

SPATIO-VISUAL PATTERNS IN ARCHITECTURE

An analysis of living rooms in Frank Lloyd Wright's houses

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Abstract. It has been alleged that living spaces in the domestic architecture of Frank Lloyd Wright feature a distinct pattern of spatial and formal features which elicit positive emotional responses from visitors. Researchers have argued that the source of this appeal is found in the unique balance Wright achieved between outlook, enclosure and mystery. While this explanation is apparently accepted, little quantitative evidence exists to confirm that these houses actually contain the type of spatio-visual properties required to provoke such similar experiences. This paper utilises isovist analysis to seek mathematical evidence of patterns in the prospect, refuge and mystery related characteristics of 17 of Wright's most famous houses. This analysis reveals an unexpectedly high degree of similarity between the designs, which is slightly less pronounced when exterior views are included.

Keywords. Isovist Analysis; Frank Lloyd Wright; Design Similarity.

1. Introduction

Frank Lloyd Wright's prolific career produced over 300 residential designs and the creation of three distinct architectural styles, establishing him as one of the modern movement's most successful architects. Despite stylistic differences, these designs allegedly share one unifying factor; their ability to elicit positive emotional responses from visitors. Drawing on 'prospect-refuge theory', personal accounts and a diagrammatic and historical analysis, Hildebrand (1991) offered one of the more enduring explanations of this phenomenon. Hildebrand argued that a unique formal and spatial pattern in Wright's architecture is responsible for eliciting these emotional reactions. Enumerating 13 specific design features, Hildebrand suggests that, individu-

ally they are not unique to Wright; however, Wright is the only architect to use a minimum of 10 of these in every house, regardless of its style.

Despite its apparent acceptance, little quantitative data exists to support or test Hildebrand's thesis. However, past scholars have sought to examine the relationship between emotional response and spatial and environmental features through surveys and isovist analysis (Wiener and Franz, 2005). A small number of studies have also used computational means to consider such claims in a range of artificial environments (Conroy, 2001; Stamps, 2009). What is largely absent in this research is any detailed testing of the Hildebrand's proposition. In particular, are the prospect and refuge qualities of Wright's living spaces similar enough to even constitute a pattern?

The present paper examines the living rooms of 17 of Wright's most famous houses using isovist analysis. Isovists are geometric abstractions of the space that is visible from a particular position. The 102 isovists used for this paper represent three positions in each of 17 different living rooms, and two analytical constraints; opaque and transparent glazing. Seven mathematical measures are derived for each isovist, producing 714 results, which are compared using simple statistical methods (means and standard deviations) to investigate the level of similarity exhibited in Wright's designs.

While such a study of Wright's living room spaces has never been undertaken before, this paper also compares the prospect and refuge characteristics of isovists that represent both interior spaces (the conventional approach) and exterior views up to a defined limit. This is significant because Hildebrand's definition of prospect, or outlook, encompasses both interior vistas to adjacent habitable areas and the capacity to see the outside world.

In the sections that follow the paper provides a brief introduction to relevant aspects of spatial psychology and isovist analysis. Thereafter, two hypotheses are outlined, identifying the data that constitutes evidence of a pattern of similarity. Next the method used to undertake this research is described and finally the results are presented and discussed.

2. Spatial Psychology and Wright's Living Spaces

Hildebrand argues that the emotional appeal of Wright's architecture, and Wright's living rooms in particular, is due to its carefully controlled mix of prospect and refuge characteristics. Appleton (1975) proposed prospect refuge theory as a means of understanding environmental preferences. Prospect offers the ability to see; to locate distant resources, and identify hazards, both animate (other creatures) and inanimate (storms/cliffs etc.), and refuge offers the opportunity to obtain concealment and shelter. An ideal environment provides a strong sense of both prospect and refuge; the ability to "see

without being seen” (Appleton 1975, pp. 73). The evolutionary/biological basis of this theory has generated some well-documented controversy and many scholars accept that environmental preference is due to a combination of biological, cultural and personal factors (Falk and Balling, 2010).

Reputedly, the centre of Wright’s living rooms provide a balance of prospect and refuge while the location near the hearth provide a more refuge-dominant experience. By providing such a graduated mix of spatio-visual qualities Wright enables the visitor to first enter the room and from there, identify and occupy a location appropriate to their psychological needs. However, prospect and refuge are not the sole factors determining the appeal of Wright’s architecture. Hildebrand also draws on the work of Kaplan and Kaplan (1989) to argue that mystery and complexity play an important role in Wright’s living rooms. Mystery (Kaplan 1987) – a sensation wherein new information is not seen but inferred from what is already visible – relates to the areas of the building that are just out of sight and is a positive predictor of environmental preference (Kaplan, Kaplan et al. 1989). Complexity refers to the amount of visual information available in an environment and Hildebrand notes that complex and ambiguous spatial definitions and relationships are a key characteristic of Wright’s houses.

3. Isovist Analysis

Isovist analysis captures the visual characteristics of a particular location in the form of a two dimensional polygon representing a horizontal slice through the building. This plane is typically located at the eye height of a generic, or specific, observer. The mathematical properties of the polygon may then be recorded and compared to the values obtained from isovists generated in alternate locations, or under alternate analytical conditions. Importantly, several of these measures correlate to, and have been previously utilised as, measures of prospect, refuge, mystery and complexity (Figure 1).

Originating in the field of environmental perception (Gibson, 1947, 1966, 1979), isovist analysis gained acceptance in architectural research after Benedikt and Davis demonstrated a rigorous method for generating isovist polygons, identified basic mathematical measures, and developed graphical representations of isovist data (Benedikt, 1979; Davis and Benedikt, 1979). Isovist generation follows one of two different processes which may produce slightly different results. The most common approach draws a series of radiating lines from the observation point at an equal angular distribution (Christenson, 2010; Turner, 2004). These lines terminate at the surfaces of the environment and joining their ends produces the isovist polygon. This approach offers the potential to calculate additional measures through a sta-

tistical analysis of the radial line lengths, and is typically automated within analytical software due to the large number of lines accurate results.

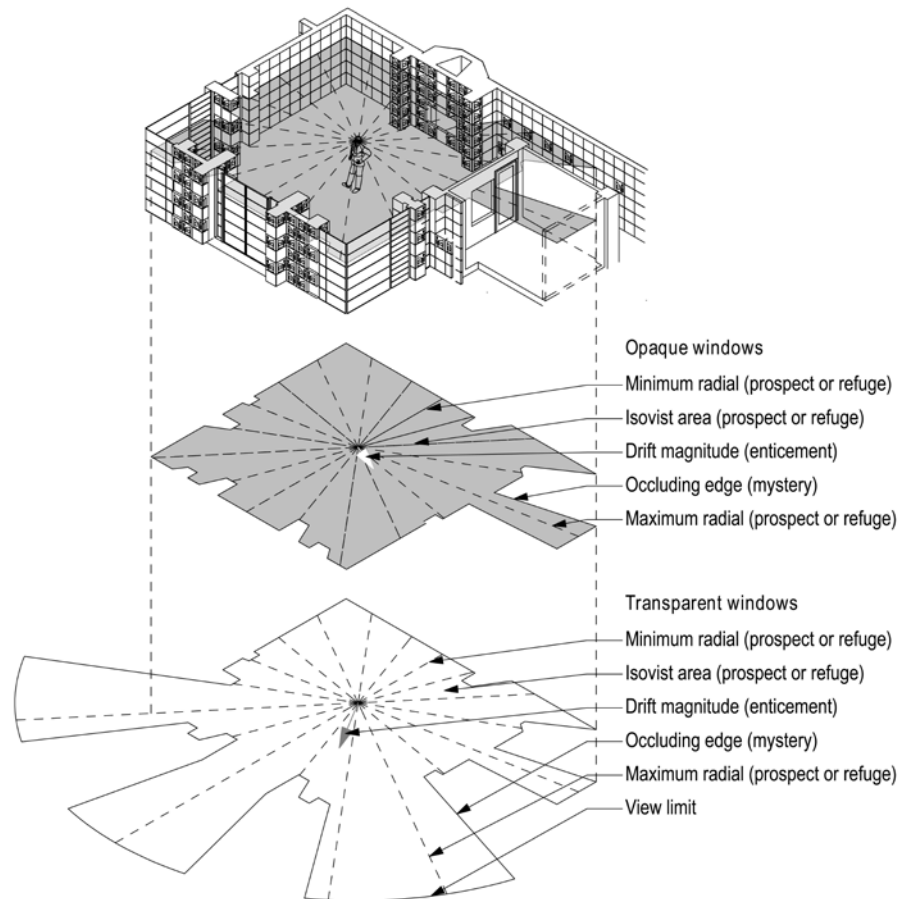


Figure 1: Isovist measures under opaque and transparent window conditions. Note some radial lines are omitted for clarity.

Isovist analyses are often limited to indoor environments. This removes the need for artificial view limits or mapping exterior, and often changeable and diffuse conditions which confuse isovist boundaries (Davies, Rodrigo, and Peebles, 2006). Thus, indoor analyses typically exclude external views by considering glass as an opaque material (Ostwald and Dawes, 2013). While some authors have undertaken both ‘indoor’ and ‘outdoor’ analyses in

a single project (Stamps, 2011) little data exists to compare differences in isovist polygons created under opaque and transparent glazing conditions.

Common measures derived from an isovist include its area and perimeter, the longest, shortest and average radial line lengths, occluding edge lengths and their percentage of the perimeter, how closely the polygon approximates a circle and distance between observation point and the polygon's centre. Isovist analysis techniques have been used in architectural research to study spatial cognition (Meilinger, Franz, and Bulthoff, 2009), way-finding (Conroy, 2001), social structure (Markhede and Koch, 2007), phenomenology (Wong, 2012), the display of valued objects within a spatial structure dedicated to this task (Peponis, Conroy-Dalton, Wineman, and Dalton, 2004; Psarra, 2005, 2009; Stavroulaki and Peponis, 2005; Tzortzi, 2004; Zamani and Peponis, 2013) and prospect-refuge characteristics (Stamps, 2005; Wiener and Franz, 2005; Ostwald and Dawes, 2013).

4. Hypotheses

Hildebrand (1991) identifies a pattern of prospect, refuge, mystery and complexity experiences in Wright's domestic architecture. If this pattern exists, it should be possible to observe mathematical similarities in the results obtained from an isovist analysis by comparing measures of the properties of individual houses against the mean value for each measure. In addition, by generating isovist results for both standard opaque and transparent glazing conditions, it becomes possible to determine if the houses are more or less similar when external views are included in the results.

In a random data sample, with a normal distribution of results, 68% of the results will occur within a range of one standard deviation above or below the mean value of the data sample. Where more than 68% of data falls within this range, the majority of the data is similar with a small number of outliers. While the houses in this chapter were chosen due to their prominence in Hildebrand's analysis, and therefore not randomly selected, it is reasonable to use a normal statistical distribution of results as a benchmark against which the presence of a pattern can be tested. If Wright's designs exhibit a normal distribution, then it might be expected that 68% - or 11.5 of the houses - will provide results within one standard deviation of the mean. If the results for the majority of the houses are particularly similar, the standard deviation will be lower and more than 12 houses will fall within this range. Conversely if the majority of the houses exhibit little similarity the standard deviation will be higher and fewer than 11 results will be located within this range.

Hypothesis 1: If Wrights houses are similar, more than 12 of the set of 17 houses will provide results within one standard deviation of the mean.

Isovist analyses often consider glazed surfaces to be opaque in order to limit their scope to fully enclosed spaces and negate the subjectivity of variable external views or setting artificial view limits. Isovist analyses with transparent glazing, incorporate external views and therefore have the potential to capture higher levels of prospect (isovist area and longest radial), mystery (occlusivity measures) and complexity (lower compactness). The differences arising from different opacity conditions are particularly problematic when using isovist analysis to compare open designs with large expanses of glazing to enclosed designs with limited or no glazing. Depending on the observation location, this method might also document reduced refuge in the form of longer shortest radial lines, while enticement (drift magnitude and direction) is highly variable. If this is accurate, houses analysed under transparent window conditions will exhibit less similarity than an analysis where isovists document interior conditions only.

Hypothesis 2: Analysis under the transparent window condition will exhibit less similar results compared to the opaque window condition.

5. Method

The houses selected for this study represent a sample of five houses from each of Wright's three styles and a unique design crafted during the transition between each style. Listed chronologically, these houses include the Henderson, Heurtley, Cheney, Evans and Robie houses from the Prairie style; the Barnsdall house; the Millard, Storer, Freeman, Ennis and Lloyd Jones houses from the textile-block series; The Kauffman house (Fallingwater); and the Jacobs, Schwartz, Lloyd Lewis, Affleck and Palmer houses from Wright's Usonian period.

The investigation commences by constructing three dimensional computer models of each house based on working drawings published in the Frank Lloyd Wright Monograph (Futagawa and Pfeiffer, 1987), and photographs taken typically during or immediately after construction. The one exception is that the model for the Lloyd Jones house is based on the plan of the constructed design (Pfeiffer and Goessel, 2010, pp. 194) as the 1987 monograph does not contain working drawings of the final design. The model of each house is the basis of two different floor plan versions; version 1 represents opaque glazing, version 2 represents transparent glazing. Effectively, the two plan versions are identical except that version 1 includes additional lines at

glazed locations which limits isovist polygon to internal areas, and version 2 includes a circular view limit, centred on the observation point. The radius of this view limit is 110% of the length of the longest radial line attainable under opaque window conditions from any of the three observation points in that house. This ensures that each observation location is able to see out any visible window, while preventing the external area from becoming excessively large (Figure 2). Both versions of the floor plans capture a horizontal slice through the building 1.65m above the main living room floor level that is intended to approximate Wright's eye height. Doors to dedicated service and storage areas which form no part of the circulation system are depicted as being closed, while all other internal doors are open.

Three observation locations are identified for each house; first is the threshold to the living room, second is the centre of the living room and the third location is set back 1m from the centre of the hearth. The only exception is the Barnsdall house which includes a shallow pool in the living room which prevents the visitor from approaching too near the hearth. In this case the third observation point is setback 1.77 m from the centre of the hearth. Both floor plan versions are analysed using UCL Depthmap (version 10.14.00b) with a grid spacing of 100mm. When analysis is complete, the results of each isovist are copied to spreadsheet software for comparison.

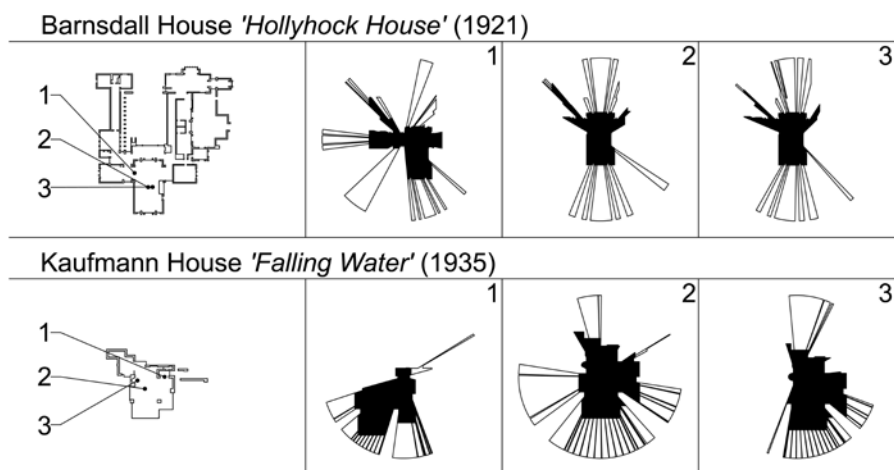


Figure 2: Example isovist polygons - 1 threshold, 2 room centre, 3 hearth - for the two unique designs. Black fill represents opaque glazing; black and white fill represents transparent glazing.

6. Results

Isovist analysis of Wright's architecture produces a total of 714 results. If we consider the 17 houses to be a single data set we arrive at 42 outcomes for the analysis, (7 measures, 3 observation locations, 2 glazing conditions). Table 1 documents the number of houses with results located within one standard deviation of the mean for each outcome. According to the first hypothesis any result greater than 12 indicates a higher than anticipated degree of similarity between the houses, and a result less than 11 indicates greater difference than anticipated. Data for each measure is also presented graphically to allow visual comparisons (figures 3-6).

Table 1: Number houses that occur within one standard deviation of the mean value.

	Opaque glazing (Internal)			Transparent glazing (External)		
	Threshold	Centre	Hearth	Threshold	Centre	Hearth
Area	14	16	14	15	12	11
Max Rad	12	14	14	13	13	13
Min Rad	13	11	15	13	11	15
Occlusivity	15	14	15	12	11	12
Prop Occ	11	14	11	12	10	12
Drift Mag	11	13	15	10	12	12
Compact	11	12	11	12	13	14

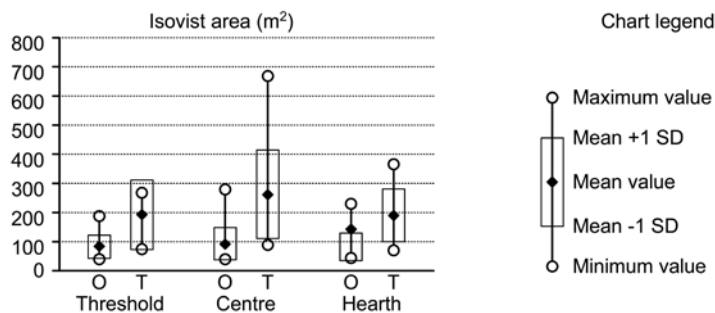


Figure 3: Data summary for the area measure and chart legend.

Data for isovist areas for all three observation positions indicates that all isovist polygons generated with opaque glazing exhibit a higher degree of similarity than expected. This is also true for transparently glazed isovist polygons located at the living room thresholds. However, views from the room centres and hearths are less similar and conform to a normal distribu-

tion of results. The data for maximum radial line lengths conform to a normal distribution for isovist polygons depicting the threshold view under opaque window conditions. Maximum radial line data indicates that all remaining isovist polygons exhibit higher degrees of similarity.

The data for minimum radial line lengths is identical regardless of glazing condition. If the observation points were closer to windows than built surfaces, a difference between results for the opaque and transparent window conditions would be recorded. Under both window conditions minimum radial line data indicates that the room centre data is exactly as similar as expected, while the experience of standing adjacent to the hearth or at the room threshold is more similar than expected.

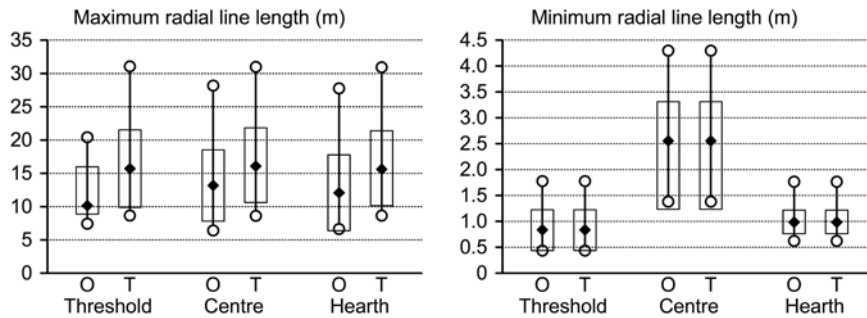


Figure 4: Data summary for maximum and minimum radial line length measures.

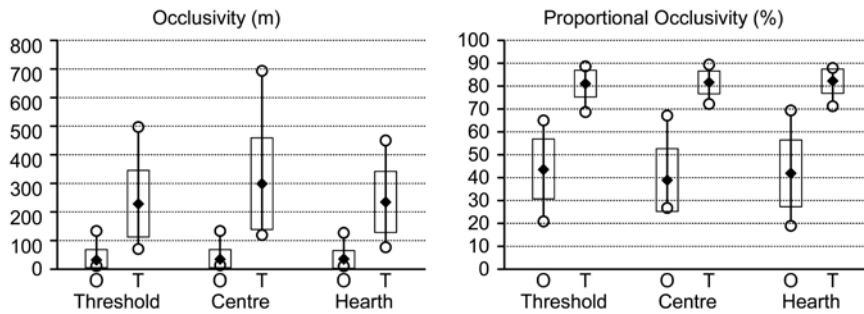


Figure 5: Data summary for occlusivity and proportional occlusivity measures.

Occlusivity represents the absolute length of the isovist boundaries that relate to the space which lies just out of sight and is a measure for the perceptual quality of mystery. Occlusivity values for all isovist polygons with transparent glazing match normal values for similarity and indicate high levels of mystery, while data for isovist polygons limited to interior spaces indi-

cate significantly higher levels of similarity but at lower intensity. Proportional occlusivity records the percentage of the perimeter that consists of occluding edges and provides a scale free measure for mystery. This measure indicates that views from the centre of the living rooms are more similar than expected with opaque glazing, and are less similar than expected with transparent glazing. All remaining data for proportional occlusivity matches a normal distribution of results.

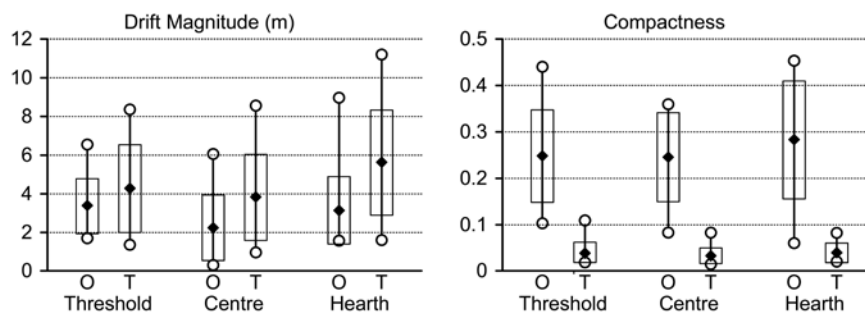


Figure 6: Data summary for drift magnitude and compactness measures.

Drift magnitude measures the distance between the observation point and the centre of the isovist polygon which entices the visitor to orient themselves in this direction to gain the largest possible view. Under opaque window conditions the isovist data for room centre and hearth views are more similar than expected, while views from the threshold under transparent window conditions show less similarity than expected. The remaining outcomes conform to values for a normal random data sample. Compactness, a measure of isovist complexity shows normal similarity for all isovist polygons with opaque glazing, and higher levels of similarity for views from the room centre and hearth under transparent glazing conditions.

7. Conclusion

This paper set out to examine claims that Wright's architecture provides similar spatial experiences despite significant stylistic differences and to determine how this similarity is affected by different analytical conditions. Of the 42 outcomes, half (21) exhibit a higher degree of similarity than expected while 19 equal the expected similarity. Only 2 outcomes demonstrate less similarity than expected. Thus the first hypothesis, that Wright's architecture exhibits a high degree of similarity in spatial experience, despite stylistic differences is confirmed.

Opaque and transparent window conditions have a moderate impact on spatial characteristics as documented through isovist analysis. Opaque window conditions generated 13 outcomes with higher similarity, and zero outcomes with lower similarity than expected. Under transparent window conditions 8 isovists were more similar, 11 as similar and 2 less similar than expected. Thus the second hypothesis, that transparent window conditions will exhibit less similarity is confirmed.

The fact that the minimum radial line length results are identical under both window conditions confirms that window condition alone will not alter the spatial experience recorded by the isovists. Window condition and observer position are linked.

The confirmation of both hypotheses suggests that the domestic architecture of Frank Lloyd Wright does demonstrate levels of similarity. However the 17 houses analysed were selected due to their prominence in Hildebrand's theory of the Wright Space which may simply have included the houses that best represent these spatial conditions.

Acknowledgements

An Australian Research Council (ARC) Fellowship (FT0991309) and an ARC Discovery Grant (DP1094154) supported this paper.

References

- Appleton, J. 1975. *The Experience of Landscape*. John Wiley and Sons. London.
- Benedikt, M. L. 1979. To take hold of space: isovists and isovist view fields. *Environment and Planning B: Planning and Design*, **6**(1), 47-65.
- Christenson, M. 2010. Registering visual permeability in architecture: isovists and occlusion maps in AutoLISP. *Environment and Planning B: Planning and Design*, **37**(6), 1128-1136.
- Conroy, R. 2001. *Spatial Navigation in Immersive Virtual Environments*. Unpublished Doctoral Thesis, University of London, London.
- Davies, C, Rodrigo, M, and Peebles, D. 2006. Isovists for Orientation: can space syntax help us predict directional confusion? *in: Space Syntax and Spatial Cognition Workshop*, Sunday 24th September 2006, Bremen, Germany. (Unpublished)
- Davis, L. S, and Benedikt, M. L. 1979. Computational models of space: Isovists and isovist fields. *Computer Graphics and Image Processing*, **11**(1), 49-72.
- Falk, J. H, and Balling, J. D. 2010. Evolutionary Influence on Human Landscape Preference. *Environment and Behaviour*, **42**(4), 479-493.
- Futagawa, Y, and Pfeiffer, B (Eds.). 1987. *Frank Lloyd Wright Monograph* (Vol. 4-6). A.D.A. Edita. Tokyo.
- Gibson, J. J. 1947. *Motion Picture Testing and Research, (Report No.7. A.A.F. Aviation Psychology Research Reports)*. U.S. Government, Printing Office. Washington D.C.
- Gibson, J. J. 1966. *The Senses Considered as Perceptual Systems*. Houghton Mifflin Company. Boston.
- Gibson, J. J. 1979. *The Ecological Approach to Visual Perception*. Houghton Mifflin Company. Boston.

- Hildebrand, G. 1991. *The Wright Space: Patterns & Meaning in Frank Lloyd Wright's Houses*. University of Washington Press. Seattle.
- Kaplan, R, and Kaplan, S. 1989. *The experience of nature: a psychological perspective*. Cambridge University Press. Nw York.
- Kaplan, R. Kaplan, S. and Brown, T. 1989. Environmental Preference A Comparison of four Domains of Predictors. *Environment and Behavior*, **21**(5), 509-530.
- Kaplan, S. 1987. Aesthetics, Affect and Cognition: Environmental Preference from an Evolutionary Perspective. *Environment and Behavior*, **19**(1), 3-31.
- Markhede, H, and Koch, D. 2007. Positioning Analysis: social structures in configurative modelling. *6th International Space Syntax Symposium*, Istanbul.
- Meilinger, T., Franz, G, and Bulthoff, H. 2009. From isovists via mental representations to behaviour: first steps toward closing the causal chain. *Environment and Planning B: Planning and Design*, Online publication (Jan 26), 1-16.
- Ostwald, M. J., and Dawes, M. J. 2013. Prospect-refuge Patterns in Frank Lloyd Wright's Prairie Houses: Using Isovist Fields to Examine the Evidence. *Journal of Space Syntax*, **4**(1), 136-159.
- Peponis, J., Conroy-Dalton, R, Wineman, J, and Dalton, N. 2004. Measuring the effects of layout upon visitors' spatial behaviors in open plan exhibition settings. *Environment and Planning B: Planning and Design*, **31**(3), 453-473.
- Pfieffer, B, and Goessel, P. 2010. *Frank Lloyd Wright 1917-1942 The Complete Works*: Taschen.
- Psarra, S. 2005. Spatial Culture, Way-Finding and the Educational Message. in S. Macleod (Ed.), *Reshaping Museum Space: Architecture, Design, Exhibitions*. Routledge. London.
- Psarra, S. 2009. *Architecture and Narrative. The Formation of Space and Cultural Meaning*. Routledge. London.
- Stamps, A. E. 2005. Isovists, enclosure, and permeability theory. *Environment and Planning B: Planning and Design*, **32**(5), 735-762.
- Stamps, A. E. (2009). On shape and spaciousness. *Environment and Behavior*, **41**(4), 526-548.
- Stamps, A. E. (2011). Effects of Area, Height, Elongation, and Color on Perceived Spaciousness. *Environment and Behavior*, **43**(2), 252-273.
- Stavroulaki, G., and Peponis, J. 2005. Seen in a Different Light. Icons in Byzantine museums and churches. *5th International Space Syntax Symposium*, Delft.
- Turner, A. 2004. *Depthmap 4, A Researcher's Handbook*. Bartlett School of graduate studies, University College London. London.
- Tzortzi, K. 2004. Building and Exhibition Layout: Sainsbury Wing Compared with Castelvecchio. *Architectural Research Quarterly*, **8**(2), 128-140.
- Wiener, J, and Franz, G. 2005. Isovists as a Means to Predict Spatial Experience and Behavior. in C. Freksa, M. Knauff, B. Krieg-Brückner, B. Nebel and T. Barkowsky (Eds.), *Spatial Cognition IV. Reasoning, Action, Interaction*. Vol. 3343, pp. 42-57: Springer. Berlin / Heidelberg.
- Wong, J. F. 2012. The script of viscosity: the phenomenal experience in Steven Holl's museum architecture. *Journal of Architecture*, **17**(2), 273-292.
- Zamani, P, and Peponis, J. 2013. Co-Visibility and Pedagogy: Innovation and Challenge at the High Museum of Art. *The Journal of Architecture*, **15**(6), 853-879.