A Data-Cluster Analysis of Façade Complexity in the Early House Designs of Peter Eisenman

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Abstract: *Relatively few quantifiable and objective methods exist for the analysis of architectural elevations. Only one of these methods has been repeated by multiple researchers and used for the analysis of a wide range of historic and modern buildings and architectural types. In the present paper, the computational variation of this method–the fractal approach to determining characteristic visual complexity–is applied to the early house designs of Peter Eisenman. The results of this analysis are then subjected, for the first time, to cluster analysis in an attempt to uncover patterns in the way in which Eisenman's houses are shaped by orientation, address and permeability. Such an analysis is of interest because Eisenman argues that he set out to design these early houses without regard for such factors. The paper concludes that the mathematical data generally supports Eisenman's contentions regarding his Houses I, II, III, IV and VI.*

Keywords: *Visual complexity; fractal analysis; data-clustering; Peter Eisenman.*

Introduction

In 1996 Carl Bovill adopted Benoit Mandelbrot's "box-counting method" and used it to produce an approximate fractal dimension of an architectural façade. While largely untested until recent years, Bovill's method remains one of the few approaches for producing a quantitative determination of the visual complexity of a building's form and, for this reason, it has been applied in multiple studies (Bechhoefer and Appleby, 1997; Burkle-Elizondo, Sala and Valdez-Cepeda, 2004; Burkle-Elizondo and Valdez-Cepeda, 2006). Despite these examples of the method being repeated in its manual form, Lorenz (2003) was the first person to attempt to test the method and, since that time, Ostwald, Vaughan and Tucker (2008) have developed a computational variation and a response to its known limitations. This computational variation has since been refined and applied to multiple additional studies (Ostwald, Vaughan, Chalup, 2008; 2009).

In all of the past applications of this method, the resultant data has been used to provide a simple comparison between relative visual complexity in architectural projects. For example, Bovill (1996) originally demonstrated the method by showing that the front façade of Frank Lloyd Wright's Robie House is more complex than the front façade of Le Corbusier's Villa Savoye. However, in its computational form the method has been able to develop much larger sets of data about architectural projects and this suggests the possibility of new forms of analysis. For example, an analysis of the elevations of a series of houses contains sufficient information for a simple application of data-clustering. This approach, can be used to seek patterns in sets of data which could either be used to reveal new, previously hidden, tendencies in an architect's works or to confirm previous, intuitive or espoused readings of that work (Johnson, 1994).

In the present paper, the computational method is used to calculate the characteristic visual complexity of the elevations of five of Peter Eisenman's early houses. These results are then analyzed, using three simple data-clustering approaches, to seek patterns in Eisenman's design strategies. The primary purpose of this analysis is to use mathematics to investigate Eisenman's claim that these early house designs were produced without obvious reference to their surroundings, the needs of his clients or even functional requirements. These houses are significant in the history of architecture because they mark the rise of an allegedly "post-functionalist" and "post-humanist" architecture (Eisenman 1987). If Eisenman's design aspirations are reflected in these early houses then the data-cluster approach should not be able to reveal any clear patterns in the relationship between the form of the house and its orientation, response to human approach and apparent permeability.

Quantifying characteristic visual complexity

Fractal geometry may be used to describe irregular or complex lines, planes and volumes that exist between whole number integer dimensions. This implies that, instead of having a dimension, or *D*, of 1, 2, or 3, fractals might have a *D* of 1.51, 1.93 or 2.74. Fractal geometry came to prominence in mathematics during the late 1970s and early 1980s. In the years that followed fractal geometry began to inform a number of approaches to measuring and understanding non-linear and complex forms. However, it was not until the late 1980s and the early 1990s that fractal dimensions were applied to the analysis of the built environment.

The box-counting method is one of the most common mathematical approaches for determining the approximate fractal dimension of an object. Importantly, it is the only method currently available to analyze the fractal dimension of an architectural drawing. In its architectural variant, the method commences with a drawing of, for example, an elevation of a house. A large grid is then placed over the drawing and each square in the grid is checked to determine if any lines from the façade are present in the square. Those grid boxes that have some detail in them are recorded. Next, a grid of smaller scale is placed over the same façade and the same determination is made of whether detail is present in the boxes of the grid. A comparison is then constructed between the number of boxes with detail in the first grid and the number of boxes with detail in the second grid; this comparison is made by plotting a log-log diagram for each grid size. By repeating this process over multiple grids of different scales, an estimate of the fractal dimension of the façade is produced (Bovill, 1996; Lorenz, 2003).

There are several variations of the box-counting approach that respond to known deficiencies in the method. The four common variations are associated with balancing "white space" and "starting image" proportion, line width, scaling coefficient and moderating statistically divergent results. The solutions to these issues that have been previously proposed by Bovill (1996), Lorenz (2003), Foroutan-Pour, Dutilleul and Smith (1999) and Ostwald, Vaughan and Tucker (2008) are adopted in the present analysis.

The software programs *Benoit* and *Archimage*, the latter produced by the present authors, automate and refine the box-counting operation and encompass the majority of the known refinements. The *D* data generated by *Benoit* and *Archimage*, when averaged together, produces a $D_{(Elev)}$ result for each elevation which is a measure of the relative complexity of the façade. When four $D_{(Elev)}$ results for a house are combined together, a composite result or $D_{(Comp)}$,

Table 1
D calculation for each elevation for each of Eisenman's five houses, and a composite results for the average D result for each house

House	$D_{(Elev)}1$	$D_{(Elev)}2$	$D_{(Elev)}3$	$D_{(Elev)}4$	$D_{(Comp)}$
I	1.335	1.355	1.424	1.296	1.352
II	1.527	1.491	1.498	1.225	1.436
III	1.503	1.513	1.5625	1.594	1.543
IV	1.395	1.4065	1.3935	1.397	1.398
VI	1.405	1.4175	1.409	1.427	1.415

is produced which is a measure of the average characteristic visual complexity of the complete design (or average fractal dimension for the 2D visual qualities of the design).

Visual complexity in the architecture of Eisenman

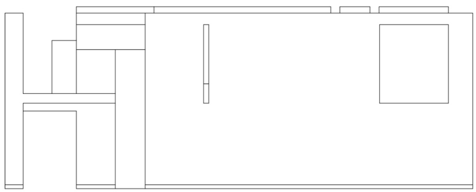
Five of Eisenman's house designs were selected for the present research. These are; House I (1968), House II (1970), House III (1971), House IV (1971) and House VI (1976). House V, the only one missing from this sequence, was not completed in enough detail to be used for the current research. For the rest of the designs, all of the elevations used for the analysis were redrawn to ensure consistency and were sourced from the published sets of drawings produced by the office of Peter Eisenman (Dobney, 1995).

If the 20 views (five houses each with four elevations) are subjected to two variations of the computational method (*Benoit* and *Archimage*), each using 520 data points for comparison, then 40 separate *D* results are generated which are then averaged into 20 $D_{(Elev)}$ results and five $D_{(Comp)}$ results for the visual complexity of Peter Eisenman's early houses (Table 1).

Of these five early houses of Peter Eisenman, House III had the highest average value for visual complexity with a result of $D_{(Comp)} = 1.543$. The lowest result is for Eisenman's first design, House I; $D_{(Comp)} = 1.352$ (see figure 1). The most complex façades are typically in House III and are lead by Elevation 4 ($D_{(Elev)} = 1.594$) (see figure 2). This is significant because it is relatively rare, in the fractal analysis of modern architecture, to produce a result which is close to $D = 1.6$.

Data-cluster analysis

One of the practical challenges with applying the data developed from the computational method for the fractal analysis of architecture is that it produces a single, numerical result for each case being considered. This means that the data is in the form of isolated numbers on a linear scale and within a fixed range. This is akin to producing a chart which has a single "x axis" along which points are placed. The application of this type of data is essentially limited to comparisons between, for example, façades that have higher levels of complexity and those which have lower levels. Or alternatively, this data can be used for comparisons between different architects' works (Bovill, 1996; Ostwald, Vaughan and Tucker, 2008). While such comparisons have been used to confirm a range of intuitive readings of architectural form, the potential of fractal analysis is limited without an additional dimension being considered; in effect, producing a "y axis" to compliment the current, isolated, "x axis".



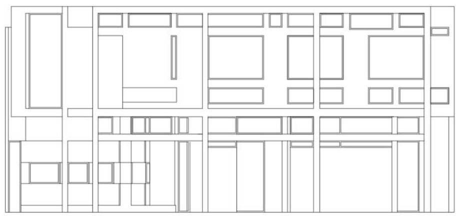


Figure 1 (left)
One of Eisenman's least complex façades. House I, Elevation 1, $D_{(Elev)} = 1.335$

Figure 2 (right)
Eisenman's most consistently complex façade. House III, Elevation 4, $D_{(Elev)} = 1.594$

Three simple methods for augmenting fractal data, and allowing it to be analyzed in more detail, rely on the assumption that a building's form can be understood as a reflection of its *orientation*, *address* or *permeability*. For example, Moore, Allen and Lyndon argue that the design of houses often appears to be "in response to the resources, climate and topography of a particular region" (1974, 71). They also argue that a "house is in delicate balance with its surroundings" and that it "speaks" of or expresses something about its capacity to accommodate "human activities" and attitudes (1974, 49).

The first of these three data cluster approaches, orientation, is related to the impact of the environment on a design. Most houses are shaped to respond to the movement of the sun, either to restrict its impact or to capture its energy. The second assumption is concerned with the way in which a building addresses a visitor, or the way the building presents its public and private façades. The design of a façade generally shifts to acknowledge points of entry and to signal rights of access. The final of the three approaches anticipates that the function of a building in some way shapes the external expression and permeability of a building's façade. This is not the same as suggesting that "form follows function". Instead, this approach is reliant on the idea that the number, size and type of openings in a building's façade, along with an understanding of the spaces these openings are associated with, are significant for interpreting or understanding the building. For example, Moore, Allen and Lyndon argue that "[w]indows do more than let in light and air. The way they are placed in a wall affects our understanding of the whole house" (1974, 211). These three assumptions that underlie the data-clustering approaches are all reliant on the belief that design is adaptive and responsive. However, whether or not a building has actually been designed to respond to these conditions is largely irrelevant. They simply provide alternative scales against which various buildings and façades can be consistently charted. Moreover, in the case of Eisenman — an architect who denies such influences — a lack of consistency in some of the augmented scales will be more telling.

Orientation

This first approach categorizes the façades of a detached house by their orientation to the cardinal points of the compass (north, south, east and west). Not only is the differentiation of façades using this nomenclature common practice in architecture, but a determination of orientation, by way of magnetic bearings, is a universal system which can potentially be used for comparisons between most buildings. The primary exceptions to this would relate to geographic areas bounded by lines of latitude that approach the Arctic and Antarctic circles.

The results for Eisenman's early house elevations, clustered by orientation and scaled for visual complexity, don't reveal any of the patterns that would be expected for a conventional house that had been shaped by siting or environmental considerations (see figure 3). For example, the north elevation of House III is its most complex, while the North elevation of House II is its least complex. Houses IV and VI show very little variation in formal complexity or modeling between any of their façades.

Address

This second approach classifies the façades of a house by using a common, experiential system. Whereas, the previous method sought to connect façade information to a universal system – magnetic bearings – the second approach is concerned

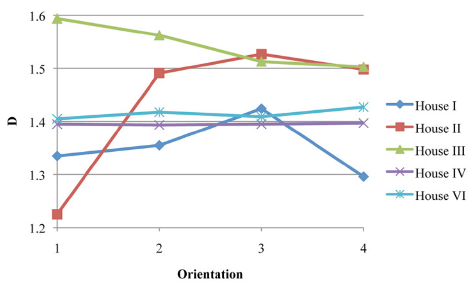
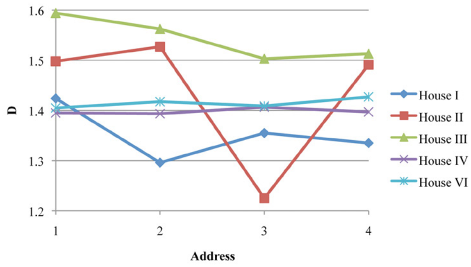


Figure 3
Data-clustering by orientation (North = 1, South = 2, East = 3 and West = 4)

Figure 4
Data-clustering by address (Front = 1, Back = 2, Left = 3 and Right = 4)



with local and more intuitive determinations. While it might be imagined that houses designed for uniformly flat, rural sites would be strongly shaped by their orientation, for the majority of houses, the strategic siting options are much more limited and the impact of orientation tends to be ameliorated by the importance of addressing a street.

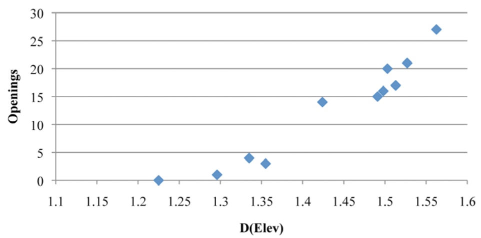
The majority of housing sites have a single obvious public face or address and a single private face. This means that the major factor shaping the design of a typical façade is more likely to be related to the presentation of the house to the street, and the impact of positioning appropriate internal spaces to face the street, than to the passage of the sun. This implies that, perhaps more so than orientation, patterns should be discernable in the way in which dwellings orient their public and private façades.

The most common way of identifying the façades of a house revolves around the delineation between "front" and "back", with the former typically being the street address which most often also contains the formal entry to the house. Once the front is defined, most of the remainder of the façades are described in relation to the front. Thus, the façade that is facing in the opposite direction to the front becomes the back or rear façade. The remaining two façades, in a predominantly orthogonal or rectilinear plan, are the side façades. These also tend to be distinguished from each other by their relationship to the front. In particular, they are typically called the left or right side of the house, as viewed from a point perpendicular to the front facade.

The five early houses of Peter Eisenman considered here are typically on rural or suburban sites and have no street address, even though they each have a formal approach and entry. For these houses, some minor, but not entirely compelling, patterns are evident in the data when it is clustered by address (see figure 4). For example, in two of the five cases (Houses III and I) the front façade is the most complex and in a third case it is amongst the most complex (House II). For two of the houses, the left façade is also the least complex. There are no strong patterns in this data in part because two of Eisenman's designs (Houses IV and VI) are so similar in all façades.

Permeability

At first glance, the concept of calculating the number of openings in a façade might seem irrelevant without a similar calculation for the size of these openings, their distribution or shape. However, the number of openings is a parameter that can easily be determined and it can have a subtle but important impact on multiple additional factors in the analytical process. For example, the number of openings in a façade might be assumed to be shaped by the orientation of the house and the street address (Moore, Allen and Lyndon, 1974). The number of windows might also be associated with the architectural character of a building and it is, most importantly, a factor which impacts on the fractal dimension calculation. This last dimension is significant because a correlation between high *D* values and a larger number of openings in a façade might be expected. This is because, the more openings there are in a façade, the more complexity it might be expected to have. But what if this isn't the case? An inverse correlation between number of openings and formal complexity can also be a telling result. If the number of openings is very low, and the *D* value relatively high, then the façade must be heavily articulated or modelled and this is possibly without reason. If the number of openings is high, and the complexity low, then the building must have little additional detail other than these openings. This latter result might be expected for a minimalist design. In this approach the



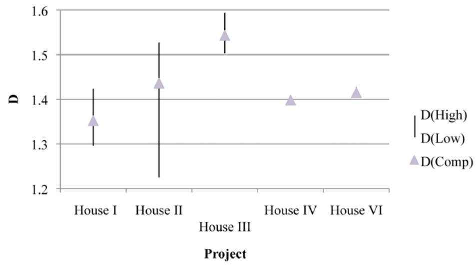


Figure 5 (left)
Data-clustering by permeability for all facades for all houses

Figure 6 (right)
Range of façade complexity. The vertical bar represents the range from highest to lowest $D_{(elev)}$ for each house. The triangle is the composite or average result

descriptor "openings" includes doors and garages as well as windows. Each of these that are visible in an elevation are counted and charted against their corresponding *D* value (see figure 5).

For Eisenman's five houses, there is a relatively high degree of correlation between permeability and façade complexity. This suggests that, in part, it is the complexity of the openings in his facades that are shaping the *D* result (a close examination of figure 2 shows why). This is why the facades with less than five windows have lower *D* results.

Conclusion

The three data-clustering approaches used in the present research do not reveal any mathematical evidence that suggests that Eisenman's designs are, in any way, influenced by orientation or address while permeability certainly shapes the visual complexity of his architecture. However, if there is any clear pattern in the data-cluster analysis presented here, it is first that, precisely as Eisenman (1987) argues, the early numbered houses represent an attempt to generate an architectural form that firmly rejects external influences. The second pattern uncovered in this paper is that, with each successive design, Eisenman came closer to achieving his aspiration of generating a "non-representational" architecture; a design strategy that rejects the conventional functional, phenomenological and semiotic approaches which typically characterize domestic design. Thus, while some minor patterns are evident in the first three houses (I-III)–including a tendency for the entry façade to be more complex than the other façades–by the final two houses (IV-VI) all differentiation between the facades has been eliminated. Moreover, while there is some variation between the simplest and most complex façades in the first three houses, by the final two there is no difference at all (see figure 6). These final two houses represent the apogee of Eisenman's early design trajectory that sought to produce "pure form" (Eisenman, 1987).

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