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Dawes, Michael J.; Ostwald, Michael J. 'Prospect-refuge theory and the textile-block houses of Frank Lloyd Wright: an analysis of spatio-visual characteristics using isovists', Building and Environment Vol. 80, p. 228-240 (2014)

Available from: <http://dx.doi.org/10.1016/j.buildenv.2014.05.026>

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Accessed from: <http://hdl.handle.net/1959.13/1295829>

Prospect-Refuge Theory and the Textile-Block Houses of Frank Lloyd Wright: An Analysis of Spatio-Visual Characteristics using Isovists.

Abstract

Prospect-Refuge theory argues that human environmental preferences are attuned to seeking spaces that offer a balance of outlook and enclosure. The first and best-known architectural application of this theory was Hildebrand's proposition that the emotional power of Frank Lloyd Wright's architecture arises from a distinct pattern of spatial enclosure and outlook. Hildebrand presented Wright's textile-block houses as ideal examples of this prospect-refuge pattern, which he called the "Wright Space". That argument has since been widely repeated and even used as a design formula in contemporary guides, but there is no quantitative evidence that its catalyst, the Wright Space, actually exists. Using isovist fields, this paper undertakes a computational and mathematical analysis of the spatio-visual properties of paths through five of Wright's textile-block houses. For each house a comprehensive two-dimensional analysis, supplemented with selected three-dimensional data, is used to derive ten measures of spatial properties with which to assess Hildebrand's application of prospect-refuge theory. Through this process the paper investigates whether the Wright Space exists, and if it conforms to the four key prospect-refuge related properties identified by Hildebrand. The paper concludes that some evidence exists to support the existence of the "Wright Space", however the strength and consistency of the pattern remains questionable.

Key Words

Isovist Analysis, Design Analysis, Prospect-Refuge Theory, Frank Lloyd Wright

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1. Introduction

During his almost 70 year career, Frank Lloyd Wright was responsible for the design of over 300 residential dwellings. When historians review this body of work, a recurring theme is the apparent ability of these buildings to evoke positive emotional responses from their occupants [1-4]. Multiple attempts have been made to account for this allegedly intuitive, immediate and universal reaction including material ethics, [5, 6], spatial archetypes [7] and *genius loci* [3, 8]. However, the most widely accepted rationale for the positive emotional impact of Wright's architecture is Grant Hildebrand's [9] combined application of Habitat theory and Prospect-Refuge theory.

First proposed by Jay Appleton [10], Habitat theory and Prospect-Refuge theory collectively suggest that environments which offer a balance of outlook and enclosure, satisfy basic human psychological needs through their capacity to evoke spatial qualities reminiscent of those which shaped human evolution. This combination of the spatial properties of prospect and refuge forms the basis for Hildebrand's investigation of the emotional appeal of Wright's architecture. Drawing on prospect-refuge theory Hildebrand argues that the experience of moving through an environment is crucial to shaping a person's emotional state. Furthermore, if the path being followed has the right balance of outlook and enclosure, then this experience is psychologically comforting or uplifting. Through a detailed graphical and textual analysis, Hildebrand suggests that the paths in Wright's houses leading from the front door to the living room, feature a pattern of prospect-refuge qualities that account for their phenomenological impact. Hildebrand dubbed this pattern the "Wright Space".

Since the publication of Hildebrand's theory, the existence of Wright Space has seemingly been accepted by critics and become central to the promulgation of prospect-refuge theory in architecture, as both an analytical and environmental design strategy [11-13]. However, despite this apparent acceptance, little quantitative evidence exists to support Hildebrand's original analysis of Wright's architecture. In particular, if there is a distinct spatio-visual pattern in the paths through Wright's most famous houses, it should be measurable and consistent. Thus, the present paper uses a computational and mathematical approach to examine five of Wright's most famous works, the textile-block houses, for evidence of Hildebrand's theory.

The method used for this research is isovist analysis, an approach that is capable of measuring the geometric properties of the human visual experience of a space. Isovist analysis has previously been employed in studies of spatial cognition [14], wayfinding [15] and social structure [16] and prospect-refuge related characteristics of architecture [17-19]. For the present paper, an isovist view field is used to construct a comparison of the visual experience of moving along a path, from the front door to the living room and hearth, through the textile-block houses. Every step along this path generates a different isovist, from which the changing spatio-visual experience of the architecture can be described and mathematically compared to determine whether the Wright Space exists. Thus, the

purpose of this paper is not to test prospect-refuge theory, but rather to methodically examine several of the designs that have been repeatedly presented as ideal examples of prospect-refuge theory in architecture.

The isovist method used in this paper has several theoretical and technical limitations. First, it is only capable of providing quantitative data pertaining to the geometric properties of the environment by recording sight lines within the environment. The method is incapable of accommodating or modelling an individual's actual perception of the environment as personal factors such as physical stature, age, cultural background, education and previous experience all influence environmental perception [20, 21]. Furthermore, the role of prospect-refuge "symbols" (including the representational content of artwork on walls or decorative artefacts within an environment) cannot be assessed using this method. Technical limitations of the method include a lack of capacity to capture the experiential qualities of colours, surface textures or patterns, all of which may have a psychological effect on the experience of a space. Finally, isovist analysis is conventionally a two-dimensional method, focussed on plan geometry. To partially ameliorate this issue, data relating to floor-to-ceiling heights at each isovist generation position along the path is also recorded for analysis. Thus, while not a comprehensive three-dimensional review of each house, both two and three-dimensional geometric features are included in the results and analysis.

The paper commences with a brief introduction to Habitat theory, Prospect-Refuge theory and Hildebrand's application of these ideas in architecture. Thereafter isovist analysis is described along with the four hypothesised outcomes of the current investigation. These outcomes are the ones that are anticipated in the final data if the Wright Space exists in the five textile-block houses. Specific methodological details of this analysis are described in the following section before the data for each house is presented textually and graphically. The five houses that are analysed in this paper are the Millard ("La Miniatura"), Storer, Freeman, Ennis and Lloyd Jones houses. The paper concludes by reviewing the hypothesised outcomes in light of the final results.

2. Background to Prospect-Refuge Theory

Appleton's (1975) Habitat theory proposes that we possess an innate ability to assess whether an environment can satisfy our basic biological needs for survival. If the environmental conditions are perceived as being conducive to survival, we experience a positive emotional response. If the conditions are perceived as less suitable, we experience an anxious or restless reaction. Habitat theory maintains that such reactions impel humanity to seek environments that are conducive to survival, a process which allows people who are sensitive to these factors to live long enough to procreate, and thereby pass that environmental-preference onto future generations. Conversely, people occupying adverse environments may be exposed to hazards, and eventually eliminated from the population through natural selection.

The essential criteria underlying Appleton's model of environmental preference is the "ability to see without being seen" [10], an idea which he encapsulated in the combined spatial conditions of

prospect and refuge. Prospect is the property of an environment that offers an unimpeded opportunity to see, and therefore the capacity to locate distant resources, the route to these resources and the ability to identify any hazards that might be encountered along the way. Refuge is the property of an environment which offers an opportunity to hide or take shelter from hazards, both animate (other creatures) and environmental (storms, cliffs, etc.). Furthermore, environmental assessments are not limited to the physical properties of an environment but can also include “symbols” that, when interpreted by the observer, represent and thereby evoke prospect and refuge properties. Thus, Habitat theory describes the intuitive psychological response we feel when in environments that we perceive to satisfy our biological needs and manage our exposure to threats, whereas Prospect-Refuge theory defines the spatial, visual and formal elements that constitute such an ideal environment.

While Appleton’s theories were developed to explain landscape preference, he also argues that “there must be at least a *prima facie* case for thinking that prospect-refuge is not irrelevant to the analysis and criticism of architecture” [10]. In 1991 Hildebrand took up this challenge to argue that certain elements of Wright’s architecture – including long window bands, raised terraces, deep eaves and prominent chimneys – constitute potent prospect and refuge symbols. Moreover, the physical form of the interior of these houses allegedly features spaces that provide an ideal balance of enclosure and outlook. But most importantly, Hildebrand proposed that Wright’s use of constricted and twisting paths through space serves to heighten the experience of emerging from a smaller, labyrinthine passage, into a larger, open room with high ceilings and elevated views over surrounding areas.

Hildebrand also argues that several additional spatial characteristics are present in the paths through Wright’s houses, including screening devices and column placements that impede direct views through space and thereby create a sense of mystery that draws a visitor through the design to the centre of the living room. To support this argument Hildebrand draws on the work of Kaplan and Kaplan [22] to argue that mystery and complexity also play an important role in the Wright Space. Kaplan and Kaplan’s information variables of “legibility” and “coherence” seemingly combine into a single concept called “order” that Hildebrand argues is present in the modular grids that define Wright’s architecture, and which are especially prominent in the textile block designs. Hildebrand hesitates to provide a specific definition of what he means by complexity, but Scott proposes that complexity refers to a “setting’s spatial geometry, meaning its volumetric shape and internal articulation” [23].

Ultimately, Hildebrand defines the Wright Space as being made up of a series of thirteen factors several of the more tangible of which are used by Wright to choreograph a particular shifting balance between five spatio-visual factors as a person moves through space. The five factors – prospect, refuge, complexity, mystery and visual pull – are deliberately not constructed as oppositional pairs. As Hildebrand notes, in Wright’s architecture, “an increase in prospect have to be accompanied by a decrease in refuge” [9]. Furthermore, Hildebrand argues that Wright’s houses possess a design strategy wherein specific spatial qualities are simultaneously reinforced by multiple formal strategies. This quality, called “reduplication”, occurs when, for example, a narrow corridor has a low ceiling, or a

large room has a high ceiling, the combination of formal elements serving to emphasise the desired condition. Thus, the Wright Space is characterised by the changing and reduplicated relationship between these five factors, and not the presence of a single static condition.

The biological determinism of Appleton's theories of environmental preference is a source of significant controversy, with critics arguing for a counter position of cultural determinism [24, 25]. Discussing the legitimacy of these criticisms is beyond the scope of the current paper, instead this paper follows Bourassa [26] and Falk and Balling [27] to attribute environmental preference to a complex amalgam of biological, cultural and personal experience factors. Hildebrand's argument that the emotional appeal of Wright's architecture arises primarily from visual characteristics of prospect, refuge, mystery, complexity and pull, and the formal properties of Wright's architecture, can be easily defined, a quantitative review of the architecture at least, if not its emotional appeal, is definitely possible.

3. Isovists

An isovist can be conceptualised as a polygon drawn on a building plan that represents the extent of space that is visible in any direction from an observation point. Mathematical data used in isovist analysis is derived from the geometry of the polygon and includes direct measures such as the area and perimeter of the polygon and calculated measures including the ratio between the area and perimeter (Figure 1). Isovist analysis gained acceptance in architectural research after Benedikt and Davis demonstrated a rigorous method for generating isovist polygons, identified basic mathematical measures, developed graphical representations of data, and the concept of the isovist field [28, 29].

Figure 1: Annotated Isovist polygon

The isovist field imposes a regular grid over a building plan and generates an isovist polygon from the centre of each grid square. This allows for comparisons of spatial experience to be made from multiple alternate positions. Due to the large numbers of isovists required to achieve this effect, their generation is typically automated using software that exports graphical and numeric data [30-32]. Most software applications are only capable of producing two-dimensional isovists, and while examples of three-dimensional isovist analysis exist [33-35], researchers have not yet widely adopted this technology or determined how to interpret the results. The present paper employs a hybrid method, combining a comprehensive two-dimensional analysis with a limited incorporation of the third dimension, achieved by measuring the floor to ceiling height at the location of each isovist observation point.

Past research has demonstrated that several mathematical properties of isovists (area, radial line length, occlusivity, jaggedness and height) appear to correlate to spatial perceptions, including those relating to outlook, enclosure, mystery and complexity [14, 17-19, 36-38]. In addition to these

established measures, drift indicates direction and distance from the observation point to the centroid of the isovist. In order to survey the largest possible isovist area, a human observer with a limited ($\approx 180^\circ$) view cone, must align their direction of view to the direction of isovist drift. When standing at the centre of a square room drift direction and magnitude are negligible, when closer to a corner, facing the direction of drift will allow more of the room to be visible at any instant, and the greater the distance to the isovist centroid the stronger this effect becomes. Drift, therefore, has a high level of correlation to visual pull and intuitive directionality, the experiential property wherein the human eye is drawn (by combined spatial and formal cues) to look, and thereby move, in a direction. Drift magnitude (D_M) is the length, measured in metres, of this difference and Drift angle (D_A) is its angle, measured in degrees and where the direction straight ahead is 0° and directly behind is $\pm 180^\circ$. A positive value indicates visual pull to the left, a negative values indicates a visual pull to the right. The measures utilised in this paper and the experiential properties that are conventionally associated with them, are listed in Table 1. The correlation between experiential and measured properties proposed is based on the findings of past research [14, 17-19, 36-38]. Therefore, using these isovist measures, it is possible to interpret four of Hildebrand's experiential properties of the Wright Space in terms of hypothesised mathematical trends (Table 2). These four properties are all testable using the method employed in the present paper, and they form the basis for the concluding discussion of the results.

In particular, over the length of each path the 'Wright Space' is expected to shift from refuge to prospect dominance and show a correlation between different prospect and refuge measures changing simultaneously, while drift angle should remain below $\pm 75^\circ$ and drift magnitude and occlusivity measures should decrease.

In developing, testing and interpreting these properties, it is important not to confuse isovist measures with those derived from space syntax analysis. Applications of space syntax methods to view field analysis utilise graph-based approaches to determine the relationship between every observation point and every other observation point [39-40]. Because these measures relate to every point they are sometimes referred to *global* measures. In isovist analysis all observation points are independent and the measures relate only to the isovist geometry of the observation point from which they are derived [40]. These are often called *local* measures, because they do not describe the entire network of observation points. Because this paper is about a specific experience of space, local measures are more important than global ones.

Table 1: Isovist measures and perceptual indicators.

Isovist property	Measure	Spatial experience
Isovist area (A)	Area of isovist polygon.	Prospect and/or refuge.
Maximum radial line ($RL_{(L)}$)	Length of the longest single radial line used to generate the isovist.	Prospect.
Minimum radial line ($RL_{(S)}$)	Length of the shortest single radial line used to generate the isovist.	Refuge.
Occlusivity (O)	Total length of all occluded edges. Occluded edges are ones that are not defined by building surfaces, thus they are the unknown or ill-defined, part of the	Mystery.

	visual experience of a space.	
Proportional Occlusivity ($O:P$)	The percentage of the isovist perimeter (P) consisting of occluded (O) edges.	Mystery.
Jaggedness (J)	Jaggedness is the ratio of Perimeter ² to Area. A high J value indicates a more visually complex isovist.	Complexity.
Drift magnitude (D_M)	Distance from observation point to centre of mass of isovist polygon.	Visual pull strength.
Drift angle (D_A)	Angle between occupant facing direction and centre of mass of isovist polygon.	Visual pull direction.
Height (H)	Floor to ceiling height at isovist observation point.	Prospect and/or refuge.

Table 2: Hypothesised indicators of the Wright Space.

Property	Description	Mathematical Indicator
1	A shift will occur from refuge-dominant spaces near the start of the path in the entry foyer, to prospect-dominant spaces near its end in the living room.	From the start to the finish of the path: i) a primary indicator is that the linear trendlines generated for A and H will increase. ii) a secondary indicator is that the linear trendlines generated for $(RL_{(S)})$ will increase and $(RL_{(L)})$ will increase or remain stable.
2	The emotional impact of Wright's architecture is enhanced through reduplication of prospect and refuge geometry. Reduplication occurs where multiple indicators of prospect and refuge change simultaneously reinforcing same spatial experience.	From the start to the finish of the path: i) indicators of prospect and refuge will vary. ii) testing the relationship between each prospect and refuge indicator will reveal the degree of their correlation. Strong correlations provide evidence of reduplication while weak correlations show the indicators are relatively independent.
3	The space of the path should draw a person forward along the path toward the living space where the pull should then be at its lowest level.	From the start to the finish of the path, a linear trendline generated for D_M will decrease and across the path D_A will be within the range $\pm 75^\circ$ for $> 50\%$ of the path length. While a view cone in the range of $\pm 90^\circ$ is technically forward of the observer, angles beyond $\pm 75^\circ$ suggest a perpendicular rather than forward trajectory.
4	The levels of both mystery and complexity will decrease as the inhabitant moves from the entry to the living spaces and the hearth.	From the start to the finish of the path, a linear trendline generated for O , $O:P$ and J data will decrease.

4. Method

The present research uses isovists generated from new three-dimensional CAD models which were developed for this paper from Wright's final construction drawings [41] and supplemented with photographs of the completed works. The Lloyd Jones house is the only exception, because a final construction plan was not published. Instead, the model for this house is based on working plans [41, 42] and historic and contemporary photographs. Each of the house plans was then analysed using UCL Depthmap (version 10.14.00b). Several of these designs feature extensive, long distance views or are surrounded by high density vegetation for which accurate information is not readily available.

For this reason external doors were treated as being closed and windows as opaque. This situation is not unrealistic as a similar experience is encountered at night when internal lighting obscures external views. Including transparent windows would require modelling the entire extent of the views for each house (all of 1930's downtown Los Angeles in the case of the Freeman house). An alternative approach, not adopted here, is setting an artificial and arbitrary view distance limit which effectively sets the value for $RL_{(L)}$, thereby undermining the usefulness of this measure. This decision, while consistent with the theory being tested, does limit the effectiveness of some possible determinants of prospect and it ignores the impact of external landscape symbols and hazards. Furthermore, because of this limit to the available data, it is not possible to analyse the external paths leading to the house although they are included in the general discussion and diagramming in each case.

Wright was notorious for ignoring the stature of his clients and for calibrating the vertical dimensions of his designs to his own body. For this reason, each isovist is generated at a height of 1.65 meters above floor or stair level; approximately the height of Wright's eyes, when standing. The isovist field is generated using a 100mm grid, and the data selected for analysis is every 5th observation point located on a path from the front door of each house to the living room and hearth. Selecting every 5th point of the 100mm grid approximates the stride length of a person of Wright's stature and allows an accurate tracing of the path.

Where possible, the paths identified in each house replicate those documented by Hildebrand [9]. If Hildebrand did not explicitly document or describe the path, then they were generated using rules extrapolated from his diagrams and text. Thus, these paths all follow straight lines, use only 90-degree turns and minimise the distance travelled and the number of turns required to reach their destination. Paths avoid dedicated service areas – such as kitchens or servant's entrances – pass one meter in front of the living room hearth and terminate in the centre of the living room, unless the design requires the occupant to pass through the room centre before reaching the hearth where the path will end. The centre of the living room is defined as the position identified by the intersection of lines drawn from diagonally opposite corners of the room. In instances where the living room is located on a different storey to the entrance, a hybrid floor plan was created to allow for the seamless isovist analysis of the spatial experience of vertical circulation [38].

Other than the standard measures generated by the software, several additional measures inform this analysis. These were calculated using a spreadsheet and the data output from Depthmap. Following Depthmap analysis, each of the selected isovist observation points was located in the CAD model and the ceiling height at this location recorded. The final function provided by the spreadsheet was plotting the recorded data for all results in a series of graphs. The first graphs plot isovist area (A) and jaggedness (J), the second graphs plots the maximum ($RL_{(L)}$) and minimum ($RL_{(S)}$) length radial lines and ceiling heights (H), the third graph plots data for absolute (O) and proportional ($O:P$) occlusivity and the final plots drift angle (D_A) and magnitude (D_M). Each graph incorporates a number of reference points that correspond to the accompanying cut-away isometric diagram of the path through each house to allow for an intuitive visual analysis of the results that also preserves the mathematical values. The reference points are signified in the text using curly-bracketed numbers, {1} for exterior

points and capital letters {A} for interior positions. A short textual description of each path, including specific mathematical values corresponding to reference points, accompanies the graphic presentation of results.

5. Results

5.1. Millard House, “La Miniatura” (1923)

The path into and through La Miniatura is relatively short, commencing on the exterior terrace with two changes of direction {1}, before entering the foyer and following three further 90-degree turns to the centre of the living room {C} and the hearth. The isovist areas along the path are relatively consistent ($35\text{m}^2 < A < 52\text{m}^2$), suggesting limited variation in prospect and refuge. Millard later complained about the lack of an entry vestibule [43]. The lengths of the longest radial lines fall marginally across the span of the path, while the shortest increases slightly, a pair of results which, when coupled with falling jaggedness, indicates the movement toward a rounder isovist polygon, with limited complexity ($J \sim 27$) and little mystery ($O \sim 25\text{m}$). The “visual pull” of the path is strong at the start ($D_M = 4.7\text{m}$, $D_A = -45^\circ$), drawing the visitor from the front door toward the centre of the living room {C} where it abates ($D_M = 0.3\text{m}$). Along the path the visitor also moves from an entry space with a low ceiling to a double height room {B}, a factor which correlates more with the rise in shortest radial length than an increase in longest ($RL_{(S)} \sim 2\text{m}$). The visitor must then resist a minor visual pull ($D_M < 1.6\text{m}$) to move back under the protective ceiling {D} and toward the hearth ($H = 2.0\text{m}$). Along most of the length of the path the visitor finds only low levels of mystery ($O \sim 18\text{m}$, $O:P \sim 38\%$). Thus, the path might be characterised as being short and lacking significant variation in prospect, mystery and complexity, however it does demonstrate the significance of the third dimension, with room height being used to enhance or dramatize an otherwise balanced prospect-refuge condition.

Figure 2: Millard House, annotated axonometric.

Figure 3: Millard House, isovist area and jaggedness.

Figure 4: Millard House, radial line lengths and ceiling heights.

Figure 5: Millard House, occlusivity and proportional occlusivity.

Figure 6: Millard House, drift direction and magnitude.

5.2. Storer House (1923)

Entry to the house is by way of the second of five doors opening to the front terraces and, like La Miniatura, it lacks a separate entrance vestibule, delivering the visitor directly into the lounge room {A}. From this position the visitor is provided with a large (for this house) isovist area ($A = 36\text{m}^2$), long interior view distances ($RL_{(L)} = 9.4\text{m}$) and a strong visual pull ($D_M = 3.2\text{m}$) into the centre of the lounge room. However, from this somewhat grand entrance, the path to the living room and hearth is actually largely hidden, requiring six 90-degree turns and spiralling up around the central chimney to the more private living room on the level above. The experience of ascending the stair is variable, and to even approach the base of the stair is counterintuitive, involving the visitor resisting the visual pull into the lounge room ($D_M = 2.9\text{m} \rightarrow 4.2\text{m}$, $D_A > -46^\circ \rightarrow -161^\circ$). Only after the visitor is partway up the stairs {B} does the adverse pull decrease, and mystery increase ($O:P \sim 50\%$). The stairs themselves are a refuge-dominant zone ($10\text{m}^2 < A < 20\text{m}^2$) with view distances that are much shorter and more consistent than at the start of the path ($RL_{(L)} \sim 6\text{m}$ and $RL_{(L)} \sim 3\text{m}$). At the top of the first flight of stairs some of these properties change, with visual complexity ($J \sim 87$) being created by glimpsed views toward the upper level bedrooms although this is also a distraction from the main path, pulling the visitor to the left ($D_M = 1.4\text{m}$, $D_A > 83^\circ$) away from the route to the living area {B→C}. Mystery increases as the visitor approaches the third turn in the path {C} ($O:P \sim 55\%$) revealing the final flight of stairs, before stepping out from under the first floor into a space with high ceilings ($H = 2.1\text{m} \rightarrow 4.0\text{m}$) and the first views of the living room {D}. After passing the centre of the living room {E}, the view from the hearth, the end-point of the path, has limited complexity ($J = 26$) and mystery ($O \sim 7\text{m}$, $O:P 25\%$) with no vistas to adjacent interior spaces. Sweeney describes the Storer house as offering

“marked contrasts between its public and private spaces [...]. The living room, with its fifteen-foot ceiling, is the spatial climax. [...] The bedrooms, on the other hand, are closed, cavelike spaces” [41].

Figure 7: Storer House, annotated axonometric of the path.

Figure 8: Storer House, isovist area and jaggedness.

Figure 9: Storer House, radial line lengths and ceiling heights.

Figure 10: Storer House, occlusivity and proportional occlusivity.

Figure 11: Storer House, drift direction and magnitude.

5.3. Freeman House (1923)

The approach path to the house takes several steps down from the driveway {1} and a turn into a loggia that leads to the front door and a poorly illuminated entry hallway beyond. The entry {A} is a

small, refuge-dominant space ($A \sim 22\text{m}^2$) with a distant view of the masonry-mass of the hearth providing a degree of complexity ($J = 118$) and a strong visual pull leading deeper into the house ($D_M = 4.5\text{ m}$). Moving toward the hearth, the narrow corridor temporarily restricts views ($A \sim 17\text{m}^2$) and reduces mystery ($O = 17\text{m}$, $O:P = 49\%$). Approaching and crossing, the living room threshold {B} allows this space to enter view. This causes a dramatic increase in prospect ($A = 65\text{m}^2$) and while absolute occlusivity rises ($O \sim 20\text{m}$), proportional occlusivity ($O:P \sim 36\%$) falls as visual pull shifts left ($D_A 4.5^\circ \rightarrow 60.5^\circ$) to focus attention on the centre of the room. Wright further enhanced the prospect characteristics of the living room with raised ceilings forming a tripartite division of the space, centred on the hearth {C}. The visitor experiences this in two stages, the first when crossing the threshold {B} into the living room where the ceiling height increases by one and one-half blocks ($H \sim 2.4\text{m} \rightarrow 3.0\text{m}$). Here the visitor must negotiate a dogleg manoeuvre to pass under a ceiling beam, the same height as the previous corridor, before moving to the front of the hearth {C} under a ceiling three blocks higher than the entry corridor ($H \sim 3.6\text{m}$). Wright's usual low ceiling – protecting the hearth and creating a sense of refuge – is absent here, prospect dominates signalling the largest ($A \sim 75\text{m}^2$), if not longest, views from the path ($RL_{(L)} \sim 9.9\text{m}$). The centre of the living room {D} offers a similar prospect-dominant experience, but with the entire room and kitchen visible, this location has only limited mystery ($O:P = 20\%$) and complexity ($J = 37$) coupled with a slight visual pull toward the kitchen ($D_M = 1$, $D_A = -100^\circ$).

Figure 12: Freeman House, annotated axonometric of the path.

Figure 13: Freeman House, isovist area and jaggedness.

Figure 14: Freeman House, radial line lengths and ceiling heights.

Figure 15: Freeman House, occlusivity and proportional occlusivity.

Figure 16: Freeman House, Drift direction and magnitude.

5.4. Ennis House (1924)

The entry path is by way of a low, dark passage that Hildebrand likens to a Palaeolithic Aurignacian cave. The path analysed here is the one documented and experienced by Hildebrand (Figures 17 -

21), not the one originally designed by Wright, which was intended to take the visitor through the garden to the loggia adjacent to the living room. Sweeney describes the entry as evoking the “strange sense of entering a grand house through the basement”; a space “suggestive of pagan ritual” [43]. The entry {A} features small isovist areas ($A < 30\text{m}^2$), short view distances ($RL_{(L)} < 12\text{m}$, $RL_{(S)} < 1\text{m}$) and low ceilings ($H \sim 2\text{m}$) confirming a strongly refuge-dominant experience. Low jaggedness ($J < 40$) and low absolute occlusivity ($O < 30$) appear to suggest that the entry space is both simple and straightforward, however a high proportion of the limits of this refuge-dominate space are occluded ($O:P \sim 65\%$). Thus, while only a small space, it implies the presence of a more extensive space that is anticipated but remains unseen, while visual pull is initially strong ($D_M \sim 4\text{m}$, $D_A = -25^\circ$) – directing the visitor first forward and to the right. Turning to approach the stairs requires the visitor to resist a mild visual pull until this becomes negligible at the base of the stairs {B} and the entry spaces are no longer visible. Ascending the stairs requires resisting an initial visual pull to step out from beneath the first floor ($H \sim 1.9\text{m} \rightarrow 7.4\text{m}$) and allows the first glimpses of the services areas, located above the entry, to become visible thereby increasing the visual pull the visitor must overcome ($D_M 1.4\text{m} \rightarrow 4.5\text{m}$, $D_A = 166^\circ \rightarrow -21^\circ$).

From the top of the stairs {C} the visitor’s view remains restricted with only glimpses of the service areas and dining room. Moving forward through a dogleg turn into the corridor, the entire length of the loggia is brought into view, along with glimpses of the living room. As these spaces become visible, a rapid increase in isovist area ($A = 30\text{m}^2 \rightarrow 95\text{m}^2$), maximum view distance ($RL_{(L)} = 14\text{m} \rightarrow 25\text{m}$), jaggedness ($J = 148 \rightarrow 329$), occlusivity ($O = 45\text{m} \rightarrow 130\text{m}$), and visual pull ($D_M = 1.5\text{m} \rightarrow 4.5\text{m}$) occurs, all of which draw the visitor toward the hearth {D}. As in the Freeman house, the Ennis house hearth lacks a low protecting ceiling and is located on the exterior wall of the building, both features atypical of Wright’s work. Finally entering the living room through a colonnade and beneath a low beam {E}, visual pull draws attention toward the boundary between living and dining rooms where it will remain focused until the end of the path {F}. Isovist areas remain high in the prospect-dominant space ($A = 90\text{m}^2$), a property which is enhanced by high ceilings ($H = 6.9\text{m}$). The columns that divide the dining space from the living room also ensure the continued presence of heightened occlusivity and jaggedness, contributing to the room’s reputation for complexity and mystery. In total, Hildebrand argues that this space offers “some of the most splendid interior prospect in Wright’s career, perhaps in all architecture” [9]. While the veracity of the larger part of this claim is beyond the scope of the present paper, the data for the living room features many of the three-dimensional properties that might be anticipated in supremely prospect-dominant room.

Figure 17: Ennis House, annotated axonometric of the path.

Figure 18: Ennis House, isovist area and jaggedness.

Figure 19: Ennis House, radial line lengths and ceiling heights.

Figure 20: Ennis House, occlusivity and proportional occlusivity.

Figure 21: Ennis House, drift direction and magnitude.

5.5. Lloyd Jones House (1929)

The path through the Lloyd Jones house is largely linear in nature, being on one level and with only four turns, three of which are caused by movement within the L-shaped living room to reach its centre {E} and then the corner hearth {F}. In the entry {A}, the visitor experiences a strong visual pull ($D_M \sim 7m$) through the constrained foyer space ($A < 50m^2$) with seemingly low levels of mystery ($O = 55m$) and complexity ($J \sim 100$). As the visitor progresses along this path, the isovist area rises rapidly ($A = 60m^2 \rightarrow 143m^2$) and the geometry of the space draws the visitor toward the living room where some of the longest views in the house, and indeed in any of the textile block houses, are attained ($RL_{(L)} \sim 30m$). Moving along the path into the lounge area {B} causes isovist area and occlusivity to continue growing ($A = 160m^2 \rightarrow 234m^2$, $O = 90m \rightarrow 120m$) while proportional occlusivity remains high and stable ($O:P \sim 65\%$), assisted by glimpsed views through the colonnade into the adjacent dining room. The prospect-oriented characteristics of this location are enhanced by a two-textile-block increase in ceiling height {C} throughout the lounge and living rooms ($H \sim 3m \rightarrow 3.9m$). Following the direction of visual pull forward and right the visitor steps under a low ceiling beam and through a dogleg {D} in the path to emerge under the living room lantern where ceiling heights are again raised by two blocks ($H = 5.3m$, 4.5 blocks higher than the underside of the beam). Continuing forward, visual pull suddenly switches orientation to be behind the visitor ($D_A \sim -180^\circ$) as the majority of the dining room comes into view for the first time and maximum view distance and isovist area continue to increase. From this stage, the visitor is required to resist an increasingly strong visual pull ($D_M \sim 0m \rightarrow 10m$) to proceed forward, before turning, moving under the same low ceiling beam and toward the hearth {F}. While the hearth does offer slightly reduced view distances and isovist areas, and the ceiling is lower than that

of the lantern, this location remains prospect-oriented, but also offering a high degree of mystery ($O:P = 73\%$) and complexity ($J \sim 200$) relative to the other, much smaller houses. The only indication of an attempt to provide a sense of refuge at this location is the disruption of the façade glazing to feature a solid external wall adjacent to the hearth.

Figure 22: Lloyd Jones House, annotated axonometric of the path.

Figure 23: Lloyd Jones House, isovist area and jaggedness.

Figure 24: Lloyd Jones House, radial line lengths and ceiling heights.

Figure 25: Lloyd Jones House, occlusivity and proportional occlusivity.

Figure 26: Lloyd Jones House, drift direction and magnitude.

6. Discussion

To support the assessment of the four hypothesised indicators described previously (Table 2), the data derived from each path was converted into a linear trendline using the “least-squares” method

and charted against a normalised scale for path-length. Thus, the horizontal axis of the graphed results in this section show the entry to the left and the end of the path to the right, regardless of the physical length of each path.

6.1. Property 1: Prospect and Refuge

The most important property of the Wright Space is that it allegedly features a shift, across the length of the path, from refuge-dominant to either prospect-dominant or prospect-refuge balanced spaces. The primary indicators that this property is present in a house are that trendline data for A and H will increase and the secondary indicator is that $RL_{(S)}$ will increase while $(RL_{(L)})$ will increase or remain stable (Figures 27-28). The results for A show that four of the paths increase, although one of these is almost level (Storer), and one decreases (Millard). H and $RL_{(S)}$ increase in every design. For $RL_{(L)}$ the data shows that, three decrease. Thus, of the ten primary indicators, nine support the hypothesis, and of the ten secondary, seven support the hypothesised condition.

Figure 27: Trendlines generated for isovist Area (A) and maximum radial ($RL_{(L)}$) data.

Figure 28 Trendlines generated for minimum radial ($RL_{(S)}$) and floor to ceiling height (H).

6.2. Property 2: Reduplication

Reduplication is the second most important characteristic of the Wright Space. Hildebrand argues that Wright enhanced the emotional power of his designs by creating forms that cause multiple prospect and refuge indicators to vary simultaneously and cooperatively. This is measured by calculating the Pearson correlation coefficient for each combination of prospect and refuge indicators (A , H , $RL_{(S)}$ and $RL_{(L)}$) in each house. Correlation values in the range 0 – 0.3 are considered weak, 0.3 - 0.7 moderate, and 0.7 - 1.0 are strong [44].

Table 3: Correlation values between prospect and refuge indicators in each design.

	Millard House				Storer House				Freeman House				Ennis House				Lloyd Jones House			
	A	H	$RL_{(S)}$	$RL_{(L)}$	A	H	$RL_{(S)}$	$RL_{(L)}$	A	H	$RL_{(S)}$	$RL_{(L)}$	A	H	$RL_{(S)}$	$RL_{(L)}$	A	H	$RL_{(S)}$	$RL_{(L)}$
A	X	0.36	0.35	0.05	X	0.26	0.62	0.39	X	0.80	0.51	-0.72	X	0.29	0.38	0.82	X	0.74	0.70	0.37
H		X	0.79	-0.34		X	0.56	-0.64		X	0.73	-0.60		X	0.25	-0.00		X	0.72	0.22
$RL_{(S)}$			X	-0.64			X	-0.47			X	-0.51			X	0.11			X	0.41
$RL_{(L)}$				X				X				X				X				X

Four of the designs show at least one strong positive correlation between two indicators. Of these strong correlations, three exist between H and $RL_{(S)}$, two between H and A , and one each between A and $RL_{(S)}$, and A and $RL_{(L)}$. This suggests that Wright's preferred technique of reduplicating prospect and refuge characteristics was manipulation of ceiling height and distance to a solid surface. Four designs also show at least one negative correlation between $RL_{(L)}$ and other measures. One of these is strong (Freeman house) six are moderate. The single negative correlation in the Ennis house is so weak as to be negligible (-0.00005). Interestingly, an intuitive reading of reduplication suggests that the best example is found in the Storer house – where the visitor is forced to experience a prospect-dominant entry, then a refuge-dominant lower stair, leading to a brief expansion and immediate contraction of view before finally emerging from the stairs into the prospect-dominant living room – yet this is the only design without strong positive or negative correlations between prospect and refuge indicators.

6.3. Property 3: Drift

A third characteristic of Wright's architecture is that it is meant to draw people through space using formal and visual cues, to come to a position of rest in the living room, near the hearth. This means that the trendline for D_M should show decreasing values across the path, and that D_A should be in a forward direction, ideally within a range between $\pm 75^\circ$ for the majority of the length of the path (Figure 29). The trendlines for the D_M data conform to this hypothesised condition in three of the five cases, with the Ennis and Lloyd Jones houses being exceptions. For the D_A data, the hypothesised condition is true for all cases except the Storer house where only 47% of observation points match the hypothesis. However these factors should not be considered in isolation. The Millard, Freeman and Ennis houses, with generally forward visual pull, include instances where D_A suggests the design discourages forward momentum; however these locations typically correspond to very low D_M values suggesting the strength of this visual pull is negligible. In these houses, instances of high D_A values often correlate to corners on the path where direction of visual pull shifts just prior to, or just following, a change of direction by the observer and might be considered an artefact of the particular analytical

method utilised here. The Lloyd Jones house generally conforms to this rule; however the strongest instance of visual pull also corresponds to a drift angle of 93.4° . Thus seven of the ten drift indicators conform to the hypothesised result.

Figure 29: Trendline generated for Drift Magnitude (D_M) and data for Drift Direction (D_A) data.

6.4. Property 4: Complexity and Mystery

The final property which is expected in the Wright Space is that levels of mystery and complexity will decrease along the path from the entry to the living space and hearth. Thus, linear trendlines developed for $O:P$ and J data will decrease in value from left to right (Figure 29). For $O:P$ and J data trends this is true of three cases (Millard, Freeman and Storer). As was the case with several of the previous sets of results, these three houses share many spatial similarities and form a subgroup of the textile-block works, while the Ennis and Lloyd Jones houses tend to conform to a different pattern.

Figure 30: Trendlines generated for Occlusivity Perimeter ratio ($O:P$) and Jaggedness (J) data.

7. Conclusion

In total, 26 out of the 35 primary indicators analysed in this paper supported the presence of the four major measurable properties of the Wright Space. Taking into account only these primary indicators, the Freeman house is the design which most closely corresponds to the Wright Space, having the full set of spatio-visual properties, and the Storer and Millard houses each possess the majority of these properties. In contrast, the Ennis and Lloyd Jones houses rarely conform to any of the anticipated patterns having few spatial and visual similarities to the other three designs. Thus, considering only the primary indicators, the balance of data (74%) gathered and analysed in this paper does support Hildebrand's proposition, but it is not especially compelling in volume, or given that the Ennis house, a critical part of Hildebrand's argument, is consistently amongst the group that do not conform to the Wright Space pattern.

Seven out of ten secondary indicators also support Hildebrand's conception of the Wright Space. However, the use of $RL_{(L)}$ as an indicator of prospect, highlights the difficulties with translating a perceptual concept into a mathematic measure. $RL_{(L)}$ tends to be highest when the viewer is approaching the living room as this allows for the longest single view through this space. However, when the viewer enters the prospect-dominant living room, the value of $RL_{(L)}$ actually decreases as the length of the view is split in two or more directions.

Acknowledgements

This work was supported by The Australian Research Council under an ARC Fellowship (FT0991309) and an ARC Discovery Grant (DP1094154). The role of the ARC in this research is limited to providing funding only.

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