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This paper analyses Christopher Alexander's concept of 'wholeness' using the domestic architecture of Le Corbusier and Frank Lloyd Wright.

Quantifying Christopher Alexander's 'wholeness' in *A Pattern Language*

Michael J. Dawes and Michael J. Ostwald

Christopher Alexander is a notorious critic of the alleged inability of modern architecture to equal the environmental qualities of traditional design, and has devoted the majority of his career to rectifying these failings. Alexander's solutions to these issues are presented in a theory developed over three distinct stages, each of which is sufficiently conceptually differentiated and self-contained to be considered a theory in their own right. The first is contained in Alexander's doctoral dissertation, *Notes on the Synthesis of Form*, and it relies heavily on mathematical and computational models.[1] His second theory replaced the computational core of its predecessor with a series of predefined patterns of design forces that may be combined into larger wholes. This theory is documented in three canonical texts, *The Oregon Experiment*, *A Pattern Language*, and *The Timeless Way of Building.*[2] Alexander's third theory, which is presented in the four-volume *The Nature of Order*, concentrates on the concepts of centres and geometric transformations.[3] While all of these texts should be understood as stages in a potentially cohesive, extensive, and evolving theory of wholeness, the focus of the present paper is limited to testing and quantifying the concept of wholeness, as detailed within the context of Alexander's second theory of architecture. This is done by developing two quantitative measures of wholeness, which are then tested using the occurrence of Alexander's patterns in designs by Frank Lloyd Wright and Le Corbusier. This is, in essence, a test of the consistency of the claims in Alexander's second theory of architecture, rather than of the properties of the two architect's works.

A Pattern Language, a book that is believed to be the most widely read architectural treatise ever published, is also both extensively criticised and poorly understood.[4] The central proposition in Alexander's second theory is that some environments are objectively superior to others because they exhibit greater degrees of wholeness. This wholeness emerges from the careful synthesis of 253 canonical patterns that encapsulate design forces by following over 18,000 inter-pattern dependencies that form the structure of the language, in addition to non-canonical patterns developed by, and shared among, other users of the language. When the forces described within a pattern are harmoniously balanced, it gains an inherent degree of life; meanwhile, unbalanced forces result in lifeless or dead patterns. In Alexander's theory, the greater the number of balanced and complementary patterns that are present in an environment, the more whole it is. Conversely, unbalanced forces created by dead patterns will impact, infect, and destabilise adjacent living patterns and thereby undermine the wholeness of a design or environment.

Alexander claims that traditional or vernacular design arises through a slow and organic process of adaptation to changing conditions and results in buildings containing a large number of living patterns and, consequently, greater wholeness. In contrast, modern architecture arises from the combination of mass-produced and standardised materials, coupled with an image-driven culture that creates buildings containing fewer living patterns and more unbalanced ones. However, support for Alexander's assertion that superior buildings contain patterns of greater quantity and quality is often limited to poetic descriptions of idyllic situations. In response to this limited evidence, the current research develops a method for calculating wholeness, *using Alexander's pattern language as a basis*, and drawing inspiration from four precedent approaches to quantifying this property. This new method is then demonstrated by measuring the degree of wholeness in fourteen early Modernist villas; seven Prairie-style villas designed by Frank Lloyd Wright, which are aligned with Alexander's descriptions of wholeness, and seven 1920s Modernist villas by Le Corbusier, which have characteristics that recall Alexander's descriptions of architecture that lacks wholeness. If Alexander's second theory is coherent and consistent, then Wright's architecture should exhibit a much higher level of wholeness than Le Corbusier's architecture.

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Before progressing, it is important to note that this comparative study of wholeness will only determine whether Alexander's arguments in his second theory – focused on *A Pattern Language* – are consistent with, or supported by, the content of his pattern language in the context of the selected fourteen famous residences. Further limitations to the method and its findings are presented and discussed in each section.

Defining and measuring wholeness

Any attempt to quantify wholeness in the context of Alexander's second theory of architecture will encounter the problem that he did not provide a singular explicit definition of this critical concept during this phase of his career. Indeed, the concept of wholeness is so multifaceted that Alexander devotes an entire chapter of the *Timeless Way of Building* to a discussion of possible descriptors such as, whole, alive, egoless, and eternal, before deciding that no term accurately describes its nature. Eventually, he settles on referring to this elusive phenomenon as 'the quality without a name'.[5] Although a singular definition of wholeness is never provided in his second theory, Alexander does consistently discuss two variations of it, hereafter referred to as simple wholeness and complex wholeness. In his third theory of architecture, published as *The Nature of Order*, Alexander does provide more explicit definitions of wholeness as being derived from structural relationships between geometric features at multiple scales, and where applicable, this definition is discussed in the context of patterns and pattern languages below.

Simple wholeness is a measure of the number of patterns in a design and their degree of liveliness. For example, Alexander argues that the 'more life giving patterns there are in a building the more beautiful it seems'.[6] Furthermore, he states that the 'more living patterns there are in a thing – a room, a building or a town – the more it comes to life as an entity, the more it glows, the more it has this self-maintaining fire, which is the quality without a name'.[7] Both of these descriptions propose that wholeness is the product of greater numbers of living patterns. However, a more complex definition of wholeness is also alluded to by Alexander, which focuses on the interactions between patterns, or the complementary way they serve to magnify the life in other patterns. It exists, he argues, 'not when an isolated pattern occurs, but when an entire systems of patterns, interdependent, at many levels, [are] all stable and alive'.[8] This is because 'each pattern can only exist in the world to the extent that it is supported by other patterns'.[9] Alexander's notion that a pattern must be supported by complementary patterns in order to exist appears in his argument that each pattern contains an inherent degree of life. However, he takes care to explain that a living pattern requires the support of other living patterns if it is to remain alive. When it is viewed in this way, wholeness is less contradictory than it first appears, as Alexander is apparently talking about two related conditions, both of which contribute to the overall wholeness of an environment. The first is the potential or baseline beauty of an environment, which arises from the number of patterns it contains, and the second is the beauty that arises from the complementary interaction of those patterns.

Despite Alexander's reluctance to provide a clear definition of wholeness in *A Pattern Language* and *The Timeless Way of Building*, there have been four previous attempts to measure this phenomenon. Probably the most important of these comes from Alexander's own, later career work, two were proposed by scholars seeking to combine concepts of fractal geometry with either thermodynamics or statistical analysis, and the last was developed to evaluate design quality in schools. Each of these are described hereafter.

In Alexander's third theory of architecture, as set out in *A Foreshadowing of 21st Century Art* and *The Nature of Order*, he replaces patterns and their linkages with the concepts of centres and geometric transformations.[10] These works state that designs which contain more centres are more whole, and separately, that the interaction of centres produces wholeness; thus mirroring the descriptions of simple and complex wholeness found in Alexander's second theory, but providing little additional clarity. However, the first volume of *The Nature of Order* includes a series of appendices, one of which mathematically defines wholeness while another demonstrates its calculation.

> *I define wholeness* W *as the system which is created by the region* R*, together with the measure* c *and all the subregions which have measure more than some threshold and thus qualify as centres. For all practical purposes, the wholeness* W *is created by the interaction of the geometry of the region R and the rank order which is created on the centres of* R *by* c.[11]

Thus, the wholeness (W) of a region of space (R), such as a house or a landscape, is determined by the life of its subregions (c) interacting within the organising structure of its geometry. However, the exact means of quantifying the interaction of centres remains unclear, and Alexander's attempt to calculate the life of a series of seven black and white squares is so complex as to be unfeasible for use in architectural analysis. Nevertheless, as wholeness is the common element linking Alexander's second and third theories – and there are clear parallels between patterns and centres, and geometry and connections – his mathematical explanation in *The Nature of Orde*r could be regarded as one source of a quantitative definition of wholeness. Importantly, this later definition also aligns with the concept of a simple wholeness derived by determining the quantity and quality of patterns that are present in a design. This definition also suggests the existence of a complex wholeness, which accounts for the potential of patterns to interact and support each other, thereby magnifying the degree of life in all present patterns.

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Within Alexander's ontological framework, life and wholeness are synonymous with the quality without a name. Informed by fifteen years of discussion with Alexander, Nikos Salingaros quantifies life (L) and complexity (C) in architecture using analogies to thermodynamics and fractal geometry.[12] Using his method, small-scale order, or temperature (T), is determined by architectural features including: (i) intensity of small-scale detail; (ii) density of differentiation; (iii) intensity of colour; (iv) contrast of colour; and (v) curvature of lines. Large-scale order, or harmony (H), is determined by: (i) vertical symmetry; (ii) translational and rotational symmetry; (iii) visually similar forms; (iv) visually connected forms; and (v) the harmonisation of colours. In Salingaros's method, each of the variables that are used to determine the temperature and harmony of a design is scored zero if largely absent, one if partially present, and two if largely present, effectively creating a three-point scale. Thereafter the method uses temperature and harmony to calculate the life ($L = T \times H$) and complexity ($C = T\,(10 - H)$) of a design as a score ranging from 0 to 100.

The third approach to quantifying wholeness focuses on structural beauty that is derived from statistical analysis of the component parts of a design, and emerged from a graph theory based understanding of Alexander's concept of wholeness.[13] For example, a network of streets can be statistically documented as the number of streets in the network and the length of each street.[14] The structural beauty, or liveliness (L), of a design is then determined by multiplying the number of substructural elements (S) by the number of hierarchies (H) in the design.[15] In these calculations, the number of hierarchies in the design is determined by applying a scaling law, also known as the HT-index.[16] The HT-index is calculated by arranging the data into rank order and determining the mean value of the dataset. If the head of the data set contains less than 40% of the substructural elements, the tail of the data set is discarded. This process is repeated on the remaining data until the head exceeds 40% of the number of data points. The number of iterations of this procedure is the number of substructural hierarchies (H) in the design. In terms of the current paper, the measure S is very similar to the concept of simple wholeness. S would document patterns as being present or absent, whereas the current paper documents the presence of patterns on a three-point Likert scale.

The final approach is the only one based on Alexander's second theory and most closely resembles his description of simple wholeness, despite not being explicitly intended to measure this property. Faced with the need to evaluate the relationship between school design and academic achievement, Tanner devised the *Design Assessment Scale Elementary* (*DASE*) to quantify architectural quality.[17] The assessment assigns each pattern a score on a ten-point scale, based on the degree to which the pattern is present in a building, and the environmental quality of each school is the calculated as the sum of these scores. When applied to forty-four schools and compared to standardised test scores, Tanner's research identifies strong correlations between the quality of the school's design and academic achievement. Further applications of this approach to hundreds of schools throughout the United States confirmed the connection between school quality and academic achievement, providing some of the most convincing evidence to support Alexander's assertion that a greater presence of patterns produces superior environments.[18]

It is clear in Alexander's writing that wholeness is a multifaceted concept that requires two methods of quantification: simple and complex. Out of the four previous approaches, only the DASE methodology for calculating simple wholeness is based solely on *A Pattern Language*, and is directly relevant to the current research. Alexander's later writing, however, provides useful guidance for measuring complex wholeness as the following section reveals. The approaches pioneered by Jiang and Salingaros are useful in their own right, but they are more difficult to reconcile with the content of *A Pattern Language*, and therefore, have not directly shaped the method proposed in the current research.

Measuring wholeness

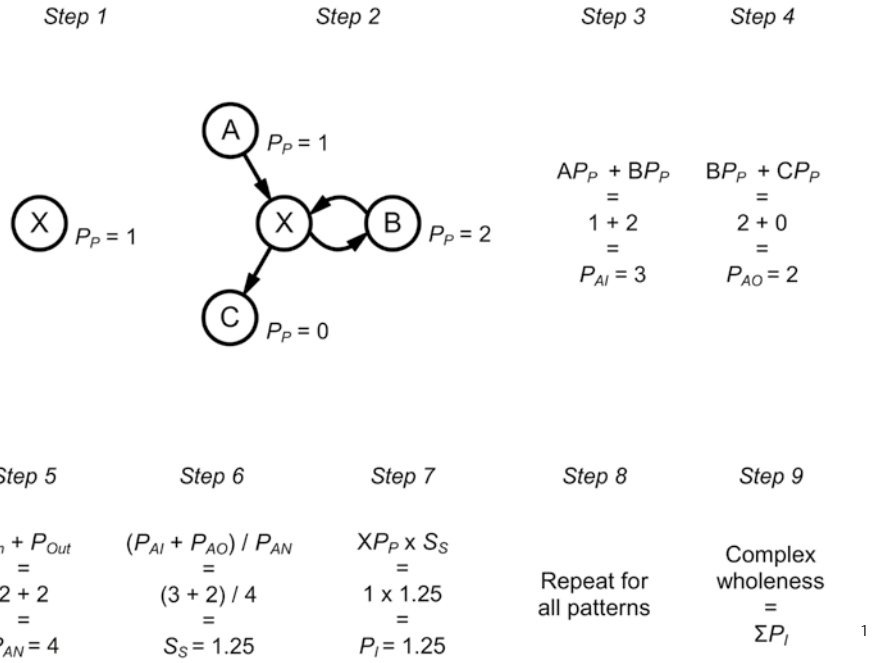
Simple wholeness

The core measure of simple wholeness proposed in the present paper is *Pattern Occurrence* (P_O), which is a factor of the quantity and quality of patterns present in a design. The method for calculating simple wholeness follows the DASE approach, although modified in accordance with Salingaros' simpler three-point scoring system. The calculation of the *Pattern Occurrence* involves a four-step process:

Step 1. Select a single pattern.
Step 2. Undertake a concurrent evaluation of each design to determine whether the pattern is largely absent, partially realised, or largely present and allocate that pattern a *Pattern Presence* (P_P) score of respectively 0, 1, or 2.
Step 3. Repeat steps 1 and 2 until every pattern is assigned a P_P score.
Step 4. The *Pattern Occurrence* of a design is calculated as the sum of all P_P scores for that design.

This analysis of each design is based on published documentary evidence, although in some cases, insufficient information may be available, making it difficult or impossible to identify whether a pattern is present. Therefore, as a means of quantifying and analysing this limitation of the method, each pattern is assigned an uncertainty (P_{UNC}) score of 0, 1, or 2, corresponding to low uncertainty, moderate uncertainty, and high uncertainty. The uncertainty of a design (D_{UNC}) is calculated as the sum of pattern

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1 Complex wholeness is calculated as the sum of Pattern Integrity (PI) for all patterns in a design.

uncertainty scores. In this way, for each design, the relative presence or absence of a pattern can be recorded along with the certainty with which this determination is made. Notwithstanding some innate subjectivity in the scale used, the process of calculating *Pattern Occurrence*, as a measure of the simple wholeness of a design, is time-consuming but otherwise relatively straightforward. The addition of uncertainty calculations, while not strictly necessary, does indicate a level of confidence in the results before progressing to calculate complex wholeness.

Complex wholeness

The measure proposed in this paper for complex wholeness is *Pattern Realisation* (P_R), which accounts for the life and interaction of patterns. *Pattern Realisation* is based on Alexander's description of wholeness as arising from the interaction of individual patterns with complementary patterns. Each of Alexander's patterns lists a series of connections to complementary patterns that serve either as the context or additional refining details for a given pattern. These complementary patterns are adjacent to each other in the underlying graph structure of Alexander's *A Pattern Language*. When these complementary patterns are present, they serve to enhance the life of a pattern, and when complementary patterns are absent, the inherent life of a pattern is unsupported, and it withers to insignificance. The calculation of *Pattern Realisation* involves a nine-step process *[1]*:

Step 1. Select a single pattern.
Step 2. Identify all the complementary patterns by creating a list of inbound connections and a list of outbound connections. It is possible that a complementary pattern may appear on both lists.
Step 3. Determine the adjacent pattern (inbound) (P_{AI}) score by finding the sum of the *pattern presence* scores (P_P) of patterns on the list of inbound connections.
Step 4. Determine the adjacent pattern (outbound) (P_{AO}) score by finding the sum of the *pattern presence* scores (P_P) of patterns on the list of outbound connections.
Step 5. Calculate the number of adjacent patterns (P_{AN}) from the lists of inbound and outbound connections, including patterns that appear on both lists or have P_P scores of 0.
Step 6. Calculate the support score (S_S) as the sum of P_{AI} and P_{AO}, which is then divided by P_{AN}.
Step 7. Calculate pattern integrity (P_I) by multiplying a pattern's P_P and S_S scores.
Step 8. Repeat steps 1 through 7 until to attain P_I scores for every pattern in the analysis.
Step 9. The *Pattern Realisation* (P_R) of a design is the sum of its P_I scores.

These steps record the interaction between pattern life ($0 > P_P > 2$) and the presence of complementary patterns ($0 > S_S > 2$), by multiplying these values to determine pattern integrity ($0 > P_I > 4$). Thus, if complementary patterns are largely present ($S_S > 1$) the life of a pattern is enhanced, and it gains integrity. Conversely, when complementary patterns are largely absent ($S_S < 1$) the life of the pattern is diminished and integrity decreases. However, if a pattern is absent from a design ($P_P = 0$), no amount of support will increase that pattern's integrity.

Consider the following worked example consisting of four patterns where *[1, step 1]*, Pattern X is the focus of attention and is partially present in the design and, therefore has a *Pattern Presence* (P_P) value of 1. The complementary patterns *[1, step 2]*,

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Measure	Note	Description + Calculation
Pattern occurrence	P_O	The sum of all P_P in a case study.
Pattern occurrence (proportional)	$P_{O\%}$	P_O achieved expressed as a percentage of the maximum possible P_O.
Pattern realisation	P_R	The P_P of a pattern multiplied by the *Ss* of that pattern.
Pattern realisation (proportional)	$P_{R\%}$	P_R achieved expressed as a percentage of the maximum possible P_R.
Pattern presence	P_p	Value assigned to a pattern during case study analysis representing the degree to which that pattern is evident in a design.
Patterns adjacent (inbound)	P_{AI}	For a specific pattern, P_{AI} is the sum of the P_p of all patterns with inbound connections to the specific pattern.
Patterns adjacent (outbound)	P_{Ao}	For a specific pattern P_{AO} is the sum of the P_p of all patterns with outbound connections from the specific pattern.
Pattern adjacent (number)	P_{AN}	For a specific pattern P_{AN} is the total number of patterns with inbound and outbound connections with the specific pattern.
Support score	S_S	The support a pattern receives is calculated as the sum of adjacent pattern (P_{AI}, P_{AO}) P_P scores divided by the total number of adjacent patterns (P_{AN}).
Pattern integrity	P_I	The integrity of a pattern when modified by the presence of complimentary patterns. Found by multiplying P_P with S_S.
Percentage difference	P_D	The percentage difference between results for the case studies is calculated as (A-B) / ((A + B) / 2) x 100.

Table 1 **Measures of patterns' presence and wholeness derived from Alexander's literature.**

are that: Pattern A is partially present in the design ($P_P = 1$) and forms an inbound connection to Pattern X, Pattern B is largely present in the design ($P_P = 2$) and forms both an inbound and outbound connection, and Pattern C is largely absent from the design ($P_P = 0$) and forms an outbound connection. Patterns A and B form inbound connections with Pattern X and their P_P values are added to give an adjacent pattern inbound (P_{AI}) value of 3 *[1, step 3]*. Patterns B and C form outbound connections for Pattern X, and their P_P values are added to give an adjacent pattern outbound (P_{AO}) value of 1 *[1, step 4]*. The number of complementary patterns is calculated as the number of patterns (P_{AN}) with inbound and outbound connections giving a value of 4, because Pattern B is counted twice, as both an inbound and an outbound connection *[1, step 5]*.

The *Support Score* (S_S) for Pattern X – the extent to which the degree of life of Pattern X is supported by connections with other patterns – is calculated to give a value of 1.25 [Figure 1, *step 6*]. The integrity of Pattern X is determined by multiplying its *Pattern Presence* value by its *Support Score* to give a result of 1.25 [Figure 1, *step 7*]. This value indicates that the degree of life in the partially present ($P_P = 1$) Pattern X, is enhanced 25% by the presence of complementary patterns in the design. The degree of life of Pattern X would be further enhanced by either incorporating more elements of Pattern X into the design, thereby increasing the *Pattern Presence* value of Pattern X, or by similarly enhancing the presence of Patterns A or C by including additional elements of those patterns into the design and increasing the *Support Score* for Pattern X. In this example, Pattern C being largely absent ($P_P = 0$) effectively serves as a negative modifier of the degree of life in Pattern X because the absence of Pattern C leaves Pattern X incomplete. Calculating the degree of complex wholeness in this worked example would require repeating steps 1–7 for each pattern *[1, step 8]* and then adding these results together *[1, step 9]*.

While this is the general process for calculating *Pattern Realisation* and measuring complex wholeness, there is a significant confounding factor that must also be taken into account. Complex wholeness is a factor of the connectedness of a pattern in Alexander's language, and there are several, equally valid ways of understanding this connectedness. One reading of the structure of Alexander's language has all connections between patterns cascading down, from higher order to lower order patterns.[19] This variation, which replicates a holistic or expert view, interprets connections listed in the prescript of a pattern as inbound and those listed in the postscript as outbound connections. Alternatively, it is possible to read each pattern from the point of view of a designer applying it. In this model, all connections listed in a pattern are treated as outbound connections. Thus, all inbound connections are listed in the entries of the complementary patterns. The former interpretation is called the *Creator Model* of the language, and the latter the *User Model*. This has no impact on the calculation of simple wholeness, but for complex wholeness, two sets of results are needed to capture both understandings of Alexander's language.

These two main measures and all intermediary measures required for their calculation and for the calculation of uncertainty are summarised in Table 1.

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Hypothesised Property	Metric
Prairie-style architecture has a *higher quantity and quality of patterns* than 1920's Modernist architecture.	Average P_O values exhibit a percentage difference of 33% favouring Prairie-style cases.
Prairie-style architecture has *a greater degree of pattern support* than 1920's Modernist architecture.	Average P_R values exhibit a percentage difference of 33% favouring Prairie-style cases in both the Creator and User model of the language.

Table 2 **Hypothesised properties of the case studies and the metrics for their evaluation.**

Hypotheses

According to Alexander's second theory, environments that possess greater levels of wholeness are superior to other environments. However, in his second theory centred on *A Pattern Language*, Alexander provides no quantitative evidence to support this claim. To test this famous argument, the present research measures simple and complex wholeness in examples of Prairie-style and 1920s Modernist architecture. If Alexander's argument is valid, both simple and complex wholeness results will be greater in Prairie-style designs by a percentage difference of 33% *[*Table 2*]*. The percentage difference arises from the tripartite scale used for identifying *Pattern Presence*. Thus 33% represents the wholeness of a superior design, which is one tier higher than an inferior design. Selecting this margin of difference is somewhat arbitrary, but also necessary as Alexander's writings fail to provide an example threshold to differentiate what he considers to be good or bad design.

Methodology

This section describes the application of the method, the logic underpinning the case selection process and its limitations.

Application

The calculation of simple and complex wholeness commences by analysing each design to determine the extent to which each pattern is present. Each of Alexander's patterns provides detailed documentation of its context, rational, supporting evidence, and the action required of the user. However, these descriptions tend to be unwieldy and thus, the present research bases pattern identification on a concise list of architectural features distilled from the canonical text. These lists include every architectural feature explicitly mentioned in the pattern and exclude any features that would occur outside the built envelope of a design. When a design contains less than one third of these features, a pattern is considered to be 'largely absent' ($P_P = 0$). If between one and two thirds of the features are present, the pattern is 'partially realised' ($P_P = 1$), and the presence of more than two thirds of these features indicates a pattern is 'largely present' ($P_P = 2$). Any pattern bordering on a higher or lower classification is considered to be partially present. Pattern presence scores are also assigned based on the fullest manifestation of each pattern. Thus, a pattern that is partially realised in one location, and largely present in another location, would be considered to be largely present and assigned a score of 2. This may also mean that a complementary pattern appears in a location that is physically removed from the pattern it is intended to support. A consideration of proximity relations implied in Alexander's language is, however, beyond the scope of the present application, although as the focus here is on domestic architecture, this significance of proximity is considerably reduced.

Despite listing the architectural features of each pattern, some patterns possess a degree of subjectivity. For example, Alexander's Pattern 110 Main Entrance, requires 'a bold visible shape to differentiate it from the rest of the building'.[20] What exactly constitutes a 'bold visual shape' and what qualifies it as different from the rest of the building remains ambiguous. Therefore, the analysis of each design occurs simultaneously and proceeds by selecting a single pattern and evaluating and comparing the manifestation of the pattern in every design being examined, before assigning and recording P_P and P_{UNC} scores. This ensures that features considered to be, for example, bold or differentiated, are evaluated consistently for every design.

Pattern uncertainty (P_{UNC}) scores are assigned simultaneously with pattern presence (P_P) scores and document the rare situations in which the documentary evidence is insufficient to determine whether a pattern is present. For example, consider Pattern 240 Half Inch Trim, which requires that any two materials be separated with a trim no larger than half an inch. The documentation available for a design might show a trim separating two materials but lack the precision to ascertain whether the trim is one half, or seven sixteenths, of an inch wide. Uncertainty scores follow the same three-point scale as pattern presence with largely absent uncertainty ($P_{UNC} = 0$) indicating sufficient evidence is available. Largely present uncertainty ($P_{UNC} = 2$) indicates the documentation is insufficient to identify the presence of a pattern and partially realised uncertainty ($P_{UNC} = 1$) indicates that some evidence is available to support the identification of a pattern.

Case selection

A selection of fourteen houses provides the basis for examining the consistency of Alexander's second theory and its claims about superior design and wholeness *[*Table 3*]*. The three determining factors in selecting case studies are: (i) designs that align with Alexander's descriptions of whole and un-whole design; (ii) architecture that is documented in sufficient detail to facilitate the

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Wright - 'organic' cases			Le Corbusier - 'mechanistic' cases		
House	**Year**	**Location**	**Villa**	**Year**	**Location**
Willits House	(1901)	Highland Park	*Villa La Roche*	(1923)	Paris
Heurtley House	(1902)	Chicago (Oak Park)	*Villa Jeanneret*	(1923)	Paris
Cheney House	(1903)	Chicago (Oak Park)	*Villa Cook*	(1926)	Paris (Boulonge-sur-Seine)
Martin House	(1904)	Buffalo	*Villa Stein*	(1926)	Paris (Garches)
Robie House	(1905)	Chicago (Hyde Park)	*Villa Weissenhof I*	(1927)	Stuttgart (Weissenhof)
Coonley House	(1907)	Chicago (Riverside)	*Villa Weissenhof II*	(1927)	Stuttgart (Weissenhof)
Tomek House	(1907)	Chicago (Riverside)	*Villa Savoye*	(1928)	Paris (Poissy)

Table 3 **Selected case study houses designed by Frank Lloyd Wright and Le Corbusier.**

identification of the largest and smallest architectural patterns; and (iii) designs of similar scale, scope, and typology.

It is acknowledged that the ideal test cases representing wholeness and beauty would be Alexander's own designs. However, Alexander's designs fail the second criterion for selection in that the available documentation of these designs is insufficient for the current analysis. Furthermore, the Centre for Environmental Structure in Berkley does not provide documentation for these works, and fieldwork evaluation of the private residences is not viable. Therefore, as a substitute for Alexander's own work, it is necessary to use extensively documented designs that are renowned for embodying the types of aesthetic features Alexander frequently equates with being whole. The Prairie-style houses by Frank Lloyd Wright, who is coincidentally one of the very few architects to earn praise in Alexander's canonical texts, fulfil this requirement. Wright's Prairie-style houses are famous for pitched and cascading roofs with deep, shelter-providing eaves, strong entrance sequences, ornate detailing, expression of natural materials, and careful integration of form and function *[2]*.[21] Indeed, not only do Wright's Prairie-style houses closely align with Alexander's ideals, but the *Cheney* and *Robie* houses are listed as the basis for Pattern 140 Private Terrace on the Street in *A Pattern Language*. Thus, Wright's houses are taken as broadly constituting works that align with Alexander's ideal.

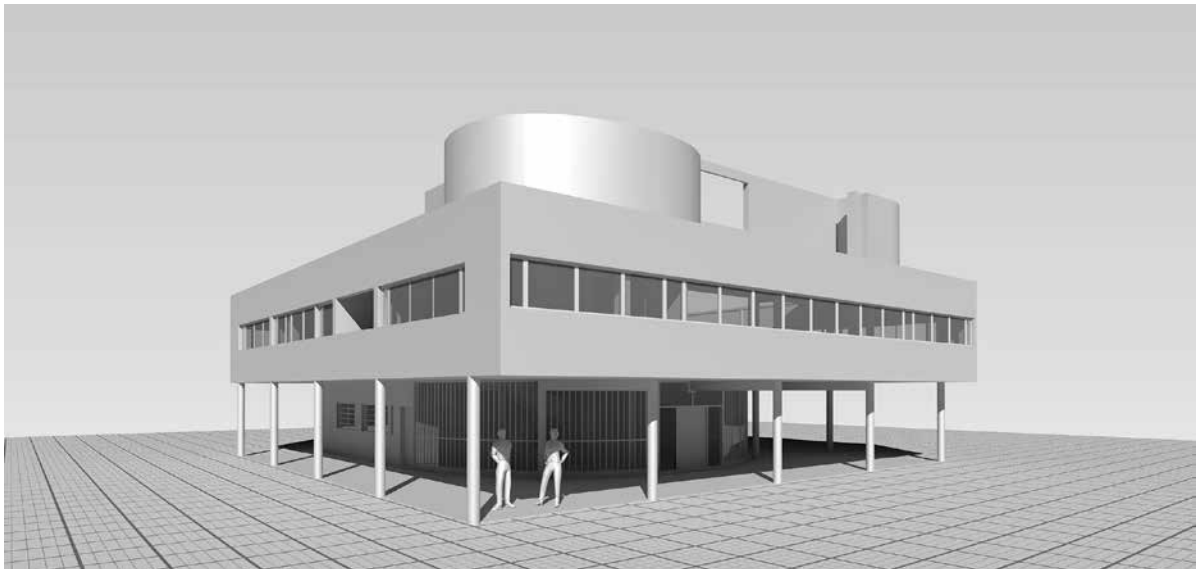
Seven villas designed by Le Corbusier (Charles-Edouard Jeanneret) are selected to represent the supposedly inferior, un-whole architecture. Alexander's canonical texts may not directly criticise Le Corbusier's architecture, but they are highly dismissive of machine-like, geometrically pure, and unadorned architecture. Le Corbusier's 1920's Modernist villas are famous for pioneering the machine-inspired, minimalist, white box aesthetic and seemingly contradict many of the values described in Alexander's second theory of architecture.[22] Significantly, these are designs which Le Corbusier conceptualised as 'as a machine for living in'.[23] However, Alexander does employ a photograph of the *Villa Savoye* to illustrate Pattern 199 Sunny Counter, so it is also possible that Le Corbusier's architecture may not be entirely antithetical to Alexander's position. However, this image also demonstrates how many of Alexander's other patterns are absent from that villa *[3]*.

It is important to note that, in selecting these fourteen case studies by Wright and Le Corbusier, there is a much deeper possible discussion to be had regarding whether the works of each architect truly



2 **The Robie House (1905) by Frank Lloyd Wright includes many architectural features that Alexander praises in traditional design such as detailed windows, cascading roofs, decorative elements, and textured materials.**

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3

3 The Villa Savoye (1928) by Le Corbusier incorporates many of the aesthetic features that Alexander criticises in Modern architecture, such as large windows with few mullions and the absence of decoration, colour, and textures.

represent whole or un-whole design and what these descriptors really entail. Such discussion, however, is beyond the scope of the current research.

The fourteen designs chosen for the analysis are selected because they are well known, of appropriate scale, and are the subject of sufficient documentary evidence. The first factor ensures that the designs conform to the style for which the architect gained notoriety, thus necessitating the inclusion of the *Robie House* and *Villa Savoye* and the exclusion of Le Corbusier's early chalets and Wright's later Textile-block and Usonian houses. Second, each design has an approximate counterpart in the other architect's repertoire in terms of scale. Thus, the *Coonley House* and *Villa Stein* are both large residences, with multiple sleeping areas, and the *Tomek House* and *Villa Cook* are both scaled for a small family. Finally, documentary evidence for each design must be sufficient to identify even the smallest pattern. Published construction drawings and archival photographs form the basis of the present analysis, which considers the residences immediately following construction and excludes later renovations or repairs. However, it must be noted that Le Corbusier's Weissenhof villas are standalone display homes that were intended to utilise shared walls. While the prototypes are analysed here, this has no impact on the presence of patterns.

Limitations

The methodological reliance on published documentation limits the analysis to: (i) aesthetic and phenomenal experiences; (ii) arising from the architectural features (iii) of single residences. The two factors limiting analysis to single residences are the need for extensive documentation and the scope of *A Pattern Language*. Single residences are often documented in sufficient detail to facilitate the identification of all applicable patterns with low uncertainty, whereas other building types are not. As such, single residences are more likely to provide a viable data set for analysis. Similarly, there are sufficient patterns in Alexander's language to account for virtually every aspect of residential design. While patterns documenting specialised functions for transport, education, or worship are included in the language, there are too few of these to completely design a station, school, or church.

The requirement for detailed documentation of cases also limits the analysis to the architectural features of a design, which includes the residence itself and external areas with direct access to indoor spaces such as terraces and roof gardens. Thus, patterns primarily relating to urban planning, landscaping, impermanent furnishing, and personal items are excluded from consideration. This need for documentary evidence also focuses the analysis on the aesthetic and phenomenal experiences of each design, including light, space, surfaces and materials, while excluding patterns that primarily record social, political, structural, and economic considerations.

Cumulatively, these limitations restrict the number of patterns considered in the analysis to 111, or 44% of Alexander's language. However, this restriction is not inherently problematic as Alexander notes that 'any small sequence of patterns from this language is itself a language for a smaller part of the environment; and this small list of patterns is capable of generating a million parks, paths, houses, workshops or gardens'.[24] Thus, considering only a subset of patterns related to certain parts of the environment, such as the design of a house, is both reasonable and even necessary when evaluating wholeness within the context of single residences.

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Results

Simple wholeness

Pattern Occurrence (P_O) quantifies simple wholeness through consideration of the quantity and quality of patterns present in a design. On this basis, the most whole design in both sets of cases is Wright's *Martin House* (P_O = (0 x 31) + (1 x 28) + (2 x 52) = 132, $P_{O\%}$ = 59%) and Wright's least whole design is the *Cheney House* (P_O = 100, $P_{O\%}$ = 45%) *[*Table 4*]*. Three of Wright's houses approximate the mean result for this set of seven designs (P_O = 117, $P_{O\%}$ = 53%) with the *Willits House* (P_O = 118, $P_{O\%}$ = 53%) being slightly closer than the *Heurtley* (P_O = 115, $P_{O\%}$ = 52%) and *Coonley* (P_O = 114, $P_{O\%}$ = 51%) houses.

The *Villa Stein* (P_O = 85, $P_{O\%}$ = 38%) is Le Corbusier's most whole design in terms of *Pattern Occurrence [*Table 5*]* and the display villa, *Weissenhof I*, is the least whole (P_O = 63, $P_{O\%}$ = 28%). The *Villa Jeanneret* (P_O = 76, $P_{O\%}$ = 34%) is closest to the mean for this set (P_O = 74, $P_{O\%}$ = 33%) and when compared to the *Villa La Roche* (P_O = 70, $P_{O\%}$ = 32%), highlights the difference between pattern quantity and quality as both contain forty-eight patterns while the former achieves greater wholeness.

Mean *Pattern Occurrence* results indicate that Wright's houses (P_O = 117, $P_{O\%}$ = 53%) are significantly more whole than Le Corbusier's villas (P_O = 74, $P_{O\%}$ = 33%). The percentage difference, or relative change (as detailed in Table 2), between *Pattern Occurrence* (P_O) results is 45%, which appears to support the coherence and consistency of Alexander's second theory.

Uncertainty

The calculation of *Uncertainty* follows the same logic as *Pattern Occurrence* and records the extent to which insufficient design documentation may impact wholeness results *[*Tables 6, 7*]*.

The *Villa Jeanneret* (D_{UNC} = 21) wholeness measure is the most uncertain result, possibly due to some small rooms being poorly documented. Conversely, the *Villa Weissenhof I* (D_{UNC} = 10) is the most certain result due to this design consisting primarily of one large, partially partitioned space in which most patterns are visible if they are present, thereby reducing the required volume of documentation. Overall Wright's houses (D_{UNC} = 12) are documented more extensively than Le Corbusier's villas (D_{UNC} = 14).

Measure	*Willits*	*Heurtley*	*Cheney*	*Martin*	*Robie*	*Coonley*	*Tomek*	Mean
$P_P = 0$	43.0000	43.0000	48.0000	31.0000	40.0000	43.0000	38.0000	40.8571
$P_P = 1$	18.0000	21.0000	26.0000	28.0000	22.0000	22.0000	24.0000	23.0000
$P_P = 2$	50.0000	47.0000	37.0000	52.0000	49.0000	46.0000	49.0000	47.1429
P_O	118.0000	115.0000	100.0000	132.0000	120.0000	114.0000	122.0000	117.2857
$P_{O\%}$	53.1532	51.8018	45.0450	59.4595	54.0541	51.3514	54.9550	52.8314

Table 4 **Pattern occurrence (PO) results for Wright's Prairie-style houses.**

Measure	*La Roche*	*Jeanneret*	*Cook*	*Stein*	*Weis I*	*Weis II*	*Savoye*	Mean
$P_P = 0$	63.0000	63.0000	67.0000	57.0000	71.0000	62.0000	60.0000	63.2857
$P_P = 1$	20.0000	26.0000	21.0000	23.0000	17.0000	19.0000	21.0000	21.0000
$P_P = 2$	28.0000	22.0000	23.0000	31.0000	23.0000	30.0000	30.0000	26.7143
P_O	76.0000	70.0000	67.0000	85.0000	63.0000	79.0000	79.0000	74.1429
$P_{O\%}$	34.2342	31.5315	30.1802	38.2883	28.3784	35.5856	35.5856	33.3977

Table 5 **Pattern occurrence (PO) results for Le Corbusier's 1920s Modernist villas.**

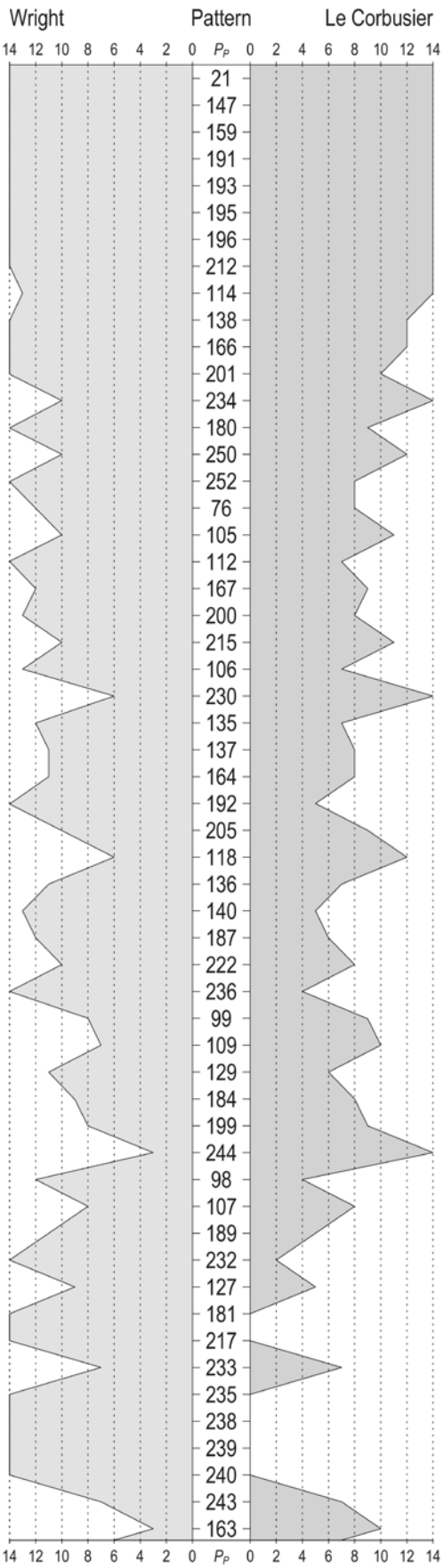
Measure	*Willits*	*Heurtley*	*Cheney*	*Martin*	*Robie*	*Coonley*	*Tomek*	Mean
$P_{UNC} = 0$	95.0000	100.0000	100.0000	99.0000	100.0000	100.0000	99.0000	99.0000
$P_{UNC} = 1$	14.0000	9.0000	9.000	10.0000	8.000	9.0000	10.000	9.8571
$P_{UNC} = 2$	2.0000	2.0000	2.000	2.0000	3.000	2.0000	2.000	2.1429
D_{UNC}	18.0000	13.0000	13.0000	14.0000	14.0000	13.0000	14.0000	12.1429

Table 6 **Number of patterns with negligible (0), partial (1) and high (2) uncertainty (U_{NC}) in Wright's Prairie style houses.**

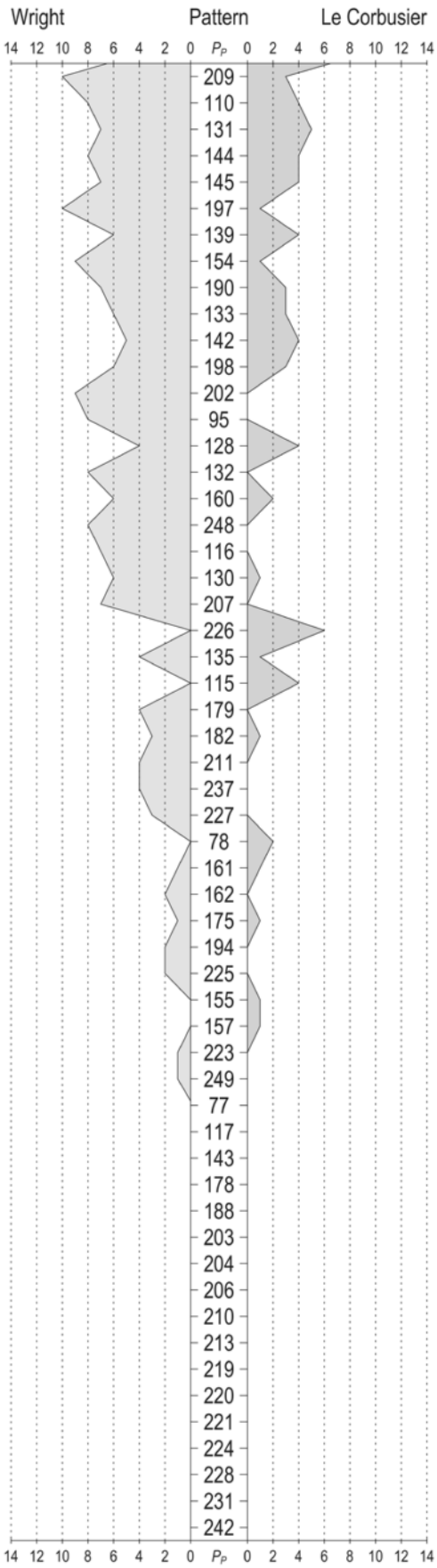
Measure	*La Roche*	*Jeanneret*	*Cook*	*Stein*	*Weis I*	*Weis II*	*Savoye*	Mean
$P_{UNC} = 0$	99.0000	94.0000	100.0000	97.0000	104.0000	101.0000	101.0000	99.4286
$P_{UNC} = 1$	10.0000	13.0000	9.0000	11.0000	4.0000	7.0000	8.0000	8.8571
$P_{UNC} = 2$	2.0000	4.0000	2.0000	3.0000	3.0000	3.0000	2.0000	4.5714
D_{UNC}	14.0000	21.0000	13.0000	17.0000	10.0000	13.0000	12.0000	14.2857

Table 7 **Number of patterns with negligible (0), partial (1) and high (2) uncertainty (U_{NC}) in Le Corbusier's 1920's Modernist villas.**

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4a



4b

4a **Pattern presence results for the 50% of patterns with highest PP scores, sorted by PP score.**

4b **Pattern presence results for the 50% of patterns with lowest PP scores, sorted by PP score.**

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Measure		*Willits*	*Heurtley*	*Cheney*	*Martin*	*Robie*	*Coonley*	*Tomek*	Mean
(C)	P_R	122.8209	118.3461	87.7324	153.5094	132.2518	112.6688	136.8440	123.4533
	$P_{R\%}$	27.6624	26.6545	19.7595	34.5742	29.7864	25.3759	30.8207	27.8048
(U)	P_R	121.4210	116.6882	86.1992	154.0163	130.7651	110.8474	135.2680	122.1722
	$P_{R\%}$	27.3471	26.2811	19.4142	34.6884	29.4516	24.9656	30.4658	27.5163

Table 8 **Pattern Realisation results for Wright's Prairie style houses calculated using the Creator (C) and User (U) model.**

Measure		*La Roche*	*Jeanneret*	*Cook*	*Stein*	*Weis I*	*Weis II*	*Savoye*	Mean
(C)	P_R	52.9969	40.4580	35.4183	65.7627	29.7511	53.0214	58.1994	47.9440
	$P_{R\%}$	11.9362	9.1122	7.9771	14.8114	6.7007	11.9418	13.1080	10.7982
(U)	P_R	52.5395	40.4088	36.8622	67.4750	28.8307	52.5166	58.8399	48.2104
	$P_{R\%}$	11.8332	9.1011	8.3023	15.1671	6.4934	11.8281	13.2522	10.8539

Table 9 **Pattern Realisation results for Le Corbusier's 1920's Modernist villas calculated using the Creator (C) and User (U) model.**

Complex wholeness

Pattern Realisation encapsulates the life and interaction of patterns. Due to ambiguities in Alexander's canonical texts, pattern realisation is calculated for both the Creator (C) and User (U) models of the language. In both models, Wright's *Martin House* is the most whole design of all cases analysed (C - $P_R = 154$, $P_{R\%} = 35\%$, U - $P_R = 154$, $P_{R\%} = 35\%$) and the *Cheney House* is the least whole of the Prairie-style houses (C - $P_R = 88$, $P_{R\%} = 20\%$, U - $P_R = 86$, $P_{R\%} = 19\%$). The different models have a minimal impact on mean pattern occurrence results (C – $P_O = 123$, $P_{O\%} = 28\%$, U – $P_O = 122$, $P_{O\%} = 28\%$) and again, the *Willits House* is closest to the mean values (C - $P_R = 122$, $P_{R\%} = 28\%$, U - $P_R = 121$, $P_{R\%} = 27\%$) of Wright's designs *[*Table 8*]*.

For the set of seven villas by Le Corbusier, once again the *Villa Stein* is most whole design (C - $P_R = 66$, $P_{R\%} = 15\%$, U - $P_R = 67$, $P_{R\%} = 15\%$) and the *Villa Weisenhof I* is the least whole design analysed (C - $P_R = 30$, $P_{R\%} = 7\%$, U - $P_R = 29$, $P_{R\%} = 6\%$). The impact of the two models is again minimal, though unlike Wright's houses, the 1920s Modernist villas attain slightly greater wholeness under the User model (C – $P_O = 48$, $P_{O\%} = 10\%$, U – $P_O = 48$, $P_{O\%} = 11\%$). Under the Creator model, the *Villa La Roche* (C - $P_R = 53$, $P_{R\%} = 12\%$) is closest to the mean, whereas the *Villa Weisenhof II* (U - $P_R = 53$, $P_{R\%} = 12\%$) is closest to the mean of the User model *[*Table 9*]*.

Mean *Pattern Realisation* results indicate that Wright's houses (C - $P_R = 88$, $P_{R\%} = 20\%$, U - $P_R = 86$, $P_{R\%} = 19\%$) are significantly more whole than Le Corbusier's villas (C - $P_R = 30$, $P_{R\%} = 7\%$, U - $P_R = 29$, $P_{R\%} = 6\%$) in both models of the language. The percentage difference, or relative change (as detailed in Table 2), between *Pattern Occurrence* (P_O) results is 88% for the Creator model and 86% for the User model, with both results confirming the coherence and consistency of Alexander's theory.

To interpret both simple and complex wholeness results for the fourteen houses in this section more broadly, with a starting point of 111 patterns, the maximum possible wholeness results are $P_O = 222$ and $P_R = 444$.

Discussion

The results reported in the previous section confirm that Alexander's arguments about the lack of wholeness in Modern architecture are consistent with the content and structure of his pattern language. In essence, Alexander's claims are supported by his theories, not that this makes either his claims or his theories correct, just congruent. While this answers the primary hypotheses framed for testing in this paper, the results also identify several additional dimensions.

The *Villa Stein*, the most whole of Le Corbusier's 1920's Modernist designs, is less whole than the *Cheney House*, which is the least whole of Wright's Prairie-style designs. However, the Prairie and Modernist designs are not entirely different. The present analysis reveals that eight patterns are strongly present in *every* design *[3]*. These patterns document features that would be expected in any single residence (such as an area for communal eating) and elements of good design (such as natural illumination that minimises glare). These patterns also include architectural features that are not strictly necessary for single residences, such as orthogonal rooms, staircases, half open walls, and corner doors, each of which appears in every analysed design *[4]*. Likewise, seventeen patterns are consistently absent from every design. For example, patterns such as dormer windows and vaulted roofs do not match the aesthetic style of either architect's selected works, and those requiring composting toilets, bed alcoves, and inconsistently dimensioned doors and windows are misaligned with norms of twentieth-century architecture.

Certain patterns are also more likely to feature in Wright's designs, such as entrance transitions, wide opening windows, and private terraces, while other patterns, including canvas roofs, roof gardens, and radiant heaters, appear more frequently in Le Corbusier's villas. Such differences serve to draw attention to the impact of cultural and temporal factors in the calculation of wholeness. For example, several of Wright's houses provide servant

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accommodation that matches Alexander's requirements for subresidences (such as Patterns 153 Rooms for Rent and 154 Teenager's Cottage), despite not being intended for these roles. In contrast, several of Le Corbusier's villas include concierge quarters, however, these are more integrated into the designs and provide fewer features of Alexander's subresidences. The inclusion of additional cases in a larger version of this study may identify whether these are quirks of the two famous architects or broader vernacular trends within Modern architecture.

It is important to note that both the houses and villas are examples of Modern architecture, envisioned as a complete design, constructed by professional tradespeople, and bestowed unto the client at the conclusion of the process. This procurement method is contrary to Alexander's desire for the user to slowly adapt a design to changing conditions. Thus, it could be argued that the current research merely documents the potential for different levels of wholeness to exist within an allegedly inferior architectural paradigm. A definitive assessment of Alexander's claims would require analysis of traditional and vernacular designs, which may also act as a benchmark from which to judge the degree of wholeness in the examples of Wright and Le Corbusier's architecture analysed here. Finally, the measurement of complex wholeness examines both the Creator and User models of *A Pattern Language.* Even though the present research is effectively the first to quantify the difference between the two, it could be argued that the results are relatively similar, and thus, a more generalised model of the language might have made a simpler and still effective starting point for such an analysis.

Conclusion

A core tenet of Christopher Alexander's second theory of architecture is that certain environments are more whole and, therefore, more beautiful than others. The current research evaluates this assertion by using *A Pattern Language* as the basis for developing quantitative measures of simple and complex wholeness. Applying these measures to seven of Wright's Prairie-style houses and seven of Le Corbusier's 1920's Modernist villas reveals that the former are significantly more whole than the latter. While these results support Alexander's assertion, a broader selection of cases, including examples of traditional and vernacular design, would need to be analysed to definitively confirm that Alexander's views about architecture are consistent with his second theory.

Finally, this analysis also reveals that eight patterns are largely present, and seventeen patterns are largely absent, in every analysed design. This may suggest that the absent patterns are somehow less useful in meeting the residential requirements of the twentieth century and require revision. It might also suggest that the architecture of Wright and Le Corbusier is partially incompatible with Alexander's vision of wholeness. Analysing a wider range of case studies including traditional buildings, Alexander's own designs, and additional examples of Modern architecture in future research, may begin to clarify this issue.

Notes

1. Christopher Alexander, *Notes on the Synthesis of Form* (Cambridge, MA: Harvard University Press, 1964).
2. Christopher Alexander and others, *The Oregon Experiment* (New York, NY: Oxford University Press, 1975); Christopher Alexander and others, *A Pattern Language: Towns, Buildings, Construction* (New York, NY: Oxford University Press, 1977); Christopher Alexander, *The Timeless Way of Building* (New York, NY: Oxford University Press, 1979).
3. Christopher Alexander, *The Nature of Order: An Essay on the Art of Building and the Nature of the Universe*, Vol. 1, The Phenomenon of Life (Berkley, CA: Centre for Environmental Structure, 2002); Christopher Alexander, *The Nature of Order: An Essay on the Art of Building and the Nature of the Universe*, Vol. 2, The Process of Creating Life (Berkley, CA: Centre for Environmental Structure. 2002); Christopher Alexander, *The Nature of Order: An Essay on the Art of Building and the Nature of the Universe*, Vol. 4, The Luminous Ground (Berkley, CA: Centre for Environmental Structure, 2004); Christopher Alexander, *The Nature of Order: An Essay on the Art of Building and the Nature of the Universe*, Vol. 3, A Vision of a Living World (Berkley, CA: Centre for Environmental Structure, 2005).
4. Wendy Kohn, 'The Lost Prophet of Architecture', *Wilson Quarterly*, summer (2002), 26–34; William Saunders, 'A Pattern Languge by Christopher Alexander', *Harvard Design Magazine*, winter / spring (16) (2002), pp. 74–8; Michael W. Mehaffy, 'Generative Methods in Urban Design: A Progress Assessment', *Journal of Urbanism*, 1:1 (2008), 57–75; Michael J. Dawes and Michael J. Ostwald, 'Christopher Alexander's *A Pattern Language*: Analysing, Mapping and Classifying the Critical Response', *City Territory Architecture,* 4:17 (2017); Michael J. Dawes and Michael J. Ostwald, 'The Mathematical Structure of Alexander's *A Pattern Language*: An Analysis of the Role of Invariant Patterns', *Environment and Planning B: Urban Analytics and City Science*, 47:1 (2018), 7–24.
5. Alexander, *The Timeless Way of Building*, p. 19.
6. Ibid., p. 134.
7. Ibid., p. 123.
8. Ibid., p. 131.
9. Christopher Alexander and others, *A Pattern Language: Towns, Buildings, Construction* (New York, NY: Oxford University Press, 1977), pp. xii–xiii.
10. Christopher Alexander, *A Foreshadowing of 21st Century Art* (New York, NY: Oxford University Press, 1993).
11. Alexander, *The Nature of Order: An Essay on the Art of Building and the Nature of the Universe*, Vol. 1, p. 447.
12. Nikos A. Salingaros, 'The Laws of Architecture from a Physicist's Perspective', *Physics Essays*, 8 (1995), 638–43; Nikos A. Salingaros, 'Life and Complexity in Architecture From a Thermodynamic Analogy', *Physics Essays*, 10:1 (1997), 265–73.
13. Bin Jiang, 'A Complex-Network Perspective on Alexander's

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Wholeness', *Physica A: Statistical Mechanics and its Applications,* 463:Dec (2016), 475–84.
14. Bin Jiang and Ju-Tzu Huang, 'A New Approach to Detecting and Designing Living Structure of Urban Environments', *Computers, Environment and Urban Systems*, 88 (2021).
15. Bin Jiang and Chris de Rijke, 'Representing Geographic Space as a Hierarchy of Recursively Defined Subspaces for Computing the Degree of Order', *Computers, Environment and Urban Systems*, 92 (2022).
16. Bin Jiang and Junjun Yin, 'Ht-Index for Quantifying the Fractal or Scaling Structure of Geographic Features', *Annals of the Association of American Geographers*, 104:3 (2014), 530–40.
17. Kenneth Tanner, 'The Influence of School Architecture on Academic Achievement', *Journal of Educational Administration*, 38:4 (2000), 309–30.
18. Kathleen Ann Yarbrough, 'The Relationship of School Design to Academic Achievement of Elementary School Children' (PhD thesis, The University of Georgia), 2001; Stephanie Maire Hughes, 'The Relationship Between School Design Variables and Scores on the Iowa Test of Basic Skills' (PhD thesis, Baylor University, 2005); Scott Andersen, *The Relationship Between School Design Variables and Scores on the Iowa Test of Basic Skills* (Athens, GA: University of Georgia, 1999); Laura Deane Mason, 'School Facility Design Characteristics Supporting California Schools to Watch: Taking Center Stage Middle Schools: Perceptions of Middle School Principals and Teachers' (PhD thesis, University of La Verne, 2008).
19. Dawes and Ostwald, 'Christopher Alexander's *A Pattern Language*'.
20. Alexander and others, *A Pattern Language*, p. 544.
21. Frank Lloyd Wright, *An Organic Architecture* (London: Lund, Humphries & Co. Ltd, 1939); Grant Hildebrand, *The Wright Space: Patterns & Meaning in Frank Lloyd Wright's Houses* (Seattle, WA: University of Washington Press, 1991); Neil Levine, *The Architecture of Frank Lloyd Wright* (Princeton, NJ: Princeton University Press, 1996); Bruce Pfieffer and Peter Goessel, *Frank Lloyd Wright 1917–1942: The Complete Works* (Koln, Germany: Taschen, 2010).
22. William J. R. Curtis, *Le Corbusier, Ideas and Forms* (Oxford: Phaidon, 1986); Tadao Ando, *Le Corbusier: Houses* (Japan: Toto, 2001); Geoffery Baker, *Le Corbusier: An Analysis of Form* (New York, NY: Van Nostrand Reinhold, 1984); Colin Rowe, 'The Mathematics of the Ideal Villa', *The Architectural Review* (1947), 100–04.
23. Le Corbusier, *Towards a New Architecture* (London: Rodker, 1931), p. 4.
24. Alexander and others, *A Pattern Language*, p. xxxv.

Competing interests

The author declares none.

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