ABSTRACT: Whenever a computational or mathematical analysis of architectural space or form is undertaken, a range of decisions must be made about how the building will be measured and what parts of the building will be included in that measure. Most often these decisions relate to which lines or data in a drawing, model or photograph of a building, are significant for analysis. Various different approaches to computational analysis, including space syntax and shape grammar, have evolved distinct answers for this question, but many other methods, including semantic analysis, fractal analysis and related applications of Zipf's law and Van der Laan septaves, do not have a similarly consistent framework. The present paper is focused on these latter computational methods that measure the distribution of detail in a design. The paper analyses the philosophical foundations of measurement-based research, before describing a framework for decision making regarding which elements in an architectural image should be measured and why. This framework is demonstrated using a series of plans and elevations showing different levels of detail in the same building, but which, after analysis, produce different numerical measures.

Conference theme: Design education and Computing
Keywords: Postpositivism, Computational Analysis, Measuring architecture; Fractal Analysis.

INTRODUCTION

When a researcher undertakes an analysis of the form of a building, two seemingly simple questions need to be answered. First, how should a building’s form be measured and second, what parts of a building should be measured? For a practicing architect or surveyor, the answer to the first question is seemingly straightforward (Watt and Swallow 1996; Swallow et al. 2004), but for the scholar or researcher, the issue is more complex and contingent (de Jonge and van Balen 2002; Stuart and Revett 2007). The often unstated assumption in architectural research is that the more accurate the measure, the better the result. However, as several researchers have demonstrated, this can provide a poor basis for testing a hypothesis (Frascari and Ghirardini 1998; Eiteljorg II 2002). The second question is even more complex; what parts of a building should be measured? Because architecture operates across a range of scales – from the macro-scale of the city and the piazza, to the micro-scale of the doorjamb or the pattern on a wall tile – there is no simple answer to this question. Stamps III (1999), when considering this problem notes that a building façade “may be described in terms of its overall outline, or major mass partitions, or arrays of openings, or rhythms of textures” (85). He goes on to ask; “which of these many possible orderings should be used to describe” (85) a building?

These questions of how to measure and what to measure are further complicated when practices in computational analysis are considered. Each of the main computational methods of formal and spatial analysis used in architecture – shape grammar, space syntax, fractal analysis and semantic analysis – rely on measuring representations of buildings or spaces. Thus, they derive data from orthographic projections (plans, elevations and sections), CAD models and photographic surveys. For two of these computational methods the rationale describing which part of a building plan to measure is relatively established. Space syntax research typically analyses habitable space, being rigorous in its geometric mapping of lines of sight or configurational permeability in a plan (Hillier and Hanson 1984; Hillier 1996). Shape grammar researchers have a different, but similarly meticulous way of extracting geometric and topological properties from a building plan before any analysis is undertaken (Stiny 1975; Knight 1992). While the logic underlying these approaches to measurement continues to be debated, there are accepted standards in each field. However, several other approaches to computational research are more explicitly concerned with the distribution of detail in a building. These methods, including fractal analysis, semantic layering and distribution analysis by Zipf's law or Van der Laan septaves (Stamps 1999; Crompton and Brown 2008; Crompton 2012), do not have such well established standards for deciding which lines on a plan or façade should be measured and why. The focus of the present paper is the development of a framework for supporting considered decisions about this issue. Furthermore, while this issue is pertinent to all of these computational approaches, it is illustrated in the present paper using fractal analysis.

Fractal analysis can be used to quantify the characteristic visual complexity of a building plan or elevation. Like architectural analysis using Zipf's law or Van der Laan septaves, it provides a measure of the distribution of detail in architectural analysis using Zipf's law or Van der Laan septaves, it provides a measure of the distribution of detail in
This paper commences by describing the philosophical paradigm that typically governs architectural research which is reliant on measuring. This paradigm, postpositivism, is then used to illuminate a common argument in architectural analysis about the misalignment between purpose and precision when measuring buildings. Thereafter the paper describes and illustrates several different ways of representing buildings as a precursor for analysis. Through this process a conceptual framework is described to support decisions about which lines should be measured and for what purpose. While this framework is demonstrated using fractal analysis, it is more widely applicable to a range of questions about measuring architecture. However, before progressing to this, three points need to be made. First, in this paper the word “measuring” is taken to include any process which extracts mathematical or geometric information from a building or representation of a building; being drawings, models or photographs. In computational analysis it is common to talk about the processes of abstracting or translating information derived from the built environment into some mathematical or geometric graph or map; these are all types of measuring. Second, while parts of the philosophical discussion hereafter are relevant to all types of measuring (including the consideration of acoustic reverberation or temperature change) the majority of the paper is more explicitly about the measurement of form. Finally, the paper does not describe how fractal analysis is undertaken: a large number of past publications explaining the method are available (Bovill 1996; Lorenz 2003; Ostwald et al. 2008). The paper does, however, provide calculated values using this method for each of the representational permutations discussed as part of the development of the framework. While these values have been prepared in accordance with the standard method, their purpose here is to illustrate how the same method of measurement, when applied to the same elevation, but identifying different characteristics or elements of that façade, will produce different results.

1. PHILOSOPHICAL FOUNDATIONS

In their book, Architectural Research Methods, Groat and Wang (2002) suggest that a person who is seeking to study a particular object or phenomenon should commence by understanding the "system of inquiry" they are operating within. At a superficial level, the concept of a system of inquiry encompasses the relationship between the research hypothesis being tested, the “tactics of information gathering and analysis” being applied, and “the practices of the researcher as s/he conducts the inquiry” (41). Thus, on one level, the system of inquiry is a framework of multiple parts, all of which are appropriate for a type of research and are consistently applied with an awareness of any limitations. But a system of inquiry is also broader than that; it refers to the philosophical or foundational values of the researcher. In this sense, the act of measuring a building, as a precursor to some form of analysis, is typically considered a postpositivist system of inquiry (Beclet et al. 1987; Groat and Wang 2002; Sirowy 2012).

Postpositivist systems of inquiry seek to ensure that four standards are met: intrinsic validity, extrinsic validity, reliability and objectivity (James 2004). The first of these, intrinsic validity, is a reflection of the degree to which the primary theoretical frameworks and methods used will collectively produce a reasonable or truthful representation of the phenomena being studied. This issue is directly associated with ensuring an appropriate correlation between a method and its purpose. In regards to the measurement of buildings, it is about achieving an alignment between what is being measured with why it is being measured.

The second expectation of postpositivist systems of inquiry is that they possess extrinsic validity. This property, which is also known as generalizability or transposability (Kuhn 1962), determines whether “the results of this study are applicable to the larger world” (Groat and Wang 2002: 36). In practice, two standard principles for ensuring generalizability relate to sample size and benchmarking. In the first instance, the larger the sample size, the more likely a set of results is able to be extrapolated to suggest useful findings. The second is that research which is focussed on cases that are well known or well documented is more likely to be widely applicable.

The expectation of reliability means that the methods being used by a researcher should be both consistent and repeatable (Fellows and Liu 1997). As Groat and Wang (2002) observe, “[w]ithin the postpositivist paradigm the assumption is that the research methods would yield the same results if the study were conducted under the same conditions in another location or at another time” (36-7). When measuring architecture, this standard applies to the selection of tools, the way the tools are used and to what is being measured. All of these details should be recorded to ensure that any future measurements will be undertaken using the same parameters and thereby allow comparisons between studies to be constructed.

The final quality of a postpositivist system of inquiry is objectivity. This refers to the apparent neutrality of the method or the capacity of the researcher to reduce, control or limit any potential bias. The measuring of architecture can and should occur in an objective way if a researcher is clear about the limits involved in the particular tools being used and of any potential error rates and mitigation strategies.
2. PRECISION OR PURPOSE

Past research into the process of measuring buildings has often intuitively adhered to the basic values of postpositivism. In particular, the issue of intrinsic validity has been repeatedly discussed in terms of the tension that exists between precision and purpose (Caciagili 2001; Eiteljorg II 2002; Hebra and Hebra 2010). A classic example of this dilemma is the argument that, in a survey of the dimensions of the Pantheon in Rome, using a laser scanner with ± 0.05mm accuracy will produce a better analysis than a conventional manual survey with ± 60mm accuracy. Consider this argument in the context of research which is seeking to examine the proposition that the plan and section of the Pantheon have the same radius dimension (Masi 1996). The purpose of such a study is to investigate evidence of design intent and, in particular, answer the question; did the architect consciously create a building where the plan and section are identically sized? Disregarding the possible existence of any written accounts of this intent, in a postpositivist sense some evidence for this proposition could legitimately be developed by measuring the historic building. However, a highly accurate measurement of the building is not necessarily better than a less accurate measure for this purpose. There are two reasons for this, one associated with the limits of construction techniques, the other with the practical problems of working with historic structures.

Roman stone masons worked with absolute dimensions – like pollice, braccio, piede and canna – which were derived from wooden copies of stone rods kept in each city in the empire (Kostof 1977). Moreover, the stone mason’s tools (the square and the rule) were typically capable of around 50-100mm accuracy for the repetitive production of elements in a quarry, although on-site, a different type of precision could be produced. For example, a mason could “fit” two stones together with a gap of less than 2mm if called upon to do so. However, this does not mean that every stone was produced with this level of precision, or even that the masons could measure this level of accuracy, only that they could produce a level of fit that was relatively precise. This is why Caciagili (2001) argues that it is fundamentally meaningless to measure a building to a higher level of precision (or tolerance) than was commonly available to the people who constructed the building. The second problem with measuring the Pantheon is simply that the building has changed over time. Not only was the Pantheon partially rebuilt on several occasions, but its foundations have also settled unevenly and its dome has slumped over time and been repositioned using secondary structures. Thus, in this case precision is largely irrelevant, a new, high quality measurement of the sectional geometry of the dome cannot be considered to provide any more evidence for this argument than an older survey using more limited technology.

Frascani and Ghirardini (1998) are highly critical of the process of measuring supposedly precise measurements of buildings to locate particular geometrical proportional systems (like golden sections) in historic and modern building plans. They too argue that it is meaningless to measure architecture without due consideration of the purpose of the process because, in “metrical terms, every constructive part of building has its geometric order: masonry, in decimeters; wood carpentry, in centimeters; metal works, in millimeters. Every part is exact enough. Every part is exactly approximate.” (68-69). This position, which maintains that precision should be relative to purpose is reflected in several studies which identify the mis-use of dimensional accuracy to suggest evidence for a proposition which is clearly not related to precision alone (Ostwald 2001; Eiteljorg II 2002). As Johnson (1994) notes, “[p]recision per se is not enough no matter how satisfying it is for the analyst” (19).

3. A FRAMEWORK

Under the postpositivist paradigm, a legitimate system of inquiry for investigating the formal properties of buildings must have a clearly aligned method of measurement and research purpose. Thus, the research question or hypothesis must be one for which measurements can provide useful evidence. While this may seem obvious, it is less common to observe that the particular architectural features being measured must also be appropriate for the research purpose. In computational analysis this is a question of representation or delineation. It is possible to delineate the façade of a building, in a drawing or model, using many different combinations of lines or textures. However, in all of these cases the act of measuring is reliant on the conventions of representation. This is because regardless of whether field dimensions were taken using a laser scanner or tape measure, the dimensions have to be transcribed into a representational system, be it a drawing or CAD model, for it to be analysed.

In order to accommodate this need, a framework is proposed wherein five cumulative levels of representation are defined and mapped against comparable research purposes (Table 1). This framework shows that it is not reasonable to study the impact of material texture on a building when only the footprint of a plan is measured. Conversely, if the impact of planning decisions regarding site-amalgamation is to be studied, then measuring the geometry of material textures in a façade is likely to be counter-productive. This framework, aligning level of representation with research intent, is also inherently cumulative. That is, it relies on fact that the building outline is required as a precursor to defining primary forms. Thereafter, secondary forms can only be added if the boundaries of the primary forms are already present, and so on. Thus, the framework is described in terms of what is added with each level of representation.

Each of the five levels of representation are described in the following sections and illustrated using variations of an elevation and plan of the same building which are presented alongside the different fractal dimension measures derived from each. The example building used to illustrate this framework is Le Corbusier’s Villa Jaquemet in Pouillerel, Switzerland. Completed in 1907, this ornate, chalet-style house, which is reminiscent of the Arts and Crafts movement, gives little indication of the type of Modernist architecture Le Corbusier would later produce. This house was previously the subject of computational analysis where it was postulated that the particular lines chosen for
analysis would have an impact on the results (Vaughan and Ostwald 2009b). The Villa Jaquemet is a four storey house with rough stone walls on the lower levels, and dressed stone around the windows and doors. The upper stories are clad in stucco-faced timber, with exposed timber panelling on highest sections of the walls. The tall, sloping roof has exposed carved timber supports and it is clad in dark tiles.

Table 1: Levels of representation mapped against research purpose

<table>
<thead>
<tr>
<th>Level</th>
<th>Representation</th>
<th>Research Focus</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Outline</td>
<td>Building skyline or footprint</td>
<td>To consider major social, cultural or planning trends or issues which might be reflected in large scale patterns of growth and change in the built environment.</td>
</tr>
<tr>
<td>2</td>
<td>+ Primary form</td>
<td>Building massing</td>
<td>To consider issues of building massing and permeability which might be a reflection of social structure, hierarchy, responsiveness (orientation) and wayfinding (occlusion).</td>
</tr>
<tr>
<td>3</td>
<td>+ Secondary form</td>
<td>Building design</td>
<td>To consider general design issues, where “design” is taken to encompass decisions about form and materiality, but not to extend to concerns with applied ornament, fine decoration or surface texture.</td>
</tr>
<tr>
<td>4</td>
<td>+ Tertiary form</td>
<td>Detail design</td>
<td>To consider both general and detail design issues, or where “design” is taken to include not only decisions about form and materiality but also movable or tertiary forms and fixed-furniture which directly support inhabitation.</td>
</tr>
<tr>
<td>5</td>
<td>+ Texture</td>
<td>Surface finish and ornament</td>
<td>To consider issues associated with the distribution or zoning of texture within a design, or the degree to which texture is integral to design.</td>
</tr>
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</table>

3.1. Level One: Outline

The silhouette of a building – its elevation and associated ground plane – when drawn as one simple continuous line, is often referred to as a skyline drawing. The analysis of skyline characteristics is common in urban design and town planning and there are many examples of this approach to considering the visual complexity of urban or architectural landscapes (Heath et al. 2000) including several applications of fractal analysis (Stamps 2002; Cooper 2003; Chalup, et al. 2008). Less commonly, the plan form of a building can also be represented in this way, as a figure of the footprint of a building or as an outline of the roof plan (Brown and Witschey 2003; Frankhauser 2008). This method has been used for the fractal analysis of large urban neighbourhoods. In both cases, the consideration of silhouettes and footprints, the purpose is typically to examine the way in which particular types of construction create distinctive patterns, which in turn are thought to reflect the individual social and cultural characteristics of a region. Thus, this approach is used where the large scale patterns found in the built environment are thought to be a reflection of distinct differences between regions or groups.

If this approach is taken to representing the Villa Jaquemet, the silhouette retains much of the character of the aggregate geometry of the design, with the roof outline, showing its hips, gables and the two chimneys being clearly discernible (Fig 1a). The curved brackets supporting the roof are shown with a permeable silhouette whereas other features, such as the windows, though which the sky cannot be seen, are not shown. The Villa Jaquemet has an almost symmetrical plan footprint (Fig 1b).

![Figure 1a: Villa Jaquemet, elevation; showing silhouette.](image1)

![Figure 1b: Villa Jaquemet, plan; showing footprint.](image2)

3.2. Level Two: Outline + Primary form.

The second level of detail which could be considered for analysis is the formal massing of the building as a whole; what might be termed its primary form. This level is focussed on major formal gestures, not secondary forms, detail or ornament. The building is represented by the outline but now with the addition of basic massing elements, including openings. Smaller scale formal changes within these elements, such as individual stair treads or brick corbels, would not be included. All windows and doors are shown as portals but with no indication of fenestration or detail. In...
elevation specifically, gross changes in form, such as protruding walls, significantly advanced and receding elements and the roof planes are also delineated. Likewise in plan, the walls and major changes in floor level are shown. This level of representation was selected by Bovill (1996), for a fractal analysis of Frank Lloyd Wright’s Robie House to gain a sense of the geometry of the major formal gestures in the plan.

The level of information in the Villa Jaquemet elevation increases at this stage as it has an articulated structural system which results in projected walls and levels, all which are shown in the representation of elevation (Fig 2a) and the plan (Fig 2b). The windows, although actually quite detailed, are only shown as blank rectangles at this stage. In the elevation, additional permeable elements, such as the foreground roof brackets, are now shown, whereas only the rear brackets appear against the skyline.

3.3 Level Three: Outline + Primary form + Secondary form.
In combination, the elements which make up the overall massing in a design along with major changes in materials could be considered secondary forms. By including secondary forms – in addition to the information previously provided by the outline and massing of the building – the primary geometric gestures that make up a design become measurable. In both plan and elevation, changes in material should be represented by a single line separating surfaces. Basic mullions in doors and windows, stair treads and other elemental projections of a similar scale should be included in plan and elevation. These representational standards have been used for the fractal analysis of Le Corbusier’s Villa Savoye (Bovill 1996) and of an urban district in Istanbul (Cagdas, et al. 2005).

The Villa Jaquemet is constructed from a range of materials and the lines where one material ends and another begins are now represented. The difference between the rough stone base of the building, the timber panelling and the smooth walls are all clearly delineated. In elevation, the windows begin to show their detail in the top mullions (Fig 3a). In plan, the window frames and individual stair treads can now be seen (Fig 3a).

3.4. Level Four: Outline + Primary form + Secondary form + Tertiary form.
Once the form of a building has been defined (along with any secondary elements or changes in material needed to support that form) then various additional features must be added to more directly support the building’s users. These tertiary forms, including doors, window panes and built-in furniture, are all critical to the inhabitation of a building, but are often simply assumed as part of a design process. For example, windows are obviously represented in design analysis but what about the glass that is so integral to the window’s function. Kitchens and bathroom have built-in furniture and fittings which are often forgotten in architectural formal analysis. If a broad definition of design is being considered – that is one which takes into account basic physical needs – then this level of detail is needed. This level of detail has commonly been used in the analysis of regional and traditional housing (Bovill and Bechoefer 1994; Zarnowiecka 1998) and of architect designed housing (Ostwald and Vaughan, 2010; Vaughan and Ostwald 2011). It could be argued that this level of detail represents design decisions which have clear consequences for inhabitation.

Drawings of the Villa Jaquemet at this level include doors (but not door swings), glass in window panes as well as beam-end details (Fig 4a). In the plan, kitchen and bathroom furniture is now clearly seen (Fig 4b).
3.5. Level Five: Outline + Primary form + Secondary form + Tertiary form + Texture.

The final level of representation is of surface texture or pattern. This level includes the repetitive surface geometry of a material (the grid marked by floor tiles, the parallel lines of floor boards or the distinctive wavy lines made by rows of roof tiles) or the patterns in ornamental tiles, wall-paper or applied decorations. In theory it could even include some level of representation of the grain in wood or marbling in polished stone. But, it has to be acknowledged that it is rare for an architect to “design” the pattern or geometry in a surface; more often a material is specified, and the grain chosen is indicative, rather than particular. Moreover, many of these textures are effectively invisible from a distance, or require very close observation to become apparent. This is why this last level of detail, while able to be represented, adds a level of abstraction or artificiality to the process. It could even be argued that the major geometry of a design is complete before the materials, fabrics and colours are chosen. Certainly, this does not mean that these surface or textural decisions are not design issues, but rather that they are no longer so clearly measurable geometric ones. Moreover, at the level of surface textures, the capacity to produce consistent results (in the way that postpositivist reasoning anticipates) is diminished by a growing number of peculiarities and singularities in the design and construction process.

Because fractal analysis operates across multiple scales of observation, this has lead various researchers to include a high level of textural or ornamental information in some examples of Mayan architecture (Burkle-Elizondo 2001) and Hindu Temples (Md Rian, et al. 2007). In these studies, any ornamental textures or painted patterns are included as part of the geometry of the design, along with representations of materials of the walls and roof in elevation, and the floors in plan.

Le Corbusier used several different materials in the Villa Jaquemet and while he chose them specifically, he could not be said to have designed the precise geometry of the building texture. For example, the rough stone blocks which make up the primary walls have a distinct texture, but not a repetitive geometry. The rendered walls, timber linings and tiles are at least consistent textures (Fig 5a). The existing plans for the house do not indicate what floor surfaces were intended in the house and so, for demonstration purposes, the house has been delineated in plan with tiled floors to the wet areas, stone to the entry foyer and timber boards for the rest (Fig 5b).

4. DISCUSSION

The particular question of how much texture to include when measuring a façade or plan is one of the more controversial ones in fractal analysis. Bovill (1996) argued that the geometric patterns produced by repetitive materials (like the horizontal lines of floorboards) should not be measured; a position which Joye (2011) has rejected. Bovill’s position has been repeated by past researchers (Lorenz 2003; Ostwald et al. 2008) even though it has been acknowledged that inconsistent decisions regarding which lines to measure in a representation can have a major impact on the result (Vaughan and Ostwald 2009a). Figure 6 charts the differing results for the images analysed in this paper showing the general rise in results with each additional layer of detail.
Zarnowiecka (2002) in particular offers a balanced account wherein she originally disagrees with Bovill’s proposition that, for example, the horizontal lines in a façade made by timber siding should be ignored. Zarnowiecka (2002), then notes that if this is the case, then “one must make a decision if a decorated top roof boarding is still a siding or a detail. Should this decision depend on the width of the planks being used in boarding?” (343). However, after measuring the difference between the elevation with planks, and without, she realises that the “concentration of the lines on the façade” (344) changes the measured result even though they may not be an important feature. Zarnowiecka’s (2002) problem is that measuring texture (to use the terminology of the current paper) skews the results of the design analysis, effectively making it unusable, whereas Joye (2011) is critical of Bovill’s (1996) method because Joye is more concerned with analysing texture rather than massing. These are effectively arguments about intrinsic validity and the alignment between the representation used for measuring and the application of the measure.

CONCLUSION

Just as the tension between precision and purpose in architectural measurement can be ameliorated by a careful alignment between method and goal, so too can the problems with computational analysis using fractals be minimised through the application of the framework described in this paper. However, there will always be instances where more reasoned and considered decisions need to be made. For example, in many of his designs Mario Botta detailed complex layers of different coloured bricks, along with different types of brick-bonds, blurring the distinction offered in this paper between tertiary form and texture. Similarly, Frank Lloyd Wright in the Robie House specified that all external brickwork would be horizontally raked, but with filled perpends; thereby giving the house an exaggerated horizontal appearance. This decision also challenges the distinction between tertiary detail and texture. Many of Richard Meier’s public buildings are modulated in accordance with the standard size of a white, square, ceramic cladding panel. While the grid appearance of the panel is clearly a texture, the whole building design is also, to a certain extent, reliant on the proportions of this grid, and to exclude it from an analysis would require careful reasoning. The framework provided in this paper seeks to give guidance about the appropriate use of representational standards for particular measuring purposes. However, as these examples indicate, there will always be exceptions that require additional consideration.

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