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A Quantitative Comparison between the Formal Complexity of Le Corbusier's Pre-Modern (1905-1912) and Early Modern (1922-1928) Architecture

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Abstract: Architectural historians are divided over the question of whether or not Le Corbusier's early, Arts and Crafts (or Art Nouveau) style chalet designs are formally related to his later, more famous, designs for Modernist villas. While there are multiple stylistic differences between Le Corbusier's early and later works, the question remains, are the houses really so different in terms of their formal complexity? The present paper uses computational means to mathematically answer this question for the first time. Recent research has shown that computational methods can be used to determine a series of quantitative results for the visual complexity of five of Le Corbusier's Modernist houses (completed between 1922 and 1928). In this paper five of Le Corbusier's early, pre-Modern house designs (completed between 1905 and 1912) are analysed using the same computational method. With these two sets of data available for testing, a detailed comparison of the mathematical difference between the works is constructed. Ultimately, this paper concludes that there are strong correlations between the formal complexity and design strategies found in these ten canonical works.

Keywords: Computational Analysis, Visual Complexity, Le Corbusier, Design Assessment

Introduction

WHILE MANY ARCHITECTS and scholars will know that Le Corbusier produced various designs before developing his famous, white, Modernist aesthetic, few will be aware of how seemingly different these early designs were in appearance. Le Corbusier began his architectural career as Charles-Edouard Jeanneret, designing decorative Swiss-chalet style homes in his local village, Le Chaux-de-Fonds. Architectural historians have offered various comparisons between these very different periods in Le Corbusier's career debating the formal differences between his early Arts and Crafts or Art Nouveau designs and his later Modern works. For example, Geoffrey Baker argues that the early houses "had a charm and innocence far removed from the mature abstractions of later years" (1996b: 52). In contrast, Jencks (2000) suggests that upon closer inspection these early works are clear formal precursors to Le Corbusier's first Modernist houses. However, despite detailed descriptions of these early works by Baker (1987; 1996a; 1996b), Jencks (2000), Weber (2008) and von Moos (1979) there is still a difference of opinion about the degree to which Le Corbusier's design approach changed between the years of 1912 and 1922 (see figure 1).

Figure 1: Le Corbusier: The Villa Stotzer (1907) (Left) and The Villa Savoye (1928)

One method for determining the mathematical difference between these two approaches to design uses non-linear mathematics to quantify characteristic visual complexity in architectural façade designs. This computational technique relies on fractal analysis software that can automate the process of analysing buildings and thereby assist researchers studying historical designs. The present research uses this method to undertake a comprehensive analysis of Le Corbusier's first five house designs (1905-1912). The fractal dimensions of the elevations and plans of these houses are calculated using TruSoft's *Benoit* (vers. 1.3.1) program and *Archimage* (vers. 2.1), a program developed by the authors. The computational method used for the analysis relies on an automated process of detecting façade detail at various scales within architectural elevations. This detail is processed using a range of algorithms to produce a determination of characteristic visual complexity. This method is useful because in architecture there are only a limited range of quantifiable approaches to the analysis of the visual qualities of buildings. In the past this method has been used to test the visual complexity of a range of historic and modern building designs, but it has never been previously used to analyse how an individual architect's approach to design has changed over time.

This paper commences with an overview of Le Corbusier's early designs. Thereafter, the paper provides a description of the method it adopts for the analysis of historical buildings and describes how the present study was undertaken. The paper then presents the results and provides an analysis of these results, investigating Le Corbusier's design methodology and establishing a comparative review between his pre-Modern and early Modern architecture. Finally, the paper concludes with several significant insights into Le Corbusier's architecture and its historical interpretation, as well as proposing further uses for this method of quantitative analysis of architecture.

Le Corbusier's Work from 1905-1914

Le Corbusier began his formal training in design at the Art School of his home town in Switzerland, Le Chaux-de-Fonds. Under the tutelage of Charles L'Eplattenier, students of the school worked to develop a style to match their local Jura region. After carefully studying natural forms, "they attempt[ed] to make the structural laws of nature visible and to express them in clear and universal geometric patterns" (von Moos, 1979: 4). Initially, Le Corbusier studied art courses at the school until L'Eplattenier declared "[y]ou will be an architect" (von Moos, 1979: 6) and in 1905, as a part of the school's unusual method of art education, L'Eplattenier set a real architectural design project for the seventeen year old Le Corbusier.

From this beginning Le Corbusier designed and helped to construct a total of four houses in Pouillerel; a small enclave on a hillside on the outskirts of Le Chaux-de-Fonds. Charles Jencks describes the collection of houses there as “Arts and Crafts villas” which, at a “ cursory glance [...] might be average Swiss chalets, but on further inspection they reveal a nobility and personality that go beyond stereotype” (2000: 19-20).

The first of Le Corbusier’s projects was the Villa Fallet (1905). This family home was designed for Louis Fallet, who was employed as a member of the Art School board. Fallet and the local architect René Chapallaz oversaw Le Corbusier’s work. The ornate chalet represents “a synthesis of Art Nouveau and the typical regional style of Jura”(Le Corbusier, *et al.*, 1987: 128); a style which Stanislaus von Moos describes as “a conglomerate of ideas distilled from L’Eplattenier’s Cours Supérieur, executed with enormous care, yet controlled by taste”(1979: 7). The Villa Fallet is often viewed as a progression of materials representing the geology and ecology of the local area. The stone base of the building is described by Baker as “heavily rusticated masonry, giving a strong effect of pattern and texture” in contrast the “[w]indows and door-frames [...] were framed of dressed stone [...] being chiselled to produce a textured surface [...] resembling Jeanneret’s geological sketches” (1996b: 52). The upper stories are clad in a decoratively carved, stucco-faced timber which, along with other parts of the house, were hand crafted by Le Corbusier and his fellow students. The tall, sloping roof has exposed carved timber supports and it is clad in dark tiles. Charles Jencks proposes that the house represents a cross section through the surrounding landscape. “Its base of heavy rusticated limestone blocks represents bedrock. [...] Then above these two layers of geology springs life, above all the pine tree” (2000: 31-32). Le Corbusier later reflected that the Villa Fallet is “in all likelihood horrible, but [...] free of any kind of architectural routine” (Boesiger, 1995: 11). The house still stands today outside Le Chaux-de-Fonds and the only significant change is an extension to the South-West corner of the terrace.

In 1907 Le Corbusier travelled across Europe, studying art and architecture. While in Vienna he designed the Villa Jaquemmet and the Villa Stotzer for additional sites in Pouillerel. René Chapallaz again provided assistance to Le Corbusier by overseeing the building work. Von Moos describes the two villas as “larger variations of the Fallet theme” yet “less pedantic in their decorative detailing” (1979: 9). The Villa Stotzer (1907) was designed for Albert Stotzer-Fallet and, according to Baltanas, it “displays the early signs of a reassessment of the historicist idiom” (2005: 19). The Villa Jaquemmet (1907) was designed for Jules Jaquemmet-Fallet and has similar planning and appearance to the Villa Stotzer. Both villas share a similar brief that required that the designs appear as single houses from the street, but actually contain two separate apartments. The initial designs for both houses were more ornate than the final buildings, with financial restrictions forcing Le Corbusier to remove much of the planned ornament. The end result is, as Jencks observes, a “premonition” of Le Corbusier’s future design approach with its “horizontal band of windows” (2000: 37).

After working in Germany for Peter Behrens and travelling further in Europe and through Greece and Turkey in 1911, Le Corbusier returned to a teaching position at his former school in La Chaux-de-Fonds. Von Moos reports that at this time Le Corbusier was offered “a series of interesting commissions that allowed him to inaugurate what one might call the second pre-Corbusian phase of his early work. It is characterised by a shift away from Art Nouveau toward a neoclassicism of German origin” (1979: 17). In 1912, Le Corbusier designed the Villa Jeanneret-Perret for his parents. Located near his other Pouillerel buildings in La Chaux-de-Fonds this two storey family home has large exposed windows in its plain white stucco

walls and a dark tiled roof that lacks the dramatic pitched form of the other houses. Jencks writes that “[i]nstead of local traditional forms and materials in the Swiss chalet image, we now have a formal composition with cubic and cylindrical volumes” (2000: 195).

In the same year, Le Corbusier designed the Villa Favre-Jacot (1912), a large family home situated in the nearby town of Le Locle. The house was for Georges Favre-Jacot, a founder of the Zenith Watch Company, with a brief “to construct a villa which would enable him to overlook his factories and the railway as well as his rural territory” (Le Corbusier, *et al.*, 1987: 126). This house, like the Villa Jeanneret-Perret, appears to be an exploration of Le Corbusier’s new thoughts in architecture. With similarities in size and form to the other houses from this period, and particularly with the Villa Jeanneret-Perret, the Villa Favre-Jacot has mostly plain white stucco walls, with a dark tiled roof displaying a form that continues Le Corbusier’s departure from the chalet-roof shape, presenting an even lower pitch than that of the Villa Jeanneret-Perret. Baker argues that the “architectural language” that Le Corbusier uses in this work is “more literally classical than that of the Villa Jeanneret-Perret” (1996b: 208). The external ornamentation that was so significant for the first three houses is, in the last two villas, much reduced and “[a] closer inspection of the decorative details reveals an updated, classicized version of the earlier Jura flora and fauna imagery” (von Moos, 1979: 17).

After a small amount of experimentation with structural concrete, in 1914 Le Corbusier produced the maison Dom-ino design; essentially a concrete skeletal frame. Jencks postulates that this purity of design may have derived from the revisions Le Corbusier was required to undertake on many of the early Villas, as the reality of such detailed, ornate design, came at great financial cost (2000: 36-37). Finally, in the early 1920’s Le Corbusier developed the 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* and *toît jardin*) are found in their most refined form in the Villa Savoye.

Analysis of Historical Buildings

The two periods of Le Corbusier’s early career appear in stark contrast when his works are considered for the first time. But exactly how visually different are they? Fractal analysis is rare method which has been employed on multiple occasions to examine historical buildings (Burkle-Elizondo and Valdez-Cepeda, 2006; Ostwald, Vaughan Tucker, 2008; Ostwald, Vaughan, Chalup, 2008; Vaughan, Ostwald 2008). Bovill’s (1996) method in particular, has been widely used even though it has only recently begun to be sufficiently refined for widespread application (Lorenz, 2003). Developed by Carl Bovill, this approach is an application of the scientist Benoit Mandelbrot’s box-counting technique, which demonstrates a method for determining the approximate fractal dimension, or characteristic visual complexity, of architectural plans and elevations. This paper uses a computational variation of the method developed in these previous works (essentially a refinement of Bovill’s method) to provide a mathematical comparison between five of Le Corbusier’s pre-Modern works, and five of his early Modern works.

Box-Counting

The box-counting approach is one method for determining the approximate fractal dimension of an image; it works as follows. Consider a drawing of an elevation of a house. A large grid is placed over the drawing and each square in the grid is analysed to determine whether any lines from the façade are present in each 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; Lorenz, 2003). 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 and refine this operation.

There are many variations of the box-counting approach that respond to known deficiencies in the method. These issues include preparation of the original image for analysis, with regard for the volume of empty space, the proportion of the image and the thickness of the lines. Other reasons for problematic results derive from elements of the method including the scaling coefficient, and the statistical divergence in the log-log graphs. Past research has described how the computational method responds to each issue (Foroutan-Pour, Dutilleul, Smith 1999; Lorenz, 2003; Ostwald, Vaughan, Tucker 2008).

Analytical Method

For the present paper, new drawings with consistent graphic conventions and scale were prepared for each of the five pre-Modern houses. The lines in each drawing typically record changes in form, not changes in surface or texture. Thus, major window reveals, thickened concrete edge beams and railings are all drawn, while the cracks in stone blocks and the patterns embedded in the stucco textures are not. In all five cases four elevations were produced for testing. The definitive set of drawings of Le Corbusier's work developed by the University of Tokyo was adopted as the source for all images (Ando, 2001).

The standard method for the fractal analysis of visual complexity in houses involves analysing the redrawn images with two fractal dimension calculators, *Benoit* and *Archimage*; each of which produces an estimate of the fractal dimension, or D , of the image. The $D_{(Archi)}$ and $D_{(Benoit)}$ results that are produced for the elevation views are then averaged together to produce a separate $D_{(Elev)}$ result for each program for the house. Past research suggests that $D_{(Elev)}$ results tend to be relatively tightly clustered leading to a high degree of consistency. Next, the $D_{(Elev)}$ results produced by *Archimage* and *Benoit* 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 (see table 1).

As a simple explanation for how D results can be read, a house with an almost blank wall would produce a D result that approaches 1.0. A house that is richly decorated, and has an excess of form (which could include ornament and decoration), would hypothetically have a result that approaches 2.0. In practice though, because most houses require windows, doors and roofs, D results tend to be clustered between 1.2 (being a relatively plain façade) and 1.5 (being a complex façade).

Table 1: Abbreviations and Definitions

Abbreviation	Meaning
D	Approximate Fractal Dimension.
$D_{(Archi)}$	D calculated using <i>Archimage</i> software
$D_{(Benoit)}$	D calculated using <i>Benoit</i> software.
$D_{(Elev)}$	Average D for a set of elevation views of a house using a specified program.
$D_{(Comp)}$	Composite D result (averaged from both <i>Archimage</i> and <i>Benoit</i> outcomes for all elevations) is a measure of the average characteristic visual complexity of the house (or average fractal dimension for the 2D visual qualities of the design).

Results

Results for the Five Houses 1905-1912

Composite results from the fractal dimension calculations of Le Corbusier's early houses show a close range of D values of between 1.458 and 1.584 (see table 2). This result places the five houses 1905-1912 within a similar scale of visual complexity (a range of only $D = 0.126$). Intuitively, this supports the understanding that these years were a distinct stylistic period of Le Corbusier's oeuvre.

In 1996, Baker published two volumes on Le Corbusier's work. The first, *Le Corbusier: an Analysis of Form* undertakes a detailed diagrammatic analysis of several of Le Corbusier's key buildings while the second, *Le Corbusier: the Creative Search* explores primary sources to analyse his approach to design issues. These two volumes will be referred to throughout this analysis as they represent a thorough historical qualitative analysis of the architecture which the quantitative results can be compared to.

Discussing the Villa Fallet, Baker suggests that Le Corbusier's "ability to compose in an elaborate and dramatic manner is evident from the very first" and further that the Villa Fallet conveys "dramatic impact" (1996b: 117). This description by Baker is confirmed by the relatively high D results for this house ($D_{(comp)} = 1.482$). The exposed timbers, ornate style and individual façade treatment of the Villa Fallet produce this level of visual complexity.

The Villas Jaquemets and Stotzer share a similar design brief and also share a similar fractal result. Baker's claim, that "the major difference between the two houses is the intensification of linearity in the Stotzer house and its reduction in the Jaquemet" (1996b: 116) is reflected in the results. With a $D_{(comp)}$ value of 1.466, the Villa Stotzer has slightly higher visual complexity than the Villa Jaquemet ($D_{(comp)} = 1.458$). For both of these houses, the south elevation is the most visually complex of the elevations. The south elevation for the villa Stotzer has a $D_{(Elev, Archi)} = 1.599$ and $D_{(Elev, Benoit)} = 1.504$ and the south elevation of the Villa Jaquemet resulting in $D_{(Elev, Archi)} = 1.636$ and $D_{(Elev, Benoit)} = 1.541$. For both houses the east and west elevations are almost mirror images, which is reflected in the almost identical D results where the east and west elevations for the Villa Stotzer are $D_{(Elev, Archi)} = 1.486$ and 1.487 and for the Villa Jaquemet they are both $D_{(Elev, Archi)} = 1.403$ and 1.402 respectively. These results match Baker's description of these two houses having "a distinct front, back and sides" (1996 a: 41).

The group of five houses analysed in this study can be further broken into two sets. With the first three villas (Fallet, Jaquemet, Stotzer) producing lower composite results of the five ($1.458 < D < 1.482$), and the later villas Jeanneret-Perret and Favre-Jacot producing the highest composite fractal dimensions ($D = 1.489$ and 1.584 respectively). The Fallet, Stotzer and Jaquemet houses, according to Baker, share an essential quality where “their massing is very powerful indeed” and the “surface and structure, and the vigour of the forms, their impact on the observer, the rapport with the site, and emphasis given to selected parts of the design, all foreshadow Le Corbusier’s later work” (1996b: 56). Of the Villas Jeanneret-Perret and Favre-Jacot, Baker remarks that these “two houses that Jeanneret designed in 1912 mark a turning point in his career” (1996b: 209). After returning from his second journey of discovery, Le Corbusier’s stylistic adaptation is reflected in the higher D results for these two buildings. Although the exterior detailing is simplified in the Villa Jeanneret-Perret, the increasing complexity in Le Corbusier’s planning at this time results in a building with more formal complexity. Le Corbusier was also experimenting with larger windows which are appropriate for a grander building. The greater number of windows in all elevations of the Villa Jeanneret-Perret contributes to its consistently high fractal dimension results ($1.474 < D_{(Archi)} < 1.589$ and $1.388 < D_{(Benoit)} < 1.521$).

The Villa Favre-Jacot was Le Corbusier’s last built work before his dramatic change in style in 1914. Although designed in the same year as the Villa Jeanneret-Perret, the Villa Favre-Jacot has a higher D value and it has the highest overall fractal dimension result of all the five houses 1905-1912 ($D_{(comp)} = 1.584$). More than the Villa Jeanneret-Perret, the Villa Favre-Jacot has the most complicated planning resulting in elevations with advancing and reducing planes, curved walls, complicated fenestration and classical columns throughout which is also revealed in the high D values for all of the elevations of this house. ($1.561 < D_{(Archi)} < 1.634$ and $1.489 < D_{(Benoit)} < 1.618$).

Table 2: D Results for the Five Houses 1905-1912

	Elevations analysed with <i>Archimage</i>				Elevations analysed with <i>Benoit</i>				
Villa	$D_{(Elev)} N$	$D_{(Elev)} S$	$D_{(Elev)} E$	$D_{(Elev)} W$	$D_{(Elev)} N$	$D_{(Elev)} S$	$D_{(Elev)} E$	$D_{(Elev)} W$	$D_{(Comp)}$
Fallet	1.540	1.597	1.463	1.503	1.450	1.528	1.373	1.400	1.482
Jaquemet	1.560	1.636	1.403	1.402	1.476	1.541	1.330	1.311	1.458
Stotzer	1.481	1.599	1.487	1.486	1.400	1.504	1.384	1.382	1.466
Jeanneret-Perret	1.474	1.558	1.503	1.589	1.388	1.460	1.419	1.521	1.489
Favre-Jacot	1.561	1.612	1.634	1.615	1.489	1.618	1.591	1.549	1.584

Analysis of Le Corbusier’s Designs

Fractal analysis allows further design investigation of historical buildings. By separating key design elements of the houses analysed, trends in Le Corbusier’s design methodology emerge. Consistently for the five houses, several key elements are revealed in the façades.

These elements can be analysed under three headings; view sunlight and terrace, and entry façade and street façade.

By observing the best view from the houses, even today, it is clear that Le Corbusier sited and oriented the houses to take advantage of an outlook which encompasses an expanse of natural or vegetated landscape. Typically, one particular façade is designed to maximize this view, with strategic windows often framing or opening out to this particular direction. For all five houses 1905-1912, this view orientation coincides with the south elevation. The south façade also has day-long sunshine and Le Corbusier's orientation of the view to the south for all five houses maximizes the amount of sunlight available due to the open outlook. Each villa also has a large terrace which is integral to the south elevation. This suggests that Le Corbusier was incorporating large outdoor living areas as an important homogeneous design element long before the *toit jardin* of his five strategies for a Modern architecture.

The second category that can be graphically analysed involves the characteristic complexity of the façade that contains the main, public entry. The front door faces north for the Villa Stotzer and Jaquemet, to the west for the Villa Fallet and Jeanneret-Perret, and east for the Villa Favre-Jacot.

The final category for analysis is the relative complexity of the elevation that faces the street. The entry and the street façades coincide for the villas Fallet, Stotzer and Jaquemet.

Figure 2: Comparison of D for Different Design Elements of Villas 1905-1912

When these different design elements are graphed to show the fractal dimension of each element for each house, clear patterns emerge (see Figure 2). It can be seen that for all the villas, the south elevation serves several purposes; it is oriented to the sunlight, frames the primary view and contains the terrace. For the first three houses Fallet, Stotzer and Jaquemet, this façade has the highest visual complexity of all the elevations (see figure 3). For these three houses also, the entry is from the street, and the street/entry elevation has a fractal dimension which is consistently lower than the south/view/terrace elevation.

Figure 3: South Elevation of Villas Fallet ($D=1.597$), Stotzer ($D=1.599$) and Jaquemet ($D=1.636$)

The results for the Villa Jeanneret-Perret and Favre-Jacot differ once again from the other three, reiterating previous scholarly groupings of these houses (Baker 1996a). For these two houses, the south/view/terrace elevation is consistently lower than the entry elevation and it is the entry façade which has the highest fractal dimension of all elevations (see figure 4). These results suggest a change in Le Corbusier's design methodology, developing from a focus on the experience of being within a house to a house which is equally designed to be viewed and experienced by an external observer. The linear motion of these graphs further indicates a difference in visual complexity and formal arrangement for these houses.

Figure 4: Entry Façade for Villas Jeanneret-Perret ($D= 1.589$) and Favre-Jacot ($D= 1.634$)

The emerging relationship between the most visually complex house façade and a specific design element supports Baker's notion of Le Corbusier designing a priority façade for each villa. Baker suggests that Le Corbusier treats the southern elevation of the first four houses as his "*tour de force* of the composition, [...] using a symmetrical format to gain maximum effect and authority" (1996b: 201), and specifically of the Villa Jeanneret-Perret, Baker proposes that Le Corbusier "modifies the cube accordingly, giving priority to the south elevation" (1996b: 196). Baker's argument is supported by the fractal dimensions for the southern elevations of the first three villas; and it could be said the elevation with the highest fractal dimension is the primary elevation, however, for the Villa Jeanneret-Perret the west (entry) elevation has the highest D value (1.589) while the southern has the second highest ($D = 1.558$).

Results for Pre-modern and Early Modern Houses Compared

The results of this analysis of Le Corbusier’s pre-Modern architecture are surprising when compared to his later, Modern work. Previous fractal dimension calculations have been undertaken on five houses from Le Corbusier’s early Modern period (see Table 3 for the $D_{(comp)}$ results). These houses were constructed during the period of 1922 (Maison-Atelier Ozenfant) to 1928 (Villa Savoye), when “Le Corbusier pioneered the flat-roofed ‘white architecture’ that became synonymous with international Modernism” (Fletcher, 1996: 1329). The five pre-Modern houses are the Maison-Atelier Ozenfant (Paris, 1922), the Villa Cook (Boulogne-sur-Seine, 1926), The Villa Stein/De Monzie (Vaucresson, 1926), the Villa Weissenhof-Siedlung 13 (Stuttgart, 1927) and the Villa Savoye (Poissy, 1928). It would be expected that the ornate, highly decorative pre-Modern house designs of Le Corbusier would have a much higher fractal dimension than his later, Modernist works. However, apart from the Villa Favre-Jacot, which has the highest D result of all the Le Corbusier houses analysed, it would appear from the results that the early works are typically no more complex than the 1920’s houses (see figure 5). From the results it can be seen that all of the ten houses analysed fall into a similar range $1.420 < D_{(Comp)} < 1.584$ and the majority of all houses cluster around a tight range of $1.466 < D_{(Comp)} < 1.584$.

Table 3: $D_{(Comp)}$ Values for all Le Corbusier Houses Analysed

Villas (1905-1912)	$D_{(comp)}$	Villas (1922-1928)	$D_{(comp)}$
Fallet	1.482	Ozenfant	1.495
Jaquemet	1.458	Cook	1.495
Stotzer	1.466	Stein/ De Monzie	1.515
Jeanneret-Perret	1.489	Weissenhof. S.	1.420
Favre-Jacot	1.584	Savoye	1.480

Figure 5: East Façade of the Villa Stein/De Monzie ($D_{(comp)}= 1.515$) and the South Façade of the Villa Weissenhof-Siedlung 13 ($D_{(comp)}= 1.420$)

However, if the results for the individual elevations of the villas 1922-1928 are plotted for their design elements, the resulting graph produces a different picture to that for the early houses (see figure 6). For these early Modern houses, the south elevation does not share its purpose with any other element in particular; however, it is the elevation with the highest

fractal dimension for the last three houses of the set (Weissenhof, Stein/De Monzie and Savoye). The elevations containing the entry are of a similar visual complexity for all buildings ($1.53 < D_{\text{(Elev, Archi)}} < 1.57$) and have the highest visual complexity for the houses Ozenfant and Cook.

Figure 6: Comparison of D for Different Design Elements of Villas 1905-1912

Conclusion

The present analysis offers, for the first time, a mathematical solution to the debate about the degree of apparent similarity or difference observed between Le Corbusier's pre-Modern and Modern houses. Le Corbusier's early chalet-style designs were essentially decorated boxes, while his later Modern houses were modelled to express their internal spaces and functions. Ironically, the end result of these quite different approaches to design was to produce an architecture that has a relatively consistent degree of visual complexity. This can be seen when comparing the early, decoratively styled Villa Fallet and the Modern, streamlined design of the Maison-Atelier Ozenfant. The composite result for these two buildings is very close $D_{\text{(comp)}} = 1.482$ (Fallet) and $D_{\text{(comp)}} = 1.495$ (Ozenfant), and several of the individual elevations produce even closer results, for example the north façade of the Villa Fallet ($D = 1.540$) and north façade of the Maison-Atelier Ozenfant ($D = 1.550$) (see figure 7).

This shifting visual impact of the decoration and the formal modelling is one possible explanation for the reason why some scholars have observed a degree of consistency in the works, while others see differences. Mathematically, the ten houses have a high degree of consistency in their visual complexity, but different approaches produce this result in the two sets of houses.

A further outcome of the present research is that it uncovers several underlying patterns in the two sets of house designs. Le Corbusier's early chalet-style houses have very strong similarities in how they are placed on their sites, how they approach dominant views, address from the road and the entry façade. In contrast, the early Modern works are far less consistent across most of these design elements, only the street façades of the five later houses have a degree of similarity. This finding could have significant uses for analysis of the work of any architect, and will be the subject of further detailed research by the authors.

Finally, the consistency of these quantitative results for each house when compared to previous qualitative analysis continues to support the development of this method. The results for the two different historical periods in Le Corbusier's oeuvre provide the initial groundwork to support further analysis of different styles or periods in the career of an architect generally.

Figure 7: North Façade of the Villa Fallet ($D=1.540$) and North Façade of the Maison-Atelier Ozenfant ($D=1.550$)

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