Data-cluster analysis of correlations between façade complexity and orientation in Modernist architecture

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ABSTRACT: A common assumption in 20th century design analysis and critique is that the visual qualities of a domestic structure are, in some way, a reflection of the siting of the house, its orientation and program. The first two of these, siting and orientation, are associated with environmental conditions and the supposition that architect-designed houses possess façade forms which broadly respond to their context. This implies that the architect has modified the form of the design to capture or restrict light, to control heat or shed snow and to take advantage of the possibilities of natural ventilation. But how might it be possible to begin to critically evaluate this assumption method?

The present research tests the idea that augmented computational fractal analysis techniques can be used to investigate the relationship between façade complexity and orientation. The paper outlines the proposed method and then applies it to twenty Modernist houses. The houses being investigated fall into two categories, Early Modern (1920-30s) and Late Modern (1970-90s), and they represent the works of two major architects from each era; respectively Le Corbusier and Eileen Gray and Peter Eisenman and Kazuo Sejima. In total, five houses by each of the four architects are analysed, giving mathematical results for the visual complexity of 73 facades that are clustered by orientation. The data cluster charts are then subjected to a simple observational test to identify the existence of any patterns.

In this way, the paper demonstrates that it is possible to use largely quantitative methods to investigate if any correlations exist between these architects’ approaches to design and the degree to which they are responsive to the physical environment. For the specific cases considered, the paper concludes that a loose correlation does exist for the early Modernist works, but not for the later ones.

Keywords: fractal analysis, computational tools, design assessment, façade orientation

INTRODUCTION

A common assumption in architectural design is that the façade of a building is typically shaped by a combination of environmental, semiotic and functional conditions (Feininger 1956; Grillo 1975; Jones 1992). These three characteristics, which have clear parallels to the ancient Vitruvian triad of architectural values – firmness commodity and delight – are not necessarily all present in all architecture, but they are apparent in many buildings (Kruft 1994). Moore, Allen and Lyndon propose that this is particularly true in the case of domestic architecture where a façade is formed “in response to the resources, climate and topography of a particular region” (1974: 71). They maintain 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). In this way, the form of a house can be understood as a reflection of three factors; orientation, address or program. The first of these three, orientation, is related to the impact of the environment on a design (Leatherbarrow 2000). Most houses are shaped to respond to the movement of the sun, either to restrict its impact or to capture its energy. The second factor is concerned with the way in which a building addresses a visitor, or the way the building presents its public and private facades (Venturi 1966; King 2005).

The design of a façade generally shifts to acknowledge points of entry and to signal rights of access. The final of the three factors anticipates that the function of a building shapes the external expression of a building’s façade. This is not the same as suggesting that “form follows function”. Instead, this concept 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 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). Moreover, “[w]indows can imply a great deal, both by the shape and their position” (1974: 211). These three assumptions are all reliant on the belief that design is a typically adaptive and responsive process.

The present research describes and tests a mathematical method for the critical examination of the first of these assumptions; the importance of orientation in shaping domestic architectural design. The starting point for this method is a computational fractal analysis technique that produces a quantitative determination of the visual complexity of an architectural façade. The data that is produced by this method is then sorted or “clustered” by orientation. Once this process is complete, then the relationship, if any, between the visual complexity of a façade and its orientation can be quantitatively determined. The paper commences with a brief description of the theory of computational fractal analysis before explaining how this information can be augmented to seek patterns in the way in which a design responds to additional factors including orientation. The proposed analytical method is then
outlined as a series of stages. The following section describes the four architects works that are being tested with this method. The next two sections record both the anticipated results and the actual results for the twenty houses that are analysed. Finally the paper comments on the usefulness of the method and the degree to which it was able to produce results that conformed to expectations.

There are several limitations to the present research. First, the results of this paper cannot be extrapolated to make generalisations about the design values of architects in general or of Modernist designers in particular. Many factors influence the form of a building including program and address, function and meaning; orientation is only one possible factor. Moreover, orientation is implicitly about the macro environment and design thinking is often dominated by micro, or local environmental factors. The development of new construction materials has further complicated this analysis because historically the form of a building was modelled or shaped to accommodate environmental concerns, whereas more recently new materials can alleviate the need for such a high level of design modelling. For example, modern curtain wall technology can accommodate ventilation, shading, heating and structure within a single, flat wall plane. For all of these reasons, the chances of producing clear patterns from such a small data set (73 results clustered into four categories) are relatively low. Nevertheless, this research offers a new way of augmenting, or adding value, to data collected from the computational fractal method. With further development, the method may be able to be used to test the optimisation of façade design in mass suburban housing to provide an indication of sustainability.

1. COMPUTATIONAL FRACTAL ANALYSIS

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. This concept can be readily understood by considering a thought experiment. Imagine the top surface of a table. From a distance, it might appear to be a perfect two-dimensional surface ($D = 2$). But, if a person rubbed their hands across the surface they would feel that the surface has some texture and this implies that the surface is more than two-dimensional. Yet, the surface is hardly three-dimensional either. Mandelbrot suggests that, in essence, if the feeling of texture is very subtle then the actual dimension of the table might be just slightly higher than $D = 2$; perhaps $D = 2.1$. However, if the surface was scarred and heavily marked with the grain of its underlying material, it might have a $D = 2.3$ (Mandelbrot 1982). There are a range of methods for making a determination of the fractal dimension of an object and one of the most common, the box-counting approach, was developed by Bovill (1996; 1997) for the analysis of architecture. Bovill's work demonstrated that the fractal dimensions of line drawings of elevations of different buildings could be determined using this approach. This method is useful because it is one of only a small range of quantifiable approaches for the analysis of the visual properties of buildings.

Although other architects have since used Bovill's approach to analyse vernacular architecture (Bechoefer and Appleby 1997), urban and landscape design (Makhzoumi and Pungetti 1999) and ancient architecture (Burke-Elizondo, Sala and Valdez-Cepeda 2004), there remains little evidence for the testing of this method and a determination of its limits (Lorenz 2003). Ostwald, Vaughan and Tucker (2008) began to address this deficiency when they developed a computational variation of the method and then undertook a detailed examination of its validity. Since that time, the computational method has been applied in research into the characteristic visual complexity of the architecture of Eileen Gray (Ostwald and Vaughan 2008), Peter Eisenman (Ostwald and Vaughan 2009), Kazuyo Sejima (Ostwald, Vaughan and Chalup 2009) and the early arts and crafts style houses of Le Corbusier (Vaughan and Ostwald 2009).

In its architectural variant, the box-counting approach commences with a drawing of an elevation of a building, typically 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 (Bovill 1996). By repeating this process over multiple grids of different scales, an estimate of the fractal dimension of the façade is produced. While this process can be done by hand, the software programs Benoit and Archimage automate this operation. 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 proposed by Lorenz (2003), Foroutan-Pour, Dutilleul and Smith (1999) and Ostwald, Vaughan and Tucker (2008) are adopted in the present analysis.

Data augmentation by clustering

One of the practical challenges with applying the data developed from the computational fractal method 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 at odds to producing a single “y axis” along which points are placed. The application of this type of data is essentially limited to comparisons between, for example, buildings that have higher levels of complexity and those that have lower levels. Or alternatively, this data can be used for comparisons between different architects' works or different periods in an architect's body of work. While such comparisons have been used to confirm a range of intuitive readings of architectural form, the potential of fractal analysis is limited unless the raw data produced in this way can be augmented with an additional dimension; in effect, producing a “y axis” to compliment the current, isolated, “x axis”. In the present paper the raw data is augmented by the orientation of the façade being examined. This approach categorises 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 facades 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 would relate to geographic areas bounded by lines of latitude that approach the Arctic and Antarctic circles.

There are several practical considerations in making a determination of orientation. First, there are only four categories of orientation in the present work. While it might be possible to subdivide orientation by angle (within a 360° array) very few architectural drawings record this information and it is not available for most of the projects being studied. This also means that when a façade does not have a clear direction (for example, it is facing North-North-West), the façade must be placed into the closest possible category (in this example, North). This data-augmentation approach is also most appropriate for dwellings that are both orthogonal and freestanding. This is because it assumes that a house may be described using a set of four elevations. If a house needs less than four elevations to describe it, then they are unlikely to be able to be classified into the four cardinal directions used here. For example, Frank Lloyd Wright designed several houses on an equilateral triangular grid and each of these houses only has, and needs, three elevations. Any attempt to force these three elevations into the four orientation categories produces problems for the accuracy and efficacy of the approach. A different situation occurs if the house has more than four major exterior surfaces or planes at different angles. For example, Wright also designed several houses that were based on a paired trapezoidal grid that produced hexagonal plans. In these circumstances, it is generally possible to identify four cardinal elevations and usefully describe the dwelling in this way. However, for such houses some of the dominant planes or surfaces may appear in multiple views and may also never be seen from a perpendicular viewpoint. This situation doesn’t prohibit the application of this approach but it may reduce the accuracy of the results.

**Augmented Method**

Prior to commencing the computational method, new drawings were prepared of each of the 20 houses using consistent line weights, graphic styles and conventions. The majority of these drawings were traced from authorised reproductions of working drawings of the completed works. The orientation of each building was also noted if it was recorded on the drawings or alternatively it was deduced by other means (including the use of Google earth and photographic observations) if it was not noted in any publication. For two of the unbuilt houses by Gray orientation had to be assumed based on her photographic observations if it was not noted in any publication. For two of the unbuilt houses by Gray orientation had to be assumed based on her standard graphic conventions and typical approach to locating functional areas.

The augmented method for the fractal analysis of visual complexity in houses is as follows.

1. The elevations of each individual house are separately grouped together and considered as a set.
2. Each elevation is analysed using Archimage and Benoit programs producing, respectively, a $D_{(Arch)}$ and a $D_{(Benoit)}$ outcome.
3. The $D_{(Arch)}$ and $D_{(Benoit)}$ results for each elevation are averaged together to produce a separate $D_{(Elev)}$ result.
4. Each $D_{(Elev)}$ result is classified into one of four orientation categories (N, S, E, W).
5. The $D_{(Elev)}$ results for each house are averaged together to produce a composite result, $D_{(Comp)}$, for the house. The composite result is a single $D$ value that best approximates the characteristic visual complexity of the house.
6. Steps 1-5 are repeated for each house by each architect.
7. Each architects’ set of five, augmented results are charted to seek patterns in the relationship between façade characteristic complexity and orientation.

2. **FOUR ARCHITECTS, TWENTY HOUSES**

The five houses by Le Corbusier that are being analysed in the present research were completed between 1922 and 1928. Four of the five are in central France and the fifth in Germany. The houses are significant because during the 1920s Le Corbusier developed five strategies for an architecture that would reflect the technological and social advances of its era. Initially published in the journal *L’Esprit Nouveau* and later collated in *Vers Une Architecture*, these strategies (*pilotis, plan libre, façade libre, fenêtre en longueur et toît jardin*) are in their most refined form in the Villa Savoye (Figure 1). The first house, the Maison-atelier Ozenfant (1922-1923) in Paris, was designed as both a home and studio for the cubist painter Amédée Ozenfant. Set on a complex and steep corner site, in a dense urban area this three storey, white rendered masonry building has large glazing areas and a saw-tooth roof. The Villa Cook (1926) in Boulogne-sur-Seine, was described by Le Corbusier as a true cubic house because, as Gans observes, “[p]lan, section and elevation all derive from the same square and in reference to one another”(2000, 66). The house is a three storey structure of white rendered masonry with a roof garden. The Villa Stein/de Monzie (1926-1928) also known as "Les Terrasses", is set on a narrow block in the suburbs of Vaucresson. The unusual domestic brief was for a house and studio for Gabrielle de Monzie and her daughter, to be shared with Michael and Sarah Stein. In the late 1920s Le Corbusier and Pierre Jeanneret were invited to produce residential designs for the Second International Exposition of the *Deutscher Werkbund* at Stuttgart. The resulting Weissenhof-Siedlung Villa 13 (1927) is on a corner block in the outskirts of the city. Le Corbusier and Jeanneret designed Villa 13 as a prototype for suburban row housing. The Villa Savoye (1928) or “Les heures Claires” is sited in Poissy, France. This famous two storey, freestanding house in white rendered masonry, with extensive roof garden, is set in an open landscape.
The five houses by Eileen Gray were designed between 1926 and 1934 for sites in Southern France. Only two of the houses were completed although the unbuilt projects were documented in sufficient detail that they can be analysed. The first of these five designs, the unbuilt Small House for an Engineer (1926), is a split-level house and office design with a large ground floor that opens out into its gardens. Hecker observes of this house that the "upper floor [...] reveals itself astonishingly as an interpretation of Le Corbusier's five points for modern architecture" (1993:42). Gray's first built work, E.1027 (1929), is located in Roquebrune on the Côte d'Azur, France. This two storey house set in a steep hillside, is Gray’s best known work and, according to Constant and Wang, "[w]ith this house Gray proved her abilities internationally. At that time", they propose, "no other architect had produced anything comparable" (1996:unpag.). Featuring elongated, white concrete walls and overhangs, with steel balustrades and strip windows, Gray acknowledges the "maritime character of the house" and the influence of the nearby sea (Hecker 1993:60). The Four Storey House (c. mid 1930’s), an unbuilt project, is Gray’s largest building design and it has strong similarities to E.1027. The house plan includes a gallery and bar in a large internal void and, on the roof terrace, a gym, sunbathing terrace, shower and dressing room. Gray’s Tempe à Pailla (1934) in Castellar, is sited on a long, narrow, hillside block with distant views over the sea and mountains. Gray designed the house for her own residence, with rooms for her maid and chauffeur, as “a place of isolation and retreat” (Constant and Wang 1996:136). The fifth of Gray’s designs, the House for Two Sculptors (1934), features a dynamic, curved two storey studio intersecting with a single storey rectilinear residence (figure 2). The form of this design is described by Hecker as an “oval shape” that “is cut up into crescent-shaped parts, which are then displaced vertically, one against the other. Placed on pillars, a cylinder-shaped and very transparent volume is created” (1993:162).

The five houses by Peter Eisenman that are being considered were all designed between 1968 and 1976. All of the houses were destined for sites in the North East of the United States of America (Vermont, Connecticut and New Jersey). The houses comprise five of the first six designs completed by Eisenman; a set which has been described as owing a debt to Le Corbusier. The first design, House I (1968), was completed in Princeton, New Jersey. Designed for the Barenholtz family, Eisenman describes it as "an attempt to conceive of and understand the physical environment in a logically consistent manner, potentially independent of its function or its meaning" (qtd in Davidson 2006: 32). House II (1970), in Hardwick Vermont, was designed for the Falk family. The house is sited on the crest of a hill with views in three directions; it is timber-framed and clad in painted plywood panels. House III (1971) was designed for the Miller Family in Lakeville Connecticut (figure 3). Like Houses I and II, it is timber framed and clad, with a painted finish. The house has been described as an attempt to “produce a physical environment which could be generated by a limited set of formational and transformational rules” (Dobney 1995, 34). House III’s position in Eisenman’s formal vocabulary is associated with the introduction of the 45° angle in plan into an otherwise orthogonal
system. House IV (1971) marks a return to the planning strategies of Houses I and II. Designed for a site in Falls Village Connecticut, House IV is an elaborate investigation of the process of design transformation wherein various structural systems are allowed to trace solids and voids in the overlapping multi-level plan of the house. House IV is significant because the formal transformations occur in three dimensions; prior to this, the operations were essentially planar in nature. House VI (1976) was constructed in Cornwall, Connecticut, for the Frank Family. Designed as a weekend house on a small rural site, it features the first clear instance in Eisenman’s architecture wherein the trace of a form (its absence represented in a void) takes precedence over its presence (the form itself). In House VI Eisenman famously divided the master bedroom, and the bed itself, in two with the trace of a missing beam; effectively cutting a void through the floor and separating the married couple.

The five houses by Kazuyo Sejima were designed for dense, residential areas in Japan (three are in Tokyo) and they were completed between 1994 and 2003. Sejima is minimalist architect whose designs are widely regarded as examples of Late Modernism. The first design, the Y-House in Katsuraya (1994) is a three-storey, flat-roofed structure with two, almost fully glazed walls (figure 4). The S-House (1996) in Okayama, is a home for an extended family including two children and grandparents. The house is a small two-storey cubic volume with an external skin of clear corrugated polycarbonate sheeting on a timber frame. The S-House requires few openings in the façade as it draws light and air through the external skin. The elevations have no ornamentation, each appearing as a corrugated plane punctuated by small windows. The M-House (1997), in Shibuya, utilises a mixture of corrugated metal external cladding and transparent sheeting to suggest an internal space behind the bare walls. With a similar external appearance and materiality to the S-House the M-House appears to have no windows to the outside at all. The building is viewed from the roadside and only the street elevation is available for analysis. The Small House (2000) is located in Aoyama. It comprises a series of stacked, irregular concrete floor slabs, which are shaped to respond to the functional needs of the inhabitants, and which are sheathed by a lightweight, translucent façade. The final design, the Villa Cook (2003), has an external skin of steel panels with insulation and gypsum board, and structural steel walls internally. With white painted, steel walls, the house is covered on all elevations by thinly framed openings of seemingly random locations and sizes.

3. ANTICIPATED RESULTS

Because all of the 20 houses are in the Northern Hemisphere between the 40th and 50th lines of latitude, it might be assumed that a comparison between all four sets could be reasonable to construct. This isn’t necessarily the case as a range of factors including local context, local materials and design approach complicate the process. For this reason, before considering the results of the present research it is worth discussing for each architect the outcomes that a qualitative historical and theoretical study would anticipate.

The first two sets of houses, from Le Corbusier and Gray, were produced at around the same time, using the same construction methods and materials and are located in a similar geographic region (Constant and Wang 1996; Gans 2000). In eight of the ten cases there is a relatively consistent design approach demonstrated by the architects. The exceptions to this are Gray’s House for an Engineer and the House for two Sculptors; the former is underdeveloped in comparison with the rest of the designs and the latter is very different in character with its oval plan form. Eight of the houses by these architects are also on rural or outer-suburban sites which means that the designs are potentially relatively unaffected by adjacent buildings or nearby structures. The two exceptions are Le Corbusier’s Maison, Atelier Ozenfant and the Villa Cook. If these four exceptions are removed from the set, then the following result might be anticipated.

1. That there are some similarities between the results for the works of Le Corbusier and Gray in terms of the relationship between façade complexity and orientation.

The five houses by Eisenman are also typically on rural or outer-suburban sites and this should suggest that they too are shaped by their context. However, Eisenman’s design theory famously evolved between the design of the first and the last of these houses as he sought to create an architecture that was not directly shaped by either orientation or function (Davidson 2006). If Eisenman’s design theory and associated intentions are reflected in his design practice, then the following should be the outcome of the study.

2. For Eisenman’s early houses (I-II) the results should indicate variation in façade complexity for each orientation thereby suggesting that the environment had some influence on these works. For Eisenman’s later houses (IV-VI) there should be little or no differentiation between façade complexity based on orientation. This is because these houses were exercises in geometric formal composition and were designed without reference to the site.

All of Sejima’s houses are sited in dense urban streets often with only one possible access route or address. To further complicate matters Sejima has developed a design approach that relies on translucent or perforated facades and on seemingly random collections of small windows. Given this situation the following result would be anticipated.

3. In the case of Sejima’s five houses there is no pattern in the relationship between façade complexity and orientation.

4. ACTUAL RESULTS

The seven stage augmented method was applied to the 20 house designs producing 146 separate results which were combined into 73 $D_{Elev}$ results for the elevations (blank, hidden or party walls were not counted and are marked with an asterisk) and 20 $D_{Comp}$ results were derived from this data (see table 1). $D_{Elev}$ results are typically recorded to three decimal places although the averaging process can sometimes generate a fourth decimal place. For each architect, a graph was then prepared showing the relationship between the characteristic visual complexity of the façade (the $D_{Elev}$ results) and its orientation (see figures 5-8). To test the first of the anticipated outcomes, a separate graph with the six projects from Le Corbusier and Gray was also prepared (Figure 9).
Table 1: Fractal dimension results, clustered by orientation, for 20 houses.

<table>
<thead>
<tr>
<th>Architect</th>
<th>House</th>
<th>North $D_{\text{Elev}}$</th>
<th>South $D_{\text{Elev}}$</th>
<th>East $D_{\text{Elev}}$</th>
<th>West $D_{\text{Elev}}$</th>
<th>$D_{\text{comp}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Le Corbusier</td>
<td>Maison/Atelier Ozenfant</td>
<td>1.515</td>
<td>1.4375</td>
<td>1.5405</td>
<td>*</td>
<td>1.498</td>
</tr>
<tr>
<td></td>
<td>Villa Cook</td>
<td>1.542</td>
<td>1.4395</td>
<td>*</td>
<td>*</td>
<td>1.491</td>
</tr>
<tr>
<td></td>
<td>Stein/De Monzie</td>
<td>1.5165</td>
<td>1.632</td>
<td>1.491</td>
<td>1.4275</td>
<td>1.514</td>
</tr>
<tr>
<td></td>
<td>Weissenhof-Seidlung</td>
<td>1.4835</td>
<td>1.5305</td>
<td>1.412</td>
<td>1.2415</td>
<td>1.417</td>
</tr>
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<td></td>
<td>Villa Savoy</td>
<td>1.512</td>
<td>1.5175</td>
<td>1.4655</td>
<td>1.450</td>
<td>1.491</td>
</tr>
<tr>
<td>Eileen Gray</td>
<td>House for an Engineer</td>
<td>1.347</td>
<td>*</td>
<td>1.292</td>
<td>1.231</td>
<td>1.262</td>
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<tr>
<td></td>
<td>E 1027</td>
<td>1.400</td>
<td>1.535</td>
<td>1.466</td>
<td>1.456</td>
<td>1.464</td>
</tr>
<tr>
<td></td>
<td>House for two Sculptors</td>
<td>1.432</td>
<td>1.377</td>
<td>1.423</td>
<td>1.470</td>
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</tr>
<tr>
<td></td>
<td>Tempe a Pailla</td>
<td>1.290</td>
<td>1.429</td>
<td>1.401</td>
<td>1.393</td>
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<td></td>
<td>Four Storey Villa</td>
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<td>1.373</td>
<td>1.391</td>
<td>1.285</td>
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</tr>
<tr>
<td>Peter Eisenman</td>
<td>House I</td>
<td>1.335</td>
<td>1.355</td>
<td>1.424</td>
<td>1.296</td>
<td>1.352</td>
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<tr>
<td></td>
<td>House II</td>
<td>1.225</td>
<td>1.491</td>
<td>1.527</td>
<td>1.498</td>
<td>1.436</td>
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<td></td>
<td>House III</td>
<td>1.594</td>
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<td>House IV</td>
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<td>House VI</td>
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<td>1.4175</td>
<td>1.409</td>
<td>1.427</td>
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<td>Kazuyo Sejima</td>
<td>Y-House</td>
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<td>1.560</td>
<td>1.316</td>
<td>1.222</td>
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<td>S-House</td>
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<td>1.097</td>
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<td>1.192</td>
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<tr>
<td></td>
<td>M-House</td>
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<td>*</td>
<td>1.309</td>
<td>*</td>
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<tr>
<td></td>
<td>Small House</td>
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<td>1.453</td>
<td>1.573</td>
<td>1.323</td>
<td>1.451</td>
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<tr>
<td></td>
<td>House in a Plum Grove</td>
<td>1.670</td>
<td>1.272</td>
<td>1.222</td>
<td>1.112</td>
<td>1.319</td>
</tr>
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Figure 5. Fractal dimension results, clustered by orientation, for five houses by Le Corbusier.

Figure 6. Fractal dimension results, clustered by orientation, for five houses by Gray.
Figure 7: \( D \) results, clustered by orientation, for five houses by Eisenman.

Figure 8: \( D \) results, clustered by orientation, for five houses by Sejima.

Figure 9: \( D \) results, clustered by orientation, for three houses each by Le Corbusier and Gray.
5. DISCUSSION
The anticipated outcomes are reviewed hereafter in light of the actual results.

1. The first of the anticipated results was that the six houses by Le Corbusier and Gray, which have both common siting and design strategies, should display broad similarities in the relationship they exhibit between orientation and façade complexity. When these six houses are graphed (see figure 9) a pattern is apparent wherein the Southern façade is typically amongst the most complex (because it is covered in windows and balconies to capture the light) and the Western façade is generally the least complex and has little modulation and only limited openings. While one of the houses, the Villa Savoye, partially resists this trend, the other houses follow a similar pattern.

2. The second anticipated outcome was that Eisenman’s early houses (I and II) would show some variation in façade complexity based on orientation and that his later houses (IV and VI) would ignore orientation altogether because they are focussed on developing a formal language which is not site specific. Figure 7 shows that the façade complexity in Houses I and II does vary with orientation. In both cases the East elevations are the most complex and the North elevation amongst the least complex. In Figure 7, Houses IV and VI display almost no variation in façade complexity as a result of orientation.

3. The third proposition was that there would be no clear pattern of results in the houses of Sejima because almost all of her designs are shaped by micro-environmental or local factors. Figure 8 shows that despite some superficial similarities between pairs of results (for example, the Y-House and S-House) the five designs do not share a common relationship between façade complexity and orientation.

In each of these three results, the augmented computational method broadly supports the anticipated findings.

CONCLUSION
The present paper demonstrates that it is possible to augment the data that has been derived from the computational fractal method and then to cluster it using categories that are appropriate for architectural analysis. This capacity has not previously been established in any research.

In terms of the specific Modernist houses which are analysed in the work; the paper concludes that the early works, when not otherwise influenced by local conditions, do broadly respond to orientation showing a clear correlation in façade complexity. Conversely, the recent modernist houses typically do not respond to orientation in any consistent way either being shaped by local conditions (Sejima) or largely ignoring the impact of orientation (Eisenman).

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