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Using Isovists to Analyse Prospect-Refuge Theory: An Examination of the Usefulness of Potential Spatio-Visual Measures.

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Frank Lloyd Wright famously called for buildings to be designed in such a way as to promote a harmonious relationship between their occupants and the environment. Some of his most famous early organic works are the Prairie Houses, open-planned residences that feature distinct visual connections between their living spaces and exterior views. In 1991, Hildebrand argued that such visual and spatial properties are ideal for evoking positive emotional responses. To support this proposition, Hildebrand drew on prospect-refuge theory, which suggests that semi-enclosed locations that frame an outlook meet an innate human desire for inhabiting places that offer enhanced survival opportunities. Moreover, Hildebrand identified several of Wright's designs, lead by the Heurtley house, which Hildebrand argued clearly demonstrate this concept. While this proposition has been widely referenced, there is little evidence that the spaces in Wright's Prairie Houses are similar in the way they shape and control vision. Moreover, the challenge facing architects who wish to design spaces that feature heightened prospect-refuge relationships is that there is no clear and consistent way of measuring these properties. It is this challenge, of measuring the geometric properties of the space-view relationship, that is the focus of the present paper. Using the Heurtley house as an example, this paper examines the capacity of mathematical visibility analysis techniques to quantify prospect-refuge characteristics. Thus, this paper is not a test of prospect-refuge theory, but of the viability of mathematical techniques for use in such a test. Specifically, the paper uses isovists to model the visual experience of the living room in the Heurtley house before considering if the mathematical results are capable of usefully quantifying prospect-refuge characteristics.

Keywords: Prospect-Refuge Theory, Isovist Analysis, Frank Lloyd Wright, Heurtley House

Introduction

Frank Lloyd Wright was one of the 20th century's most successful architects, leaving behind a complex legacy of evocative designs, many of which allegedly elicit positive emotional responses from their inhabitants (Lind 1994; Heinz 2006). Multiple attempts have been made to explain these phenomenological qualities although few have been as enduring as Grant Hildebrand's (1991) application of prospect-refuge theory to Wright's domestic architecture. Hildebrand examined the combined visual and spatial properties of Wright's architecture, identifying thirteen elements that are also characteristic of prospect-refuge theory. Hildebrand accepts that these architectural elements are not unique to Wright's work; however he argues that only Wright consistently incorporated a minimum of 10 of these elements in each of his designs. For Hildebrand, it is the combination and pattern of use of these elements – as exemplified in several of Wright's designs including the Heurtley house – that is responsible for the strong emotional response felt by visitors.

Hildebrand's application of prospect-refuge theory has been instrumental in propagating its adoption as both an analytical and a design strategy in architecture (Weston 2002; Roberts 2003; Unwin 2010). However, despite its evocative qualities, there is little empirical evidence confirming the validity of his interpretation of Wright's architecture. Indeed, one of the basic tenets of this argument, that Wright's houses exhibit similar visual and spatial properties, has never been empirically tested. Past studies have used mathematical and computational means to examine the formal similarities of Wright's domestic architecture (Koning and Eizenberg 1981; Laseau 1992; Ostwald and Vaughan 2010; Vaughan and Ostwald 2011). However, no previous study has considered the relationship between space and outlook; a connection that is central to arguments about prospect-refuge theory. Therefore, the present paper is concerned with the empirical methods that might be used to test whether the spatio-visual geometry of Wright's architecture is consistent or not. This paper does not test prospect-refuge theory, but rather it examines the viability of a particular computational or mathematical technique for quantifying various visual properties of a building that might, in turn, be used to analyse the prospect-refuge qualities of an architectural design. As such, the terminology used in this paper refers to mathematical rather than phenomenological concepts and debates about the actual psychological merits of prospect-refuge theory, or indeed its presence in Wright's architecture, are beyond the scope of the present work. The particular computational method of investigation used in this paper is isovist analysis and the test case for this research is Wright's Heurtley house.

An isovist is the set of all points in space that are visible, in any direction, from a single, fixed location. An isovist is useful because it can be rigorously constructed, using repeatable graphical and numeric rules, and its outcome may be mathematically analysed. Whereas many arguments about the relationship between space and vision, like Hildebrand's rely on qualitative propositions and poetic descriptions, the isovist provides a quantitative approach to one particular component of the experience of space. In the past the isovist method has proven useful in providing insights into spatial cognition (Meilinger *et al.* 2012), way finding (Conroy 2001), social structure (Markhede and Koch 2007) and spatial occupation (Ellard 2009). Isovists have also been used for the systematic identification of characteristic spaces; for example, the most visible or hidden locations in a plan

(Conroy-Dalton and Bafna 2003; Wiener and Franz 2005). Importantly in the present context, Stamps III (2005) suggests that skewness, a statistical measure derived from isovist geometry, “would seem to be a measure of both prospect and refuge” (740).

This paper commences with a overview of both isovist analysis and prospect-refuge theory. Thereafter the research analyses the spatio-visual characteristics of the living room of the Heurtley house. Using a new computer model of the house, three isovists are generated, and their measured and calculated properties are compared with their environmental preference characteristics; prospect, refuge, mystery and complexity. The relative validity or usefulness of each of these measures, including several proposed in past research, is then tested using textual, graphic and numeric means.

This paper has several technical and theoretical limitations; the former of which are described in a later section of this work that details the methods used to construct and analyse the isovists. However, there are also some obvious, but nevertheless important theoretical limits that need to be confirmed. Prospect-refuge theory is about human emotional or psychological reactions to combinations of environments, objects, forms and spaces. These reactions, as past studies have shown, can be influenced by a wide range of personal factors including age, cultural background and education as well as particular tectonic and spatial conditions, like the colour or texture of building materials and the quality of the light. Furthermore, Wright’s houses, as Hildebrand correctly identifies, are often richly textured, with carefully designed ornament, prominent fireplaces which provide physical warmth, and dramatic outlooks to natural landscapes. None of these factors can be studied using isovists or related computational means. However, a recurring theme in the architectural application of this theory is that a particular pattern of formal and spatial elements can, in combination with these other more ephemeral characteristics, provide a beneficial emotional reaction. It is the geometric characteristics of this spatial and visual pattern that the present paper is focussed on.

Background: Isovist Analysis

The conceptual origins of isovist analysis can be traced to the work of James Gibson (1947; 1966) an environmental psychologist working in the field of sensory perception. Gibson (1966; 1979) proposed the idea of an optic array; a conceptualisation of vision emphasising all visual information rather than just an object’s subtended angle. It was Michael Benedikt (1979) who first defined the isovist and, working with Larry Davis (Davis and Benedikt 1979), provided a stable and repeatable method for isovist generation. For Benedikt (1979), the isovist is “the set of all points visible from a single vantage point in space with respect to an environment” (47). The traditional representation of a single isovist is a simple polygon drawn over the floor plan of a building and with the observation point identified. The stability and repeatability of Davis’ and Benedikt’s method provided a solid foundation for future researchers. Their procedure required tracing lines from surface vertices in the plan to an observation point. These lines were then extended beyond their vertex until meeting a surface; this is called an “occluding radial” (Fig. 1). The isovist is the smallest polygon containing the observation point and consisting of occluding radials and environment surfaces (Fig. 2).

Figure 1. Vertex lines traced to observation point. Occluding radials shown as solid lines, vertex lines shown dotted.

Figure 2. Isovist polygon defined by surfaces and occluding radials.

While the method developed by Davis and Benedikt (1979) served researchers well, with increasing computational power, new possibilities for isovist generation have become available. For example, Batty (2001) developed a process wherein automated agents “walked” from the observation point at set angular displacement intervals until reaching a surface. Christenson (2010) refined this method by generating lines at a fixed angular increment from the observation point. In either method, the end of each radial line is linked to the end of its neighbour, forming a polygon. Further improvements in computer processing power have allowed for three-dimensional visibility analyses to be undertaken (Yang *et al* 2007; Morello and Ratti 2009), however most practical applications continue to use the two-dimensional variation.

Background: prospect-refuge theory

Jay Appleton (1975) famously asked what do “we like about landscapes and why do we like it” (vii). These questions, proposed in various forms by different authors, have since been recognised as the catalyst for the rise of research into environmental preference. In response to these questions, Appleton proposed two interconnected theories; habitat theory and prospect-refuge theory. Habitat theory outlines a supposedly innate biological motivation for seeking environments which are conducive to survival. Prospect-refuge theory “opens the way to the analysis of landscapes in terms of their strategic appraisal as potential habitats” (Appleton 1975, viii). Stephen and Rachel Kaplan argue that such appraisals occur virtually instantaneously, intuitively and unconsciously (Kaplan 1975; Kaplan and Kaplan 1982; Kaplan 1987).

Appleton’s biological motivator is derived from the sense of pleasure people experience when occupying an environment conducive to survival. He describes this instinct as driving humans to seek a location with the ability “to satisfy all our biological needs” (1975, 70). The concept of environmental preference derived from biological roots is not limited to the human species. Woodcock (1982) has argued that similar traits exist in other vertebrates and researchers have identified specific genes governing environmental preference in insects (Singer *et al.* 1988; Fox 1993; Barker *et al.* 1994). As Wecker (1964) argues, this implies “that animals show a preference for the

kind of environments in which their species prospers. In some instances, this occurs even if the animals have been raised in the laboratory and have had no direct experience with the environment in question” (qtd. in Kaplan 1987, 15). Despite this, environmental preference is not a purely biological phenomenon; past research suggests “that landscape preference is a complex amalgam of factors, with innate preferences forming a foundation which is then overlain by both sociocultural and personal experience factors” (Falk and Balling 2009, 489).

While habitat theory is useful for explaining the motivation for seeking particular environmental conditions it does not identify exactly what these conditions are. Appleton (1975) postulated that humans seek environments that offer a particular combination of outlook and enclosure; respectively called prospect and refuge. Prospect offers the “unimpeded opportunity to see” (73) while refuge offers “an opportunity to hide” (73). In survival terms, prospect allows predators to locate prey, and prey to identify approaching predators. Refuge allows predators and prey to remain undetected. The combination of these elements represents a supposedly ideal situation wherein predators can stalk unsuspecting prey, or prey can observe predators while remaining hidden. Appleton (1975) argues that each of these conditions serves to increase survival odds. Thus the ability to “see without being seen” (73) allows animals to thrive, resulting in environmentally derived pleasure.

Prospect-refuge theory offers a way of understanding the world through combinations of various “symbols”; often ill-defined forms, spaces and objects that Appleton argues represent or evoke emotional responses like happiness, fear or inquisitiveness. The capacity of such symbols to explain human emotional responses is inherently seductive and it no doubt assisted the theory to be adopted by a range of disciplines, although a high level of interpretation and abstraction has been required to make this transition possible (Heyligers 1981; Appleton 1988). The problem is that the level of subjectivity in the symbols means that universal measures for prospect-refuge theory do not exist; rather indirect, qualitative indicators are used to identify ideal conditions. Thus, in architecture Hildebrand (1991, 1999) uses a combination of historic and phenomenological arguments to support his variation of prospect-refuge theory wherein Appleton’s symbols have been translated into marginally more tangible forms: for example, the fireplace, the deep eaves and the horizontal window.

The acceptance of prospect-refuge theory into environmental preference research allowed additional measures to be introduced to prospect-refuge analyses. Probably the most persuasive of these have been complexity and mystery. Scott (1993) states that “[c]omplexity refers to the amount of visual information offered by an environment” (25) and Kaplan (1988) identifies that a “scene high in mystery is one in which (a person) could learn more if (they) were to proceed farther into the scene” (50). While complexity and mystery are not the same thing, they are often linked in research in this field because they both represent the presence of an intuitively understood, but not yet known, spatial potential or property. This unknown potential – potential to ambush or to be ambushed – directly ties these types of spatial experience to Appleton’s habitat theory. Furthermore, in addition to interpreting Appleton’s theory in terms of architectural symbols Hildebrand (1991) also makes a case for the importance of mystery and complexity as part of the total experience of a larger network of spaces required to traverse a house. In essence, Hildebrand argues that Wright’s living room spaces are at the

conjunction of a high proportion of prospect-refuge symbols and that the visual complexity of the approach path taken from the entry to the living room evokes a sense of mystery or discovery.

Returning to the challenge of translating symbols, the problem with the architectural variation of prospect-refuge theory is the lack of specificity. Hildebrand identifies “low ceilings” as a refuge symbol and “horizontal windows” as a prospect symbol. Yet, both of these properties are present in a large number of structures that would not otherwise be considered conducive to safety and psychological well-being. The majority of factories produced in the aftermath of the industrial revolution contain both of these symbols, as do many other institutional types including the clinic and the prison. The problem then is not necessarily the symbols themselves, but rather their ill-defined nature. Something more defined and repeatable is needed if this theory is to be critically examined.

Kaplan (1987) suggests that a “promising procedure might be to use the feature information” – the tangible properties of the symbols – “to construct a rough conceptual model of the three-dimensional space represented by the scene” (22). Analysing such a model would then allow the use of quantitative geometric measures of the environment, rather than relying solely on the symbolic interpretation of a scene. Geometric measures, such as those developed through isovist analysis, may then be analysed mathematically to derive universal measures of particular prospect-refuge patterns. This is the procedure the present paper follows, to extract mathematically coherent information from a set of spatial conditions that have previously been analysed only from a qualitative perspective. However, the advantage with studying architecture is that the model Kaplan describes can be a very close representation of the object of study.

Research Method

The present paper uses Frank Lloyd Wright’s Heurtley house as a focus to test the capacity of isovists to be used for prospect-refuge analysis. For this research a new 3D CAD model was constructed based on measured drawings and documentary photographs of the house (Storrer 1993; Pfeiffer and Futagawa 1987). This design, from the early part of Wright’s career, was completed in 1902 and is located in the Chicago suburb of Oak Park (Fig. 3-4). It features two levels and no basement and, unlike typical American homes of the period, the living and dining areas are on the upper level so that Wright could raise their ceilings and capture elevated views of the neighbourhood (Hildebrand 1991; Lind 1994). The house features a fireplace located at the heart of the building, on the internal edge of the living room and opposite a horizontal band of windows (Fig. 5-6). These elements or symbols, coupled with an open plan design, elevated terraces, deep overhanging eaves and a complex approach path complete Wright’s architectural pattern of the era.

Figure 3. Heurtley house, Chicago (1902), Frank Lloyd Wright – exterior, street view.

Figure 4. Heurtley house, Chicago (1902), Frank Lloyd Wright – exterior, aerial perspective.

Figure 5. Heurtley house, Chicago (1902), Frank Lloyd Wright – interior, fire place in the living room.

Figure 6. Heurtley house, Chicago (1902), Frank Lloyd Wright – interior, major windows in living room.

Hildebrand (1991) describes the Heurtley house as the first example of Wright's work that demonstrates the complete pattern of thirteen prospect-refuge elements, a minimum of ten of which would be present in each subsequent design by Wright. Thus, the Heurtley house was chosen for the present research because it represents the most complete example of prospect-refuge theory that Hildebrand identifies. Furthermore, while there is some debate about whether this is Wright's first fully realised Prairie house (Heinz 2006), or even if it is part of the same shape-grammar family (Koning and Eizenberg 1981), it has been identified in a previous computational study as being representative of the stylistic feature set of Wright's houses (Ding and Gero 2001); a determination which is close to Hildebrand's classification of the work. Hildebrand's measurable claims centre on the experience of the living room and in order to test this spatio-visual experience, three isovists were located at strategic locations suggested by Hildebrand's analysis of Wright's work. The first is located at the threshold of the main entrance to the living room, the second is one metre in front of the fireplace and the third is at the geometric centre of the room. The room's geometric centre is located at the intersection point of diagonal lines drawn between the corners of the room and corresponds to the ridge of the raised ceiling above. The isovist adjacent to the fireplace is aligned to the centre of its supporting arch. These positions approximate zones that are allegedly experientially significant in understanding the prospect-refuge characteristics of a space: the first view of the room, the ideal position adjacent to the hearth and the experience of observing the room from its geometric centre. Hildebrand's analysis of Wright's Falling Water suggests that the prospect refuge properties of these

positions should vary slightly with greater refuge experienced at the hearth and greater prospect at the room centre.

For the present paper each of the three isovists were manually constructed in a CAD program following the radial line procedure. The isovist plane was located 1.65 meters above the floor to approximate the eye level of a standing observer of Wright's stature (Fig. 7). The resolution of radial lines was set at 5° and the view distance was limited to 20 meters. The 5° radial increments do create some minor anomalies in the isovists (which would be reduced, but not entirely eliminated, by using 1° radials) but the manual processing time required to produce a more accurate result would be prohibitive and the difference in the result negligible for the purposes of the present paper. The 20 meter view limit is sufficient for the isovists to extend beyond the furthest visible windows, which are treated as transparent surfaces, while eliminating the need for accurate models of the buildings surrounds. Mullions, posts, columns and similar elements of less than 100mm width are small enough to be "seen around" by an observer tilting their head and are therefore excluded from the isovist construction. All of the calculations of isovist measures were completed using spreadsheet software.

Before progressing to the results, the measures that are to be taken from the isovists must be considered. For this paper a range of mathematical measures were derived from each of the three isovists. These include, amongst others, area, perimeter, concavity, circularity and elongation; all of which are derived from properties of the isovist polygons. From the isovist-generating lines (the 5° radials) additional measures including, skewness, kurtosis and entropy were developed. Two of these measures, relative-area and skewness, have previously been identified as being potential indicators of environmental preference which can be associated with prospect-refuge characteristics. For example, Wiener and Franz (2005) asked participants to find the best hiding and overview locations in a virtual interior. These spaces were defined as the smallest and largest viewshed areas and participants displayed a high level of competency in this task. The research of Wiener and Franz demonstrates a natural ability to assess space in terms of planar geometry. Stamps III (2006; 2008a; 2008b) takes this suggestion further when directly comparing environmental geometry with environmental preference. However, his results are inconclusive, suggesting that further consideration of other appropriate isovist measures is required. In particular, Stamps III (2005) argues that the isovist measure skewness might be a prospect-refuge indicator. In the discussion of the results hereafter, such potential isovist measures are compared against the claims and expectations of prospect-refuge theory and alternative approaches are discussed where the findings do not support the efficacy of the proposed measures.

In interpreting the measures used for isovist analysis it is also important to differentiate between what Benedikt (1979) called "skewness"— meaning the third moment about the mean or M_3 — and the more common statistical version of skewness used in mathematics, which is the relationship between the second (M_2) and third (M_3) moments about the mean. Moments are common measure used in statistics to quantify the shape of a data series, in this instance, the data series constitutes the lengths of the radial lines generating the isovist polygon. While many early papers on isovists used Benedikt's terminology, the present paper uses the standard mathematical terms and nomenclature, equations are given below (r_i is the length of a radial line and μ is the average length of all radial lines).

$$Skewness = \frac{m_3}{m_2^{3/2}}$$

$$m_2 = \left(\left(\frac{1}{N} \right) \sum_{i=1}^N (r_i - \mu)^2 \right)$$

$$m_3 = \left(\left(\frac{1}{N} \right) \sum_{i=1}^N (r_i - \mu)^3 \right)$$

Results

Three isovists were constructed to analyse the spatio-visual qualities of the living room (Fig. 8-10). Isovist 1 is from the entry, 2 in front of the fireplace, and 3 in the centre of the room. From the isovist polygons and generating lines, twenty-six measures were derived giving a total of seventy-eight results (Table 1). The results were categorised in accordance with the part of prospect-refuge theory which they might reflect. Also as prospect refuge conditions are likely to be best described by a combination of relative and absolute measures it is necessary to record whether each measure is scaled or not. A scaled measure is an absolute value (for example, length in metres, or area in square metres) while a scale-free measure is relative or normalised in some way (for example, the proportion of an isovist perimeter that is occluding or a ratio between isovist area and perimeter). Scale-free measures allow comparisons between isovists with different geometric properties, for example, two isovists may possess vastly different areas and perimeter lengths, yet the proportion of their perimeter that is occluding, the ratio between area and perimeter, and number of straight perimeter edges, may be identical. Effectively, these isovists possess different absolute measures, yet identical scale-free properties, because one is a scaled up/down copy of the other.

Figure 7. Axonometric representation of an isovist generated from **Figure 8.** Isovist 1, Living room entrance. View distance is set at 20

the centre of the living room in the Heurtley house.

meters.

Figure 9. Isovist 2, 1000mm forward of fireplace. View distance is set at 20 meters.

Figure 10. Isovist 3, centre of living room. View distance is set at 20 meters.

Isovist Measure	Abbrev.	Isovist 1 (Entry)	Isovist 2 (Fireplace)	Isovist 3 (Room Centre)	Scaled/Scale Free	Potential Indicators
Area (m ²)	<i>A</i>	167.500	254.710	323.770	S	Prospect or refuge
Perimeter (m)	<i>P</i>	221.760	248.497	295.464	S	
Shortest radial length (m)	<i>RL_(S)</i>	0.56	1.00	3.27	S	
Average radial length (m)	<i>RL_(A)</i>	5.851	7.224	9.162	S	
Longest radial length (m)	<i>RL_(L)</i>	20.00	20.00	20.00	S	
Convex deficiency	<i>Con</i>	0.66	0.52	0.62	SF	
Circularity	<i>Circ</i>	23.363707	19.29241	21.456688	SF	
Area:Perimeter Ratio	<i>A:P</i>	0.755	1.025	1.096	SF	
Elongation - Γ	<i>El_(I)</i>	0.29	0.36	0.46	SF	
Elongation - Ψ	<i>El_(\Psi)</i>	0.21	0.23	0.22	SF	
Std dev of radial lengths	<i>RL_(SD)</i>	6.052	6.969	6.735	SF	Prospect-Refuge
<i>M</i> ₂ – Benedikt's Variance	<i>M</i> ₂	36.621	48.572	45.362	SF	
<i>M</i> ₃ – Benedikt's Skewness	<i>M</i> ₃	316.683	358.701	267.833	SF	
<i>M</i> ₄	<i>M</i> ₄	5259.037	5997.043	3993.715	SF	
Skewness	<i>S</i>	1.429	1.060	0.877	SF	
Kurtosis	<i>K</i>	3.921	2.542	1.941	SF	Mystery
Occlusivity (m)	<i>O</i>	202.202	219.496	262.857	S	
Number of occluded radials	<i>RO_(#)</i>	27	28	33	SF	
Average occluded length (m)	<i>RO_(A)</i>	7.49	7.84	7.79	S	
Occluded:Perimeter Ratio	<i>O:P</i>	91.181%	88.329%	88.964%	SF	
Average Occ length:Area	<i>RO_(A):A</i>	0.04	0.03	0.02	SF	Complexity
Entropy (bits) 1mm	<i>Ent_(1mm)</i>	5.52	5.35	5.42	SF	
Entropy (bits) 100mm	<i>Ent_(100mm)</i>	3.77	4.43	3.69	SF	
Number of polygon edges	<i>Pol#</i>	42	43	53	SF	
Drift (m)	<i>Dr</i>	2.451	3.429	1.895	S	Other
Area in directed view cone	<i>T_(A)</i>	146.76	249.27	235.93	S	
% of total area in view cone	<i>VC%</i>	87.62%	97.86%	72.87%	SF	

Table 1: Mathematical results of isovist analysis.

Measures which isolate Prospect and Refuge

Prospect is, in isolation, a relatively straightforward concept. Prospect dominant views are those allowing larger volumes of space to be surveilled. High values for isovist area, average and longest

radial lengths are all indicators of a larger view area and these measures identify isovist 3 as possessing the greatest prospect characteristics ($A = 323.770$, $RL_{(A)} = 9.162$, $RL_{(L)} = 20.000$).

Refuge consists of either being hidden from view (meaning the least volume of space being surveilled) or of being enclosed (relating to boundary or surface conditions). In the former situation, this is simply the inverse of the prospect measure, with isovist 1 being the smallest of the three ($A = 167.500$, $RL_{(A)} = 5.851$, $RL_{(L)} = 20.000$). In terms of enclosure, Stamps III (2005) relates elongation measures (Batty 2001) to refuge, however, the measures suggest different isovists are the most elongated. High $El_{(r)}$ values and low $El_{(\psi)}$ values identify that a space is long and narrow. These measures suggest that isovist 1 ($El_{(r)} = 0.29$) and isovist 2 ($El_{(\psi)} = 0.23$) are the least elongated and therefore most refuge dominant views. Kaplan (1988) also relates refuge to enclosure, defining a refuge dominant space as possessing a “well-defined” boundary. If a “well-defined” boundary is an efficient means of defining space, the boundary will enclose the largest area with the minimum perimeter and approximate a circle. Isovist 3 possesses the highest area:perimeter ratio ($A:P = 1.096$) suggesting that it is the most refuge dominant view. In contrast, a high value for Benedikt’s (1979) circularity measure indicates that isovist 1 possesses strongest refuge characteristics ($Circ = 19.29241$).

One way of interpreting the possible mathematical measures derived from the isovist is to consider the research of Stamps III (2005), who identified a negative correlation between the minimum nearest distance (shortest radial length) and the sense of enclosure. This finding, suggests that being too close to a wall, or being too enclosed, undermines feelings of refuge whereas being in a larger space and being able to see all of that space, can heighten refuge feelings. On this basis, isovist 3 has the highest refuge characteristics, ($RL_{(S)} = 3.27$) and isovist 1 the lowest ($RL_{(S)} = 0.56$). While this interpretation may be reasonable, it is possible that Stamps III (2005) is identifying claustrophobic qualities in peoples’ reactions, rather than refuge tendencies, and as the Heurtley house living room is a large spacious area, this may be much less relevant.

Measures which combine Prospect and Refuge

Stamps III (2005) has suggested that some statistical measures including skewness appear to quantify the combined prospect-refuge characteristics of isovists. Stamps III also demonstrated that high skewness indicates the observation point is close to the corner of the isovist and low skewness indicates the observation point is more central to the isovist. This does suggest that statistics based measures might be able to capture the combined prospect-refuge properties of isovists. For example, the skewness result for isovist 1 is the highest ($S = 1.429$) and that observation point is close to the edge of the polygon whereas, isovist 3, which is in the centre of the room does indeed, as Stamps III predicts, have the lowest result ($S = 0.877$). However, while this result is, apparently, useful, statistical measures derived from the radials used to construct isovists are not directly related to the shape of the isovist. For example, it is possible to construct three completely different isovists, each from 16 radial lines that all have four lines of length, of 1000mm, 700mm, 400mm and 200mm (Fig. 11). While the calculated measures of M_2 , M_3 and skewness are identical for each of these three polygons, they are

differently shaped and have different areas and perimeters. Thus, statistical measures may be useful for providing an indication of “the dispersion of the perimeter relative to the observer location” (Stamps III 2005; 739) but they do not quantify the prospect-refuge characteristics of particular spaces.

Figure 11. Symmetric (left), shell (middle) and pinwheel (right) shaped isovists with identical M_2 , M_3 and skewness values; area, perimeter and, intuitively, prospect-refuge characteristics are different.

Measures for Mystery

Mystery, in spatial terms, relates to the extent of space that is just out of sight from a given location; or the space that can be sensed but not seen. If a person is within a rectangular, fully enclosed room, then the isovist will occupy the entire room and therefore there is no mystery. The component of the isovist polygon that most effectively represents this definition of mystery is the occluding radial.

Benedikt’s (1979) occlusivity measure calculates the total length of occluding edges in an isovist perimeter. For the three isovists in the Heurtley house, occlusivity increases as the occupant moves from the doorway toward the centre of the living room, suggesting that isovist 3 is the spatial experience with the highest level of mystery ($O = 262.857$). However, this may be misleading because Benedikt’s occlusivity is a scaled or absolute measure which relies on the assumption that the longest physical distance of occlusion indicates mystery. It may be more useful to measure occlusivity as a proportion of the total perimeter; a process which demonstrates that each of the three isovists is almost identical, and the smallest, isovist 1, is the most mysterious ($O:P = 91.181\%$)

It might also be suggested that the total number of occluding radials could be an indicator of mystery, however a large number of extremely short occluding radials, such as those generated by a wall with a perforated surface, may hold very little potential for mystery. Perhaps then, the average length of occluded radials is a better measure than total length or highest number. Following this logic isovist 2 has the highest result ($RO_{(A)} = 7.84$). However, average radial length is a scaled measure, biased toward larger isovists. Dividing average occluded radial length by isovist area allows a scale free comparison and indicates that, like the measure for relative or proportional occlusivity, isovist 1 is the most mysterious view ($RO_{(A)}:A = 0.04$).

Measures for Complexity

Stamps III (2003) demonstrates a strong correlation between entropy and visual complexity and suggests that the length difference between adjacent radial lines is a good indicator of isovist complexity. The maximum possible entropy of radial line length difference, resulting in the least homogenous perimeter, for a 72 radial (5°) isovist is 6.17. Using this measure, isovist 2 possesses the lowest entropy value when measuring the difference in radial line lengths at 1mm accuracy ($Ent_{(1mm)} = 5.35$) a result which suggests that isovist 2 is the least complex view.

Because of the artificial visibility boundary which is set at 20 meters, a large portion of the radial lines in all three isovists have the same length. If these lines were to continue until intersecting a solid element the portion of lines sharing no length difference would decrease and therefore, the entropy measures of the three Heurtley house isovists calculated here are likely to be artificially low. When measuring the line length differences at 100mm accuracy isovist 2 possesses the highest entropy value ($Ent_{(100mm)} = 4.42$) suggesting this is the most complex view. If entropy is to be the measure of complexity, then defining an ideal accuracy of measurement is critical. An alternative measure of complexity is simply counting the number of straight edges of each isovist polygon, because a more complex polygon requires a greater number of edges. On this basis, which also makes sense from a phenomenological perspective, isovist 3 is the most complex view ($Pol_{\#} = 53$).

Other measures

While past scholars have not directly associated Conroy's (2001) measure of drift (Dr) with prospect-refuge theory, it does capture some isovist properties that are missed by other measures. Drift is the distance between the observation point and the centre of gravity of the isovist polygon. This distance represents both the direction and magnitude of the "visual pull" of the isovist. A larger magnitude of drift indicates that a larger proportion of the isovist area, thus prospect, is located in one direction relative to the observation point. In a room with three, mostly solid walls, and a fourth wall that is largely open, drift would provide a reasonable measure of the dominance and strength of the prospect, relative to the refuge. However, in the living room of the Heurtley house, there are fragments of views in four directions; something which is especially evident in isovist 3 ($Dr = 1.895$), which might be expected to have the strongest "pull", but which actually has the weakest (Fig. 12). But then, an isovist is the view in any direction from a point in space, whereas it could be argued that prospect is dependent on the human cone of vision. To achieve the maximum prospect in a single view at any given time, one must face the dominant view direction. By aligning a 180° view cone to the drift direction it is possible to measure how much of the isovist is visible when looking towards the dominant visual orientation. Using this measure, 97.86% of the complete isovist from position 2 is visible in the human cone of vision in the direction of the drift and only 72.87% for isovist 3. This is an interesting result because, another definition of mystery might include the space that is sensed behind the viewer but is not directly surveilled by them while watching the dominant outlook. In this sense isovist 2 has the least mystery and isovist 3 the most.

Figure 12. Isovist 1 (left), Isovist 2 (middle) and Isovist 3 (right), showing drift direction, strength and view cones aligned to the direction of visual pull.

Conclusion

While the majority of the measures derived from isovists of the Heurtley house appear to broadly correlate with the prospect-refuge characteristics identified by Hildebrand, under close scrutiny they become problematic and, it must be concluded, that none of them are ideal for this purpose. Even those measures like skewness and drift, which might seem to capture some essence of prospect-refuge theory in a simple room, do not work for more complex spaces.

Conceptually, prospect-refuge should be geometrically measurable using some combination of the strength and direction of the outlook (prospect), the proportion of the isovist that is bounded by solid surfaces (refuge), and that which is made up of occluded radials (mystery). Furthermore, it is likely that there are limits, or ranges for the proportion of each of these three characteristics that an isovist must fall within for a room to exhibit desirable prospect-refuge qualities. For example, if the visual thrust (Dr) is insufficient, then the room does not have a clear outlook or the visual direction is confused by too many conflicting outlooks. Thus, a minimum drift value may be a useful test. Second, if the room is either too enclosed or too open – claustrophobic or agoraphobic – then there is no sense of refuge. Setting a range for either the perimeter length of the isovist that is “surface” or the combined angle of radials which meets a “surface” could also provide a minimum and maximum value. Between the outlook and the enclosure is mystery and complexity, the first of which is represented by occlusivity, something that can be measured, but is meaningless in the present context unless the prospect and refuge conditions are already within the optimal range. Without this, mystery descends into confusion; for Appleton, knowing where the unknowns are is pleasurable, not knowing where they are is distressing. Complexity can readily be measured using entropy, although, once again, it would seem that a range (neither too monotonous nor too aleatory) is desirable. Thus, the geometric properties of a prospect-refuge balanced polygon, might be defined by a strong positive value for prospect, and a balanced result for the other three.

Prior to commencing any future isovist analysis of prospect-refuge characteristics, two approaches could be taken. First, the particular combination of prospect-refuge-mystery and complexity can be tested using a set of abstract room configurations, which can be used to examine the relative sensitivity or robustness of each measure and their combination. Following this, combined measures

must be verified through their application to more complex works of architecture. An obvious first choice for this is the residential works of Frank Lloyd Wright where the measures should identify, and quantify, the geometric and associated phenomenological features discussed at length by authors such as Hildebrand (1999).

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Addendum

Skewness is not the relationship between the second and third moments about the mean as noted in the text. The correct measure of skewness is M3 (Benedikt's skewness). All mention of 'skewness', including the provided equation for calculating skewness ($S=m_3/m_2^{3/2}$) - that does not specifically relate to the third moment (M3 – Benedikt's Skewness) - should therefore be ignored.

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