr>
<tr>
<td>F85</td>
<td>40.1±1.0</td>
<td>44.3±0.9</td>
<td>42.3</td>
</tr>
<tr>
<td>F95</td>
<td>39.8±0.7</td>
<td>46.6±1.2</td>
<td>45.6</td>
</tr>
</tbody>
</table>

3.4 DNA Mass accumulated on AHU Filters

In the second stage of this study, we intend to investigate the biological related pollutants accumulated on the filters and their associations with the environmental characteristics. As the Qubit Fluorometer uses fluorescence-bases detection approach, we would like to highlight that the total DNA signal should include all of those from human, plants or animal cells that responds to the designed fluorescence wavelength. Although this measurement cannot provide species related information on the source of DNAs and their potential threats to human health, it serves as a general indicator on the bio-related pollutants in the indoor environments. Table 3 lists the concentration of extracted DNA mass per filter surface area for each of the AHU filters from different indoor environments, ranging from 1.1 to 21.4 ng per cm².

Some studies have reported that human can be an important source of indoor bioaerosols. For example, human generate the bio-effluent by shedding from skins/hairs and breathing/coughing. In addition, human activities also re-suspend the surface-deposited bioaerosol into the air (Noris et al., 2011; Hospodsky et al., 2012; Qian et al., 2012; Adams et al., 2015). To assess the influence of occupancy on the accumulation of biological material on the filters, we try to investigate the relationship between the occupant counts and the amount of DNA deposited. The total occupancy in classrooms were estimated from the course registration and timetables, and the occupancy in library were obtained via the gate counts over a 3-week period.
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Table 3: Total DNA abundance per AHU filter surface area.

<table>
<thead>
<tr>
<th>Indoor Environment</th>
<th>Occupancy (N, person-h/wk)</th>
<th>Total DNA/filter area (ng/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classroom 1</td>
<td>250</td>
<td>1.3±0.4</td>
</tr>
<tr>
<td>Classroom 2</td>
<td>800</td>
<td>3.1±0.7</td>
</tr>
<tr>
<td>Classroom 3</td>
<td>1800</td>
<td>6.1±1.1</td>
</tr>
<tr>
<td>Classroom 4</td>
<td>1000</td>
<td>4.3±0.9</td>
</tr>
<tr>
<td>Classroom 5</td>
<td>1550</td>
<td>4.6±0.7</td>
</tr>
<tr>
<td>Library 1</td>
<td>850</td>
<td>4.4±0.7</td>
</tr>
<tr>
<td>Library 2</td>
<td>1900</td>
<td>12.9±1.1</td>
</tr>
<tr>
<td>Library 3</td>
<td>1300</td>
<td>4.5±1.2</td>
</tr>
<tr>
<td>Library 4</td>
<td>1750</td>
<td>15.6±2.2</td>
</tr>
<tr>
<td>Library 5</td>
<td>2250</td>
<td>21.4±1.9</td>
</tr>
</tbody>
</table>

Plotting the data revealed further insights on the relationship between occupancy level and total deposited DNA. Figure 3 shows the classroom data in hollow circles and libraries in solid squares. It seems both groups had positive linear relationships, but with different slopes. This suggests that our data support the findings that human occupancy is an important factor in indoor bioaerosols. The more occupants it serves, the more biological related materials can be found on the HVAC filters. In addition, the slopes in Figure 3 can be considered as the human associated emission factors. It seems that the occupants in the library contributed more bio-materials on the filters than those in the classrooms. These possible differences in emission factors would suggest that occupants shed and/or re-suspend biomass at a more rapid rate in locations with higher occupant activity levels (e.g. libraries). We observed that many occupants were actively walking with carts and old books in the libraries, whereas occupants were mostly seated and working at desks in the classroom. The other possibility might due to a higher amount of surface-deposition biological related material in the library environment, such as books, carpets and book shelves, which lead to more bioaerosols got re-suspended into the air when there is a human activity nearby.

![Figure 3](image-url)  

**Figure 3.** Total DNA per filter surface area and the occupancy level for 5 classrooms and 5 libraries. Trendlines indicate the best linear fit and error bars show standard deviation among samples.
4. Conclusion

We report the performance evaluation of four different grades of filters applied in FCUs as an ad hoc mitigation strategy for compromised outdoor conditions. The results has provided a solid evidence to contradict the commonly false impression of “higher grade filter will definitely provide better protection to the indoor environment”. The data indicated that using F85 and F95 led to comparable overall particle efficiencies, mainly due to the trade-off between filter efficiency and filter resistance. High resistance also creates a significant pressure drop across the filter, leading to a loud noise and higher energy consumption for the whole system. Although the indoor environment might vary from location to location, it is important to choose a proper balance between various factors.

This study also provides the information on culture-independent abundance on biomass that accumulated on AHU filters in classroom and library environments in a university setting. The accumulation of total DNA generally showed good correlation with occupancy level. The data also indicated that the setting/usage of the indoor environment affect the filter bioaccumulation significantly. While there is no current regulation on the filter quality in the ventilation system, the knowledge obtained in this study can highlight the needs of more research efforts to gain deeper understanding regarding the roles of air handling systems in indoor environments.

Acknowledgement

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References

Architectural Technology

The Technology of Architecture

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Abstract: Architectural Technology is a relatively new discipline and relates to the anatomy and physiology of buildings and of their production and performance. The practice of Architectural Technology is underpinned by the application of science, engineering and technology and is closely aligned to industry. Architecture Technology is also set within an industry that is under capitalised, resource intensive, risk averse and litigious. Industry is now recognising the value of the discipline of Architectural Technology as critical in the digital age given its focus on empirically based design. Digitalisation of design and construction through Building Information Modelling, relates to production, performance, environmental sustainability, economic efficiency and effectiveness. BIM enables simulation, standardisation, systematisation, and optimisation in design and construction. One example of the relevancy of the discipline is how the skills of Architectural Technology align with those necessary for BIM and this hopefully create greater recognition of the discipline in the future. To improve the recognition of the discipline beyond the UK, this paper presents the educational and professional standards for Architectural Technology. The argument is made that concurrent industry interests in Building Information Modelling and in the profession, is an opportunity for both the expansion of the discipline and greater BIM adoption.

Keywords: Architectural technology, architecture, technologist, BIM.

1. Introduction

The profession of Architectural Technologist has moved away from the earlier draftsperson and technicians’ role (Cheetham & Lewis, 2001). Architectural technology has been defined as the technology of architecture and encompasses knowledge and understanding which underpins the design of buildings and structures, as both a product and a process (CIAT, 2015). The profession is considered as a specialisation, with technologists contributing to construction teams as specialist designers who have unique strengths in building performance, production and process.

Architectural Technology operates within an industry that is described as under-capitalised, resource intensive, risk averse and litigious (Caplehorn, 2017). Building information modelling (BIM) is often acknowledged as a tool to navigate this challenging environment and deliver Lean construction (Dave et
al, 2013). BIM is now recognised as key in the optimisation in the design, construction and resulting performance of buildings (Arayici et al., 2011; Hamza & Horne, 2006). The prominence of BIM aligns closely with the specialisms of Architectural Technologists, which lie in design and project management processes linked to the building life cycle through the integration of technology (Emmitt, 2009). BIM adoption is one example of the increasing relevance of Architectural Technologist as a growing profession and provides an opportunity for technology orientated professionals to take a key role within the industry (Morton & Thompson, 2011).

Architectural Technology is recognised as an academic subject in several countries and there are undergraduate and postgraduate programmes internationally in Denmark, USA, Canada (Armstrong et al, 2013; Barrett, 2011). In the UK, for example, there are 34 architectural technology degree programmes accredited by the Chartered Institute of Architectural Technologists (CIAT, 2015), most of which are aligned with other built environment provision, such as architecture, quantity surveying, building surveying and construction management. This paper will focus upon the formal and professional recognition of the discipline. For clarity, the UK is focussed upon in this paper because it has a single national professional body, and one which is increasingly also international in scope. A key purpose of this paper is to raise awareness of the value of Architectural Technology in order to support wider recognition internationally. To achieve this goal, there are three sections to this paper: the first familiarises the reader with the focus and scope of Architectural Technology as a discipline in the UK; the second details the educational context of Architectural Technology as a distinct career pathway; the third highlights BIM as a driver to greater professional recognition.

2. Defining Architectural Technology and the CIAT Example

Architectural Technology, as a design function relates to the anatomy and physiology of buildings and their production, performance and processes and is based upon the knowledge and application of science, engineering and technology. This is further linked to robustness and the life span characteristics of building systems, materials and components to achieve long term durability. It is also fundamental to the retrofit design of existing buildings and the methods of assessment needed to evaluate structures through the use of building diagnostics and pathology. Recent research on barriers to adaptive reuse existing buildings, highlights the need for a greater focus upon new knowledge and interest in technical performance standards of building regulation (Armstrong, 2016). A lack of discussion and empirical data of existing building technology present significant barriers to sustainable reuse of existing building stock (Hu, 2017). Previous regulatory shifts from prescriptive standards to performance standards requires technological, social, legal and economic understanding applied in a design methodology (Visscher et al, 2016). Looking to the future, there are now calls for building regulation codes and enforcement systems to shift again: from performance-based standards to risk-informed performance-based building regulation mechanisms (Meacham & van Straalen, 2017). A deep understanding of how design sits within technological, social and economic contexts is key to navigating legal minimum requirements.

As a discipline, Architectural Technology is able to crucially influence design in relation to construction processes throughout a building’s lifecycle. This ensures that buildings remain economical, efficient and effective: desirable outcomes which are fundamental to new buildings and also the retrofit of design to existing buildings. Environmental concerns calling for carbon emission reduction (UNEP, 2009) underpin a renewed interest in the repurposing of existing obsolete buildings (Wilkinson, 2014). These concerns have generated the need to develop new approaches to evaluate existing structures through knowledge of building diagnostics and pathology to ensure that design solutions are compatible with the existing
structure. Architectural Technology is exceptionally well placed to enable better project and design management process of the building life cycle through the integration of technology and the use of ICT, including modelling and enabling furthering collaborative practice to aid production, performance, efficiency and effectiveness.

Established in 1965, the Chartered Institute of Architectural Technologists (CIAT) is the professional Institute representing and supporting over 10,000 professionals working and studying in the field of Architectural Technology in the UK and overseas (Allwinkle 2008). Although CIAT began in the UK, CIAT has seven centres internationally and is actively developing international partnerships with universities and aligned professional bodies (CIAT, n.d.). CIAT is a Principal member of the AEEBC, (Association d’Experts Européennes du Bâtiment et de la Construction) and has Memorandum of Agreements with: Association of Architectural Technologists, (AATO) in Ontario, Canada; and Danish Association of Building Experts, Managers and Surveyors, known as Konstruktørforeningen (KF). However, one barrier to this is a lack of a wider recognition of Architectural Technology as a distinct profession, for example in countries such as UAE, Australia and New Zealand. Historically, UK has been a driver to the professionalisation and formalisation of distinct roles within the built environment, such as the Quantity Surveyor and Building Surveyor (CIQS, n.d.; AIBS, 2016).

3. Career pathway of Architectural Technologists

Historically architectural technology was a subject within other built environment courses e.g.: architecture and surveying. However, over the last 3 decades, Architectural Technology has emerged as a distinct academic course (or programme) which stands as a discrete and increasing well-respected career pathway. In the UK, there are currently 34 higher education institutions offering CIAT accredited Architectural Technology courses, as an undergraduate degree or masters program. In addition to CIAT accreditation requirements, these courses are governed by an established national system of quality standards that have been specifically developed for each course and provide national consistency and a recognised standard of education. Subject benchmark statements form part of the UK Quality Code for Higher Education (QAA, 2014b) which sets out the expectations that all providers of UK higher education are required to meet. The Quality Code (QAA, 2014b) aligns with the Standards and Guidelines for Quality Assurance in the European Higher Education Area (Thune, 2005). Subject benchmark statements (QAA, 2014b) describe the nature of study and the academic standards expected of graduates in specific subject areas, and in respect of particular qualifications. They are reviewed five years after first publication, and every seven years subsequently and is undertaken by an advisory group, representing the sector of architectural technology including chartered architectural technologists, academia, the profession and industry (QAA, 2014a). The Architectural Technology benchmark statement (QAA, 2014a) is a useful document to understand the distinctiveness and value of the profession.

3.1. Accredited Qualifications: Subject benchmark statements

Subject benchmark statements provide a picture of what graduates in a particular subject. The Subject Benchmark Statement for Architectural Technology (QAA, 2014a), sets out for example, what a graduate of BSc. (hons) Architectural Technology, might reasonably be expected to know, do and understand at the end of their programme of study and are used as reference points in the design, delivery and review of academic programmes. This general guidance for articulating learning outcomes associated with educational programmes is not intended to represent a prescriptive curriculum, but instead allow for flexibility and innovation within a framework agreed by the subject community. An advantage of a non-
prescriptive benchmark statements is they are flexible enough to be helpful for international education providers who are seeking formalisation of technology programs as a distinct career pathway.

The ever-increasing professional diversity within Architectural Technology is also recognised in the benchmark statement (QAA, 2014a). Alongside this, the statement also highlights the demand for the subject at honours and master’s degree level. The professional competencies of the Chartered Institute of Architectural Technologists have been used to inform and contribute to the content and body of knowledge that underpins this statement. It is predicted that an architectural technology career pathway and job functions will be diverse and evolve within an industry that is likely to go through major changes in the next decade (Morton & Thompson, 2011). The demands on practicing and the nature of procurements systems adopted by the construction industry invites projects to work actively with specialisms from their onset (Muir and Rance, 1995). In recognition of the professional diversity and employability of those working within architectural technology, the benchmark statements encourage adaptability, agility, diversity and specialisms in a fast-changing industry and work place with an attempt to future-proof knowledge and the development of new competencies and contexts. The design and construction functions have therefore become more complex and architectural technology is now a key subject in both functions with a primary focus on designing for building performance and construction production through and by the integration of technology.

The ever-increasing impact and influence of architectural technology on building design, the science and engineering of buildings, building and the design and construction processes, within the subject of architectural technology, has seen rapid growth and change. These changes are now impacting on the broadening and deepening of the subject knowledge of architectural technology and the need for specialisation and diversification beyond honours degree level. As a result of this evidence there is now a master’s degree level criteria included within this subject benchmark statement.

3.2 Principles of Architectural Technology in Education

Realisation of architecture and its technology needs to be driven by a pragmatic decision-making process and a thorough understanding of the socio-technical context in which architecture sits, such as translating performance-based building regulations or codes into architecture. Performance of design requires socio-technical understanding as an increasingly central component of architecture (Imrie & Street, 2011). This demand requires designers to consider the broad range of end-user needs and to form creative solutions to meet the diversity of how end users with disabilities, older people or families with small children perceive, experience and use all aspects of the built environment. Considering core educational principles of the discipline, it is useful to make a distinction between the discipline and the academic representation. To help, there are 6 defining principles in the benchmark statement to consider (QAA, 2014a). These are comprehensive ranging from the need to have and international perspective (2.2) to requirement to develop collaborative relationships within the design team (2.5). Principle 2.1 provides an overarching definition of architectural technology as ‘a subject that is integral to the design of buildings and structures. It is rooted in science and engineering knowledge applied to the design of buildings to achieve optimum functionality; efficient and effective construction; and robust, durable and sustainable design solutions that perform over time’ (QAA, 2014a). Taken together, these defining principles adopt a holistic socio-technical perspective on the built and natural environment, and on the contribution architectural technology as an academic subject makes to the social, economic, legal, cultural, environmental, technological, business and political frameworks.
At an academic subject level, BIM is one mechanism useful to organise and generate architectural technology information. BIM is a tool which allows practitioners to efficiently and quickly manage building information (performance, process and product) to address the multitude of frameworks mentioned above. This view of BIM is expressed by Vanlande et al (2008:71), when they say, ‘A BIM system is a tool that enables users to integrate and reuse building information and domain knowledge throughout the lifecycle of a building’. It is not without coincidence that recent research has also framed BIM within a socio-technical framework (Sackey et al, 2014). The academic subject of architectural technology and BIM are intertwined as BIM manages technical information pertinent of the lifecycle of a building. However, the link between BIM and the discipline of Architectural Technology is more subtle. The above defining principles of architectural technology as a subject can be argued to be the ideal outcomes of a successful construction project. The distinction of Architectural Technology, is in its focus on the skills and knowledge needed to deliver these outcomes (QAA, 2014a).

The subject benchmark statements are a revision of the QAA subject benchmark statement, published in 2007, which has now undergone a further review and been updated in response to a rapidly changing industry, society, environment, national and international economic dimension. The architectural technology subject benchmark statement reflects the changes in the context of the industry within which the subject sits, including the need to produce graduates that are employable yet adaptable, agile and flexible to respond to challenges and future changes. One criticism of this emphasis on employability, is that it is a generic and well-trodden narrative present in graduate employability policies in universities across the world. However, it could also be argued that the defining principles are abreast of wider university initiatives around graduate employability and industry demands.

The subject of architectural technology does not sit in isolation but is part of a larger academic domain comprising the built and natural environments, so this statement may be cross-referenced with other related subject benchmark statements (Allwinkle, 2008). All programmes are encouraged to draw upon knowledge concepts and paradigms from a wide range of sources. Professionals and students exist within a rapidly changing industry, where they play significant professional roles in leading, designing and managing projects and integrated teams, to deliver and achieve a sustainable built environment. This includes applying architectural technology as the link between design and construction to achieve the optimisation of production and long-term performance, with the use of ICT and modelling technologies, for example BIM adoption, for managing, assessing and evaluating projects.

One beneficial distinction of Architectural Technology is that it focus on technological design straddles STEM and creative subjects. In the UK, Architectural Technology is categorised as generating ‘creative graduates’, alongside other architecture related courses such as landscape and interior architecture (Faggian, et al., 2013). Comunian et al. (2014) highlight the often overlooked contribution that these groups of graduates make to the creative economy. They also outline the findings of UK based research, and which confirms a commonly held belief that Arts and Humanities (ie creative) courses often have career progression within lower paid jobs than those within science, technology, engineering, and mathematics (Comunian et al., 2014:426). One attractive distinction for architectural technology graduates in the UK, and elsewhere is that their creative knowledge is applied through a STEM specialism. Further research is needed to examine how Architectural Technology graduate salaries compare with other creative courses in Arts and Humanities.

The STEM aspect of Architectural Technology has other appeals for potential higher education students. In a paper on marketplace in higher education, Wilkins et al. (2013) describe an ‘increasing shift in the cost of higher education from the state to the student’ highlighting that arguments about value for
money of respective university courses are often rehearsed (p.125). They claim that this shift is not limited to England, where fees were first introduced in 1998, and is a global shift, occurring also in Australia, Canada, Italy, Japan, the Netherlands, New Zealand, Spain and the USA (Wilkins et al., 2013). The benefits of this STEM focus need to be investigated further by research and in terms of attracting potential students who are dissuaded by the cost of long courses in built environment and given resulting salaries. In this context, it is relevant to note Architectural Technologist can become chartered through a degree plus an industry experience assessment. Masters level courses in Architectural Technology are focussed on developing a deeper specialisation and depth of knowledge rather than a linear route to chartered professional status in Architectural Technology.

Beyond the QAA Subject Benchmark Statement for Architectural Technology, the Chartered Institute of Architectural Technologists publish Educational Standards for graduates in progressing to Chartered Architectural Technology recognition. The standards are concerned with the application of knowledge and the developing best practice in industry. The statement thresholds and standards are similar to those demanded by other aligned professionals. However, it is their emphasis and synthesis of science, design and management of the technology of architecture which is distinct.

3.3. Career Profession of Architectural Technologists

Common to other built environment professional memberships and qualifications, currently there are two routes to becoming a Chartered Architectural Technologist (CIAT, 2017). One is through professional recognition of built environment experience and application of knowledge in industry. This requires professionals to submit a Professional and Occupational Performance (POP) Record and to successfully pass a professional practice interview with CIAT (CIAT, 2017a). This POP route is arguably more suitable for professionals who are seeking chartership through the range of industry experience built up over time. Graduates of CIAT accredited courses, however, often choose the second route: via the MCIAT Professional Assessment, which involves graduates successfully passing a professional practice interview after producing an in depth, critical report. The report must summarise: ‘their knowledge, understanding and application of the construction process with regard to planning, design, construction and use, as well as relating it to their professional experience’ (CIAT, 2017b). This latter route has been streamlined for graduates to reflect the subject benchmark statements (QAA, 2014a) and uses language familiar to those who have studied on a CIAT accredited course. These two routes are in recognition of the equal value placed on formal academic achievements and industry experience, as well as recognising the range of skills and variety of work undertaken by Architectural Technologists.

The interview process is designed to reflect the broad nature and range of professional practice within the profession and discussions are based around the information provided in the candidate’s POP Record or Professional Assessment Report. This assesses a candidate’s: knowledge of the construction process; relevant experience in their field of Architectural Technology; overall experience in the industry; and also their professionalism (connected to Code of Conduct). The interview is assessed by a panel of experienced Chartered Architectural Technologists, who have undergone training in the moderation and assessment of candidates. The interview is a peer to peer assessment and designed to enable the Institute’s assessors to make a judgement regarding an applicant’s professionalism and suitability to represent the Institute as a Chartered Architectural Technologist. Candidates are also encouraged to seek mentorship and professional development through the CIAT network to support their application and to demonstrate their professionalism and understanding of the technology of architecture. The professional interview is assessed using the Institute’s Code of Conduct.
Nadim & Goulding (2009) claim that there is a gap between the knowledge and skills of graduates of built environment courses and the needs of industry, and note there is no firm agreement between academia and built environment industry leaders in how to bridge the barriers to greater collaboration (p.148). CIAT is professional organisation comprised of members in industry (QAA, 2014a). It could be argued that the partnership between industry and higher education, intrinsic to current Benchmark Statements and Standards, and which define the profession, are produced through collaboration from the outset. Assessment involved in progression to Chartered status through and the peer-to-peer assessment of the professional interview is also an example of this collaboration to ensure that the skills of a Chartered Architectural Technologist meet the needs of industry.

4. Architectural Technology and Changes in Industry: BIM

BIM adoption involves moving away from traditional architectural information production and designing towards a different was of designing and communicating. Traditional drafting by hand, or through using 2D computer aided design (CAD), remains a drafting tool with its purpose to represent designs on paper. In their influential guide to BIM, Eastman et al (2011), claim that BIM involves a revolutionary shift, away from abstracted drafting to the realities of building: ‘modelling is akin to actually building the building’ (Eastman et al, 2011: 388). BIM technologies are more than just a new generation in CAD. Their use requires process-based understanding of construction as well as a sound familiarity with architectural technology. The skills set described by Eastman et al, (2011) as necessary for BIM adoption is in symmetry with Architectural Technologists, as set out in the subject benchmark statements (QAA, 2014a).

This is a major opportunity for Architectural Technologists and for Architectural Technology being critical in the digital age and empirically based design through Building Information Modelling (BIM) relating to production, performance, environmental sustainability, economic efficiency and effectiveness (Kouider & Paterson, 2014). Ghaffarianhoseini et al (2017) highlight that although rhetoric is encouraging, BIM has yet to be adopted widely in the global construction industry. In the fifth NBS National BIM Report (NBS, 2012), a national survey in the UK involving over one thousand respondents, Architectural Technologists are the second largest professional group in the UK to adopt BIM (21%). Registered architects are the largest professional group who report to have adopted BIM (37%). At the time of the NBS BIM survey (2011), UK had over 55,000 registered architects (RIBAJ, 2016). Whereas current membership of professionals who are allied to the professional body CIAT was around 10,000 (CIAT, n.d.). As the number of UK registered architects are greater in number than CIAT members, the uptake of BIM overall by Technologists can be argued to be proportionally much larger.

BIM is a significant design tool for architecture but needs to expand from aesthetic presentation towards an increasing emphasis on simulation, standardisation, systemisation, simulation and optimisation (Hamza & Horne, 2006). BIM is therefore critical to optimise and improve industry performance as a process and buildings as products Architectural Technology is now an essential design function and through the application of BIM will ensure that design solutions result in buildings that can be constructed economically and perform efficiently and effectively within the context of user needs, environmental, regulatory and budgetary requirements. BIM and its design influence on the construction process cannot be understated as this will ensure that buildings are economically efficient and effective and design and construction innovation in terms of scalability, replication, robustness and reliability will form a major part of this design function. BIM and software applications will need to be harnessed and Integrated into education and professional and industry standards at all levels to ensure that the construction industry is modernised and is able to achieve various
EC targets. BIM, Architectural Technology and Architectural Technologists are inextricably linked and offer the industry and society the platform and professional competence to ensure that BIM challenges and changes are achieved (Hamza & Horne, 2006).

As we look to the future, there will be unprecedented opportunities in the sphere of design practice for Architectural Technologists. Functions, procurement, and practices are continually changing and are becoming more diverse. The adoption of BIM will drive further major changes encouraging a growth in specialisation, specialisms and an increasing need for specialists. We argue that Architectural Technology is ideally placed to take a central and integral role in the adoption of BIM, through these changes. As a profession, Architectural Technology will benefit from the diversity, adaptability, agility, and specialisation of its members. Increasing complexity in projects and their procurement routes will necessitate less focus on professional title and more focus on function or roles within a design team.

A key driver for these changes in the UK is the government’s commitment to Construction 2025 (Cable et al., 2013). This strategic policy has some ambitious aims, including: lowering construction costs and the whole life cost of built assets by 33%; lowering carbon emissions by 50%; and delivering projects 50% faster with a 50% improvement in construction exports. These targets present major challenges and require major changes in practice. The discipline specialism and particular practices of an Architectural Technologist have long been highlighted as beneficial in the drive to link lean design with lean construction (Brookfield et al, 2004). In the recently published Architectural Technology Benchmark Statement, greater emphasis is placed on design principles to achieve effective, robust and sustainable design solutions (QAA, 2014a). Architectural Technology can have a key role together with BIM, providing the framework and the applications to achieve commitments set out in Construction 2025. Modernising the construction industry through BIM adoption requires creation of new communities of practice and collaboration (Caplehorn, 2017). In addition, enhanced collaborative working is one of the benefits of BIM adoption (Sacks et al, 2010). As Architectural Technologists often operate as a design specialist within a team, they are well adapted to the demands of collaborative working in communities of practice (Thompson, 2012).

5.0 Architectural Technology: Conclusion

The increasing recognition of graduates skilled in the science of architecture, coinciding with an increasing call for greater BIM uptake, is an important concurrence. This paper has argued that Architectural Technologists are best placed to assist in the adoption and increased use of BIM in industry to drive lean and more sustainable modes of design and practice. Further research is needed to ascertain if this view is occurring in reality in industry, and if so, can the Benchmark Statements and Standards be further developed to convert the rhetoric of BIM into widespread adoption in industry.

Whatever the future may hold for Architectural Technology is there will always be a pressure to meet changing circumstances which create demands on the industry, focused not only on ever more technically complex, high profile structures but also on the provision of sound, reliable building to meet the requirements of those seeking more traditional solutions. The professional discipline and performance of architectural technologists in successfully meeting these demands will surely remain one of the prime objectives and will ensure their increasing recognition and value as it meets the challenges and grows in stature, as it most certainly will.

The development of Architectural Technology has come a very long way, certainly, much further than any of the founders imagined when it entered the world of professional institutions in 1965 (Allwinkle, 2008). Endacott (2005) chronicles the progress made since then, but what cannot readily be recorded are
the efforts made to reconcile the desire and commitment for recognition with the challenges inherent in establishing a new discipline. It is a tribute to all concerned that against a background of constantly changing technology and legislation, the needs of the profession have been met through soundly implemented education and training policies in the UK. The professional status, now achieved, is underlined by the respect and value accorded to Architectural Technology. The professional body, CIAT is included in the wider councils of the UK construction industry. This inclusion underlines the industry recognition afforded to the discipline, professional body and its members.

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