

QUANTIFYING THE CHANGING VISUAL EXPERIENCE OF ARCHITECTURE

Combining Movement with Visual Complexity

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Abstract. Computational fractal analysis provides a repeatable and reliable method for determining the level of characteristic, or typical, visual complexity in the elevations of a building. The present paper describes and demonstrates an alternative application of fractal analysis using perspectival images. Conventionally, orthogonal views, such as plans and elevations, have been the only images used for this approach to the measurement and analysis of architecture. However, a perspective image is a more realistic representation because it is closer to the way humans visually experience space and form. This paper describes an application of computational fractal analysis to perspective views to analyse and measure the visual phenomenon of moving towards or through a building. This method is demonstrated by calculating the characteristic complexity of a series of perspective images recording the process of approaching and entering Frank Lloyd Wright's *Robie House*.

Keywords. Spatio-visual experience; Frank Lloyd Wright; fractal analysis; computational analysis.

1. Introduction

Architectural historians and theorists frequently offer detailed first-hand accounts of their experience of moving through famous buildings. Such descriptions are often presented as a record of the spatial qualities or personal impact of a design (Rasmussen, 1964; Meiss, 1990; Shephard, 1994). For example, studies of the specific positions within the architecture of Le Corbusier have been undertaken by Baltanás (2005) and Paul Rudolph developed extensive annotated diagrams of the experience of moving through Mies van Der Rohe's Barcelona Pavilion (De Alba, 2003). Some of the most

detailed accounts of the experience of approach paths, both to and through buildings, have been written about Frank Lloyd Wright's architecture. In particular, Hildebrand (1991) used this method to argue that a distinctive pattern of spatio-visual experience is found in Wright's domestic architecture, when a person follows the path from the entry to the living room. Hildebrand's study provides a phenomenally-framed description of the route with a diagrammatic analysis of the house. What it lacks, like the majority of these other examples, is a way of supporting or testing the account using quantitative evidence.

One quantitative method for categorising and measuring the geometric properties of architectural space is fractal analysis. This mathematical method determines a numerical value (fractal dimension) which represents the visual complexity of an image (Mandelbrot 1982; Voss 1986). The standard technique for this process, first applied to architecture by Bovill (1996), is to analyse orthographic projections (elevations and plans) of buildings. While Bovill used orthographic views, he also asked; why don't we measure the fractal dimensions of perspective views of buildings? Plans and elevations are universal modes of representation and this is why they are useful, but they do not replicate the way we view or move through the world. This paper offers an alternative way of thinking about the fractal analysis of architecture and then demonstrates this approach using a novel application of the method to the changing visual experience of walking through a building.

The actual experience of movement through space involves many different sensory inputs including sight, sound, smell and touch. The approach proposed in this paper is, however, restricted to consideration of purely visual features, and further, to a special type of isolated visual experience that is reflected in computer-generated images. However, the method used in this paper could be further developed to include other visual parameters, provided they were clarified for consistency and their methodological impacts were well understood.

The building used to demonstrate this approach, the *Robie House*, was chosen because it has been the subject of previous accounts of visual complexity (Bovill 1996). In this paper the *Robie House* is analysed by following a defined circulation path from the entry to the living room. While there are many ways to travel around and within a building, this paper has specifically selected a route through the *Robie House* that has been the subject of previous analysis and documentation. The path used in this paper follows that suggested by Hildebrand (1991) who not only suggested the general route, he defined the pathway in precise terms, noting the views and angles of approach. The exact path used in Hildebrand's study was later used in a study of isovist fields in the *Robie House* (Ostwald and Dawes 2013). In this pre-

sent study, over 50 perspective images at 1 meter increments are generated from a computer model along this path. The images are then analysed using software and a chart of the sequential measures of spatio-visual experience is compiled. This data is then compared with qualities described in previous accounts and data derived from past attempts to analyse this house and its spatial experience.

2. Fractal Analysis of Characteristic Visual Complexity

When undertaking a quantifiable description of the formal qualities of a building, only a limited range of existing approaches are available. For example, there are mechanical and computational approaches to identifying and compiling information to describe the form or shape of a building (Mitchell, 1990; Chuang and Henderson, 1990; Crompton and Brown, 2008), there are several semantic systems for describing architecture's visual properties (Gero and Park, 1997; Gero and Damski, 1999) and a number of well-developed theories about the rules that might be used to describe the development of the formal properties of a building (Mitchell, 1990; Stiny, 2006). However, despite such works, there is only one method currently in use that accurately measures the characteristic visual complexity of a building's façade in a consistent and repeatable manner. That method is *fractal analysis* and it is of interest not only because it is a rare quantifiable method for the analysis of architectural form, but also because there are several further applications of the fractal dimension data which can increase our understanding of the built form. For example, fractal dimension data has previously been used to test the correlation between visual complexity and façade orientation (Ostwald, et al. 2009) and scientists and psychologists have used it to investigate a range of visual and attitudinal phenomena (Keller, et al. 1987; Hagerhall, et al. 2004; Stamps, 2002). Psychological studies have traced human environmental preferences to particular fractal dimensions in urban skylines (Stamps, 2000; Joye, 2007; Chalup and Ostwald, 2009) and fractal analysis has been used to test claims that some buildings are closely related, in terms of visual properties, to their sites or context (Vaughan and Ostwald, 2010).

The origins of the fractal analysis of architecture may be traced to a unique application of Mandelbrot's theory of 'fractal' geometry by Carl Bovill in 1996. In the late 1970s, Mandelbrot had proposed that a fractal dimension (D) is a non-integer number, used to measure the characteristic complexity of an image which appears more detailed than a simple one-dimensional line ($D = 1$) and yet less complex than a filled plane ($D = 2$) (Mandelbrot 1982). Thus D is a value between 1.0 and 2.0, with lower val-

ues (say $D = 1.1$) denoting an image of an object with minimal complexity and high values (say, $D = 1.9$) suggesting a representation of a visually complex object. Bovill (1996), following a suggestion by Mandelbrot that the fractal dimension of architecture may be calculable, determined the D values of elevations of houses by Le Corbusier and Frank Lloyd Wright using the “box-counting” method. This method calculates the amount of information present in an object over a range of scales, and then determines the average level of distributed information in that object (Mandelbrot, 1982).

The manual version of Bovill’s method has since been used for the analysis of a range of building types from different periods, but with only limited success (Bechhoefer and Appleby, 1997; Cagdas et al., 2005; Wen and Kao, 2005; Burkle-Elizondo and Valdez-Cepeda, 2006). Several programs now automate this operation, including *Archimage* and *Benoit*, providing more consistent results. The reliability and accuracy of the method has also been improved over time with multiple studies identifying improvements (Foroutan-pour et al, 1999; Cooper and Oskrochi, 2008; Ostwald, 2013, Ostwald and Vaughan, 2013). Such refinements ensure that the image being analysed is prepared and processed in a manner which produces both repeatable results and reduces methodologically-derived errors ($< 0.5\%$). The optimal setting for the computational method has most recently been applied to the architecture of Glenn Murcutt (Vaughan and Ostwald, 2014).

3. Analysing Perspective Views

Bovill (1996) proposed that architecture is necessarily produced through the manipulation of rhythmic forms. He expanded this idea to argue that fractal geometry allows a ‘quantifiable measure of the mixture of order and surprise’ (p.3) in this architecture to be developed and, moreover, that this will reveal the essence of its formal composition. For Bovill, ‘[a]rchitectural composition is concerned with the progression of interesting forms from the distant view of the facade to the intimate details’ (p.3).

There are two facets of Bovill’s argument which are worth considering in more detail, the first historical and the second methodological. First, it is possible to be critical of Bovill’s position and respond that, with only a few exceptions, the desire to ‘maintain interest’ or produce a ‘cascade of detail’, has not been a major theme in any established architectural theory since Ancient Rome (Kruft, 1994). But the more important issue Bovill alludes to relates to the method of measuring changing fractal dimensions in response to the shifting position of the viewer. He effectively asks, why don’t we measure the fractal dimensions of perspective views of buildings? Bovill (1996) offers a practical answer to this question by suggesting that it is impossible

to meaningfully compare the measures derived from different buildings unless there is a common orthographic basis for them. But what if we are not interested in a comparison between buildings, but of the way a specific building is visually experienced from different positions in space?

The human eye reads the world through a perspective lens, which is why it is impossible to actually experience an elevation in the same way that it is drawn. The problems of parallax ensure that in the 'real world' no two lines are ever, perceptually at least, parallel. Thus, as previously stated, plans and elevations are universal modes of representation and this is why they are useful, but they do not replicate the way we view the world. But what if we wanted to measure the changing visual experience of a person as they approach and move through a building? Admittedly, such a measure would provide at best an approximation of the visual experience of an individual with a certain height, visual acuity and facial dimensions (the distance between the eyes has an impact on the way we view space). But for some purposes, such an estimate might be useful.

The idea of analysing perspective images using fractals is not necessarily a new one. Ostwald and Tucker (2007) propose three variations of perspective-based applications of fractal analysis, each of which relies on a different combination of viewpoints, perspective planes and picture-planes. These variations also introduce the role of the cone of vision; something conspicuously lacking from past attempts to use fractal analysis for considering photographs of buildings. The first two variations proposed by Ostwald and Tucker (2007) model the way a human eye would view a building if a person walked either directly towards a façade, or at a consistent angle to the façade, and wished to examine its changing visual complexity at each step. At each viewpoint the standard cone of vision of the human eye (or at least its high acuity zone) determines the extent of the façade that is depicted and then analysed. The third variation commences with the identification of a distinct path – to and through a building – that is relevant for the assessment of that design. At evenly spaced intervals along this path viewpoints are established for the generation of perspective images. At each viewpoint the cone of vision of the human eye determines the extent of the building that is recorded and the fractal dimension of this image may be calculated. This is the closest of any of the three variations to measuring the visual experience of a person approaching or using a building.

However, the challenge with this third approach is that it is hard to see how it could be usefully repeated for multiple buildings and what it might be used to measure or assess. In order for this variation of the method to be useful, there must be a rationale for choosing a specific path and for determining why the visual experience of the path is important.

4. Application of the Method

The domestic architecture of Frank Lloyd Wright has been the subject of regular, and often highly detailed speculation about the relationship between visual experience and spatial psychology. Probably the most famous of these studies is by Hildebrand (1991) who, drawing on the work of Appleton (1975; 1988), argues that a distinctive pattern of spatio-visual experience is found in Wright's architecture when a person follows the path from the entry to the living room. Hildebrand provides a phenomenally-framed and graphically illustrated description of the visual properties of this route through many of Wright's most important dwellings. Ostwald and Dawes (2013) have tested the validity of Hildebrand's theory using isovist fields to provide a quantitative analysis of the paths identified by Hildebrand. A further study by Bhatia (et al., 2013) also examines specific paths through Wright's domestic architecture to determine if they have sufficient visual cues to support spatial cognition. These previous studies confirm the existence of a distinct and well-documented path through space, which also possesses theorised visual properties.

The existence of Hildebrand's proposition overcomes the general problem with the last of the perspective variants described previously, that the decision where to produce views for fractal analysis may be completely arbitrary. Therefore, following Hildebrand's logic, a computational fractal analysis of the path through the *Robie House* was undertaken to demonstrate the alternative method. The path that was analysed follows the everyday entry route from the street through the garage forecourt and into the house by way of the 'back door', through the central hallway, upstairs and around the circulation zone into the living room, where it ends. This is the path that would be taken by occupants or regular guests; it is not the route that would be followed by formal visitors or servants.

5. Results and Discussion

The location of the path through the *Robie House* is recorded in Figure 1. Along this path, perspective images at 1 meter increments (steps) were generated and analysed using the box-counting method. While the viewpoint of the person moving through the building would differ based on their height, eyesight and gait, for this study, the perspective eye height for the images was 1.65 meters (to match Wright's stature and eye level) and a high-acuity cone of vision of 90° was used.

Figure 1 also includes a diagrammatic representation of the direction and location of 23 of the 52 cones of vision that were used to generate the perspectives. These 23 selected perspective views, which are indicative of the

more interesting positions along their path, and their *D* results, are presented in Figure 2. The complete set of results, which chart the changing visual complexity of passage through the *Robie House*, are in Figure 3.

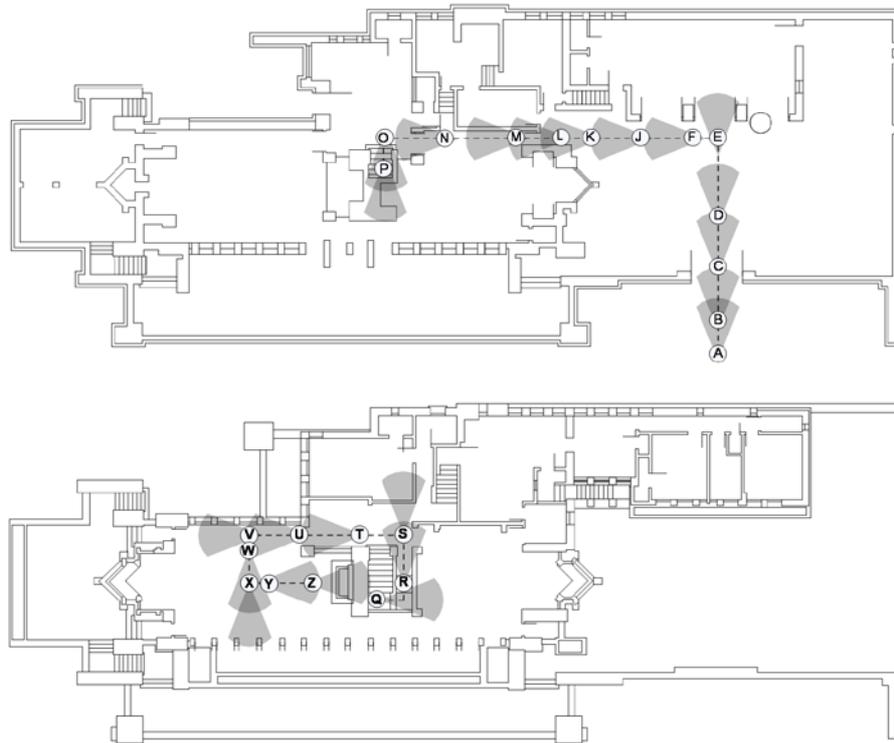


Figure 1. Perspective route through the ground (top) and upper floor (bottom) plans of the *Robie House*.

While the purpose of the present paper is not explicitly to test Hildebrand’s argument, it is of interest that one of his suggestions is that these paths commence with a higher degree of mystery and visual complexity and that this phenomenal property reduces towards the end of the path. Importantly, this reduction is not meant to be a linear sequence, but rather a shifting pattern of rising and falling levels that gradually reduce (from left to right in Figure 3).

When this property was previously tested using isovists (Ostwald and Dawes, 2013), a marginal fall in mystery and spatial complexity was noted, largely as a result of the spatio-visual geometry of the plan which is more complex on the lower level, and less complex in the relatively open-planned upper floor. However that study did not take into account the elaborate deco-

rative modelling and detailing of the roof that was so typical of Wright at this time.

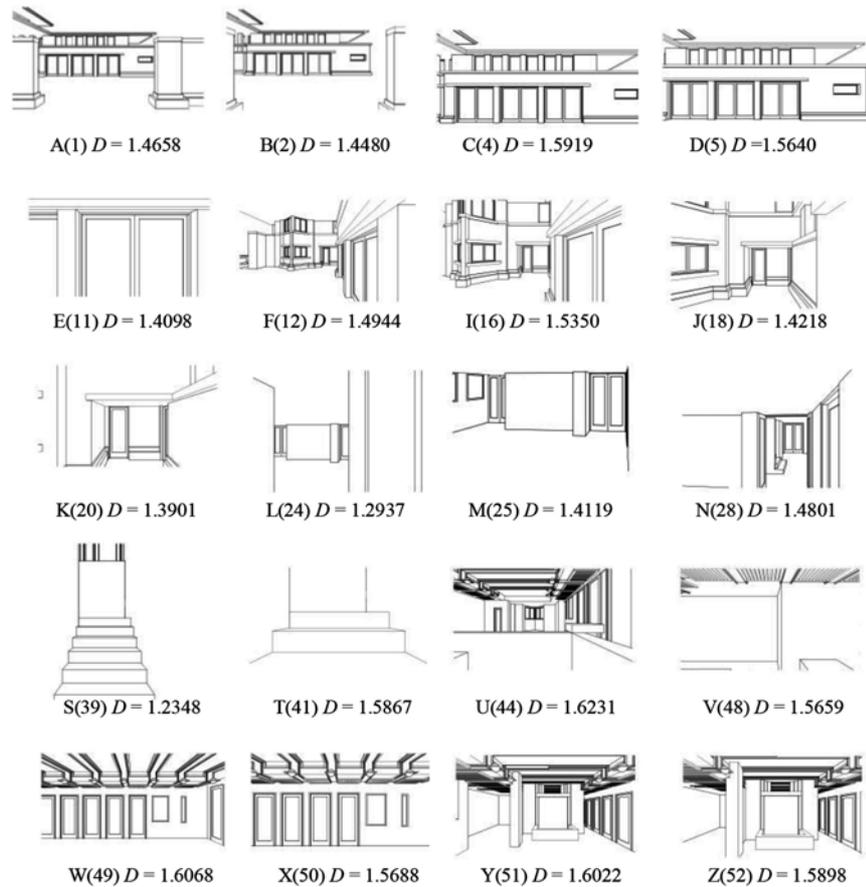


Figure 2. Selected perspective views, with their fractal dimension results (D). The route reference is denoted as a letter, the graph reference is the number following in brackets.

The fractal analysis results for the three-dimensional visual complexity of the *Robie House* path are variable, but generally fall marginally along the exterior section of the path (Figure 4), before rising (from left to right) along the interior section of the path (Figure 5). The second part of this outcome is heavily influenced by the decorative mouldings in the living space and the window and lighting forms, none of which were considered in the previous isovist analysis. A more comprehensive study of a larger number of works would ultimately be required to test Hildebrand's assumptions, along with a

much tighter definition of what visual complexity actually entails in his analysis of Wright’s architecture. For example, is visual complexity largely spatial or does it extend to include more decorative modelling? If it is the former case, then the evidence collected in the present paper infers that Hildebrand may be correct, but the evidence does not support the latter case.

Ultimately, the results for the path analysis demonstrate how the visual experience changes as a person moves through a building. The low points in the graph generally relate to positions on the pathway where the viewer is in very close proximity to the building and thus there is little to see. The higher results are for views that take in more information, or are further from surfaces and other limits caused by physical forms or occlusion. While this result might seem obvious, it would be interesting to compare the same method for the Villa Savoye, which does not possess such a high degree of detail and might, conceivably, generate a more consistent set of *D* results. Further speculation on this topic is beyond the scope of the present work, nevertheless, Bovill (1996) argues that, ‘[a]s one approaches and enters a building, there should always be another smaller-scale, interesting detail that expresses the overall intent of the composition’ (p.3). Within its interior, the *Robie House* displays a growth in visual complexity, rather than a consistent level of it, as it is traversed. With an almost 43% range in the results, the experience of the form of the *Robie House* (rather than its materiality) is one of a reduction in complexity as a person approaches, before an increase as a person moves through the interior.

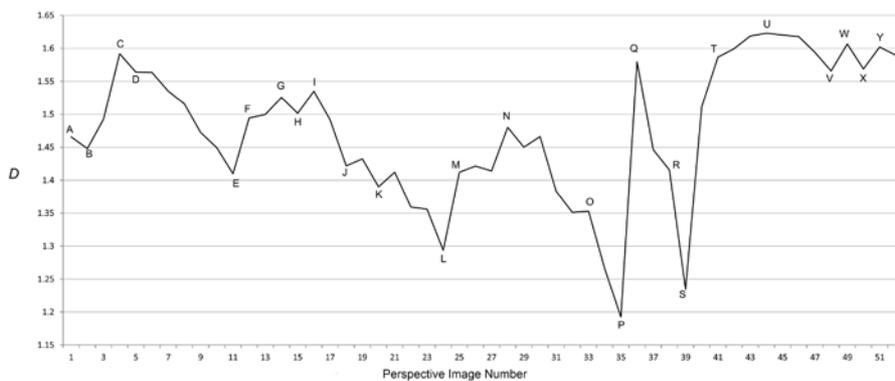


Figure 3. Fractal Dimensions of perspective views experienced in the Robie House

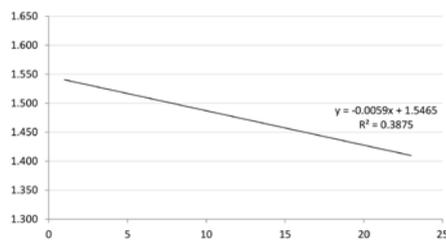


Figure 4. Linear Trend-line for fractal dimensions, extrapolated from the exterior section of the path.

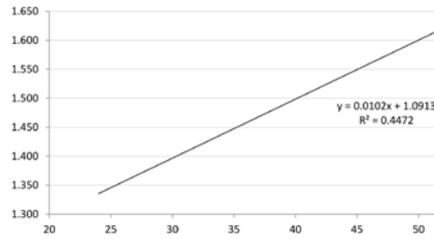


Figure 5. Linear Trend-line for fractal dimensions, extrapolated from the interior section of the path.

6. Conclusion

In contrast to the standard way in which Bovill and many others have used orthographic images of historic buildings for fractal analysis, this paper proposes and demonstrates an application using perspective images, to simulate the combination of movement and visual complexity in spatial experience. Perspective views potentially offer a more realistic view for analysis and it might be suggested that they are superior to the standard method in all but one, important, way. Bovill's method has the advantage that it is a straightforward, repeatable and potentially universal process. It has to be the starting point for any comparative study of the characteristic complexity of architecture. Nevertheless, the variations set out in this paper, and especially the final one, suggest that there are powerful applications of fractal analysis that could be further developed or tested and which will be useful for producing a more nuanced or detailed, reading of visual complexity in the built environment.

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