COMPUTATIONAL MEASUREMENT OF PROSPECT-REFUGE PERCEPTION IN TWO-DIMENSIONAL BUILT SPACE

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Abstract. Prospect-refuge theory, as a noted environment preference pattern, holds that the environment providing conditions to unimpededly see others without being seen can evoke a psychobiological pleasure for people. Although being an effective approach to understand successful and enduring emotional experience, less special attention has been paid to uncover the concrete degree of “prospect” and “refuge” properties of locations. With this background, this paper develops a computational model, Prospect-Refuge Analysis (PRA), for quantitatively measuring the diverse prospect-refuge perceptions in two-dimensional built space. Then the paper verifies the measuring effectiveness of the PRA via comparatively examining the data-perception consistency in Frank Lloyd Wright’s domestic projects.

Keywords. Simulation and Analysis; Environmental and Behavior Psychology; Prospect and Refuge Theory; Spatio-Visual Analysis Model.

1. INTRODUCTION
As a well-known environment preference pattern, the prospect-refuge theory was firstly proposed by geographer Jay Appleton in *The Experience of Landscape* (1975). The theory holds that taste in art is “an acquired preference for particular methods of satisfying inborn desires” (Appleton, 1975). These desires include the simultaneous possession for opportunity and safety, which is genetically derived from survival needs in the primal environment. In order to survive, any species needs environment benefitting to track its prey to realize successful hunting and simultaneously enable itself to easily hide from its predator’s attack. The spatio-visual environment property supporting the former unimpeded gaze is defined as “prospect” by Appleton, while that supporting the latter convenient hiding is defined as “refuge”. Appleton (1975) argued that, in a suitable combination, these two properties define an environment that is conducive to survival. During the long evolutionary process, such pragmatic superiority is gradually transformed from a biological need into an environmentally derived pleasure in a psychological and aesthetic sense.

Since its proposition, the theory has been widely supported by plentiful parallel researches and experiments, such as Stephen and Rachel Kaplan’s (1989) information-processing mechanism, Fisher and Nasar’s (1992) crime prevention
study as well as Komar and Melamd’s(1993) paintings preference experiment. However, although tracing these two bidirectional spatio-visual properties, prospect and refuge, constitutes one of effective approaches to psychobiologically understand successful and enduring emotional experience, less special attention has been paid to measure the degree of them of locations in two-dimensional built space. The application of such theory is largely limited to the symbolic definition regarding prospect and refuge places(Appleton,1975) rather than the quantitative state description of them. This deficiency leaves a potential gap in both accurately understanding diverse prospect-refuge perceptions in two-dimensional built space and controlling such a perceptual state in relevant design practice.

With this background, this paper seeks to explore a special Prospect-Refuge Analysis(PRA) model for quantitatively measuring these double properties of locations in two-dimensional built space. The first part explores the two-dimensional space mechanism for influencing the degree of prospect-refuge perception; Based on it, the paper then constructs the rule of PRA model; The third part aims at using Grant Hildebrand’s(1991) perception recording about Frank Lloyd Wright’s domestic projects to verify the measuring accuracy of PRA; Finally, the paper concludes with a discussion about the main research limitations.

2. TWO-DIMENSIONAL SPACE MECHANISM FOR INFLUENCING DEGREE OF PROSPECT AND REFUGE

To measure the above degree of prospect and refuge perceptions, it is necessary to transform the static and symbolic concept of prospect-refuge into a gradient and measurable spatio-visual state. A careful analysis suggests that "prospect" referring to favorable conditions to see others, to track act of prey in the primitive sense, can be described by relatively easy conditions in which the considered viewpoint actively recognizes the behavior of a target, generally another person in the context of built space. Similarly, "refuge" referring to favorable conditions to hide, to escape from predator’s visual locking in the primitive sense, can be described by the relatively difficult condition in which the considered viewpoint’s behavior is passively recognized by that target person. Therefore, the measurement for prospect-refuge degree of locations in two-dimensional built space can be equivalently transformed into the measurement about how the accuracy of visual recognition of target person’s behavior in a scene is influenced by the architectural plan. In this agenda, the "prospect" degree of considered viewpoint is equivalent to the recognition accuracy in which he or she actively see others’ behavior, while that of "refuge" is equivalent to the recognition accuracy in which his or her behavior is passively seen by others.

From common sense, the understanding of a person’s behavior in architectural plan relates to two spatial factors: One is the integral degree of visible surrounding environment where the person behave, which can be abbreviated to visual integrity; The other is the enduring time in which target person appears in the scene, in other words, the shortest distance the person can choose when escaping from another person’s gaze, which can be abbreviated to visual continuity. It can be empirically found the more complete these two factors are, the more accurately the viewer can understand the scene narrative.(Fig.1a) Theoretically,
such intuition can be validated by several visual-cognition theories. One is the Gestalt theory (Hochberg, 1968, etc.), which holds that the human brain has an initiative information processing capacity to construct visible content as a meaningful whole. As the loss degree of visible content increases, the relevant completion structure becomes increasingly difficult to be identified, thus making the scene cognition increasingly rely on complement reorganization from the perceiver’s brain. In this process, the cognitive deviation between actual and processed content about such scene is increasingly enlarged. Similarly, another theory, Empiricism Perception (Gregory, 1974, etc.) also holds that the scene with information loss will be inferentially reconstructed. However, such process relies on the perceiver’s experience and knowledge accumulation rather than the physiological brain as asserted in Gestalt. As the loss degree of visible signal increases, the signified units in a scene will reduce, thus increasing the deviation in such reconstruction. The third is Ecological Optics (Gibson, 1979, etc.). It holds that direct visual perception realizes by receiving a series of informative optical arrays reflected from the scene objects. During movements, the array patterns of change are lawful. For adapting intricate environment, human have evolved the ability to extract such invariant array patterns in changing scenes for understanding scene narratives. Therefore, any information loss of a scene will disturb the invariants cognition by synchronically mutilating the completeness of optical array pattern or diachronically interrupting the regularity of its movement sequence. Both of them will reduce cognition accuracy.

On above basis, it can be found that built components like wall and column in an architectural plan can make the visual integrity and visual continuity in both active and passive visual interaction of considered viewpoint to be different via visual occlusion. This occlusion shapes the asymmetrical behavior recognition accuracy in such bidirectional gaze, thus defining the differentiated degree of “prospect” and “refuge” properties of the considered location. (Fig. 1b)

Figure 1. (a) Spatial factors for influencing accuracy of behavior recognition. (b) Two-dimensional built component (wall, column, etc.) shaping asymmetry in active (A sees B) and passive (B sees A) visual interaction of considered point (A).
3. CONSTRUCTING A PROSPECT-REFUGE ANALYSIS (PRA) MODEL

3.1. ABSTRACTION OF ARCHITECTURAL PLAN AS INPUT DATA

Building on the above findings, the actual measurement of PRA can be conducted via programming.

In the modelling, the built case can be sectioned at 1.7 m, the height of the human eye, from the standard floor height of major plan zone. If necessary, the plan zone with a slight height difference, usually less than 1 m, with the major zones can also be involved considering less impact such difference evokes. The zones that do not satisfy the above conditions will be eliminated from consideration.

The plan area after the above sectioning can be represented by two point matrix systems with same density. One is the main point matrix including all bodily inhabitable positions in plan. Another is the secondary matrix including all visible contextual positions. Under this rule, the secondary matrix should always cover and sometimes exceed the area of the main matrix. Generally, the interval of around 1 m between two adjacent tested main points can be set to simulate the walking stride of person. Any position which can neither be bodily arrived nor be visually seen in plan will be excluded from both matrices.

Within these established nodes, all built components in plan will be abstracted into two types of polyline. The first type refers to the sight-blocking line such as walls higher than eye height and thick columns. The second type refers to all path-blocking line which not only covers all sight-blocking lines but also includes lines such as a fence above 0.5 m which is hard to step over, or a glass wall which blocks physical passage but maintains visual interaction.

3.2. PROSPECT-REFUGE DEGREE MEASUREMENT TO ANOTHER SINGLE VIEWPOINT

Based on the previous cognition theories, the recognition accuracy to a person’s behavior \( s_p \) is positively correlating to both the visual integrity \( i_p \) and visual continuity \( c_p \). Quantitatively, we can use the product of \( i_p \) and \( c_p \) to measure...
such accuracy, which means the accumulated amount of visible scene information defined by visible information of unit time and the shortest enduring time of such information:

\[ s_p = i_p c_p \]  

Procedurally, visual integrity \((i_p)\) can be calculated with the following steps: 1. Setting a circle around the viewed point B to represent the contextual area of target person behavior. The radius of the circle can be adjusted for maximizing the differentiated condition of each location. 2. Connecting the viewed point B to all secondary sample points within the circle. The number of connection without intersecting with any sight-blocking wall line can describe the whole effective contextual area of target person \((M_e)\). 3. Connecting the viewer point A to all effective points in step 2. The number of connection without intersecting with any sight-blocking wall line can describe the watchable contextual area of target person from viewer in point A \((M_w)\). 4. The ratio of step 3 to step 2 could quantitatively describe the visual integrity in which point B exposes to point A \((i_p)\):

\[ i_p = M_w / M_e \]  

Similarly, visual continuity \((c_p)\) can be calculated by several steps: 1. Connecting the viewer point A to all the secondary sample points in the plan. The points of which connection line intersects with any sight-blocking wall line can describe the blind positions of point A. 2. Connecting the target point B to all blind points in step 1. If the connection line intersects with any path-blocking wall line, defining the shortest polyline which goes through any other secondary point as the effective connection line. 3. Selecting the shortest one of all effective connection lines in step 2 to describe the shortest sight-escaping distance a person could choose \((N)\), in other words, the visual continuity of which point B exposed to point A \((c_p)\):

\[ c_p = N \]  

Within the above measuring logic, the considered viewpoint will be given double values, \((X)\) and \((Y)\). The \((X)\) is produced in direction this viewpoint actively views target person as the degree of “prospect” property, while \((Y)\) is produced in direction this viewpoint is passively viewed by target person as the degree of “refuge” property. In such manner, the “prospect-refuge” degree of the considered viewpoint to another single viewpoint can be described as below:

\[ (X, Y) = (s_p, s_p') = (i_p c_p, i_p' c_p') \]  

3.3. PROSPECT-REFUGE DEGREE MEASUREMENT TO OVERALL VIEWSHED

In actual space analysis, the target person may appear in every points of viewshed of viewer. In this sense, the behavior recognition accuracy to a whole viewshed \((s_n)\) can be measured as the summation of synthetic information completeness of every inhabitable location of target person:

\[ s_n = \sum(s_{p1} + s_{p2} + s_{p3} \ldots + s_{pn}) \]  

Being similar with logic of two interactive viewpoints, the considered viewpoint
will also be given double values, \((X)\) and \((Y)\). The \((X)\) is produced in direction the viewer views all potential locations of target person in his viewshed represented by the main point matrix. The \((Y)\) is produced in direction this viewer is viewed by all above potential locations of target person. In such manner, the “prospect-refuge” degree of a considered viewpoint to its whole viewshed can be described as the continuous addition formulation:

\[
(X, Y) = (s_n, s_{n'})
\] (6)

3.4. POSSIBLE SUB-MEASUREMENT OPERATION

Like other spatio-visual models, the PRA can be flexibly operated based on diverse purposes. For example, we can take all visible points into calculation to describe the absolute “prospect-refuge” degree of a location, while we can only take visible points outside convex space of considered point into calculation to describe the relative one of a location considering all points in same convex space have other interactive behaviors which can restrain the visual interaction effect.

3.5. OUTPUT DATA REPRESENTATION AND ITS PERCEPTION MEANING

In above measurements, the double values, \((X)\) and \((Y)\), of every location can be visualized as two concentric circles with respective areas to reveal several basic spatio-visual conditions associated with relevant perception implications: First, if \((X)\) is larger than \((Y)\), relevant location is a type of prospect-refuge area evoking more security and promising feeling; if smaller, such location evokes more insecurity and unpromising feeling. Second, the greater difference between \((X)\) and \((Y)\) means the location accommodates intensified feeling in either security and promising aspects or insecurity and unpromising aspects. Third, when the ratio is constant, the higher total value, \((X)\) plus \((Y)\), implicates the location is more strongly influenced by prospect-refuge related perception.

4. VERIFICATION OF PRA: A CASE STUDY OF WRIGHT’S DOMESTIC SPACE

After constructing the PRA model, the following part aims at using Hildebrand’s (1991) prospect-refuge perception recording about Wright’s domestic space to verify its measuring accuracy.

4.1. PERCEPTUAL PATTERN

Wright’s domestic designs after 1901 have been widely praised for their capacity to stimulate positive phenomenological attraction(Laseau and Tice,1991; Lind,1994; Hienz,2006). One of convincing perspectives that explains the experience of Wright’s houses is from its elaborately-designed spatio-visual property(Blake,1964; Twombly,1979; Salter,1999). By applying and extending Jay Appleton’s prospect-refuge theory, such spatio-visual property is embodied by Hildebrand(1991) into a prospect-refuge related perception system described as “Wright Pattern”. Based on that, Wright’s post-1901 domestic projects share the two types of prospect-refuge perception quality that conjunctively shape the
psychobiological pleasure of their inhabitants (Hildebrand, 1991):

More Similar Processional Incredibility: The first aspect lies in the more similar processional incredibility of prospect-refuge property along the path from entrance to heart of living room in most post-1901 houses. The concrete similarity includes: 1. Dominant refuge perception in the entrance foyer. 2. Remarkable increasing of prospect perception in the end of entry foyer near the living room. 3. Increasing refuge perception from the end of entry foyer to the seating space near fireplace (Prairie) or alcove (Usonian). 4. Decreasing refuge perception from the seating space near fireplace (Prairie) or alcove (Usonian) to the center of living room. 5. Increasing prospect perception from the seating space near fireplace (Prairie) or alcove (Usonian) to the center of living room. By providing such continuously changing dominant spatio-visual quality between prospect and refuge in dynamic path, Wright enables the visitor to first set foot on the room with a curious mind and lower expectation; Then surprisingly discover and continuously experience either a more exposed or a more covert location after entering. Such “processional incredibility” (Johnson, 1958) can evoke positive emotional responses by allowing a person to move to a more prospect-dominant position when searching for resources or information and to a more refuge-dominant one if danger appears (Hildebrand, 1991).

Increasing Global Heterogeneity: The second aspect lies in the increasing global heterogeneity of prospect-refuge property in most post-1901 houses. It means that the combinational relation of prospect and refuge properties of every location in public living zone of post-1901 houses presents higher diversity than that in prevailing Victorian style houses. By shaping such richer array of prospect-refuge condition, Wright provides diverse individuals with varying moods generated from not only gender and individual personality but also time of day, time of year, and time of life a suitable position to inhabit (Hildebrand, 1999).

4.2. MEASUREMENT METHOD

Eight houses are chosen in each of three typical periods of Wright’s domestic designs, the Victorian before 1901, the Prairie and the Usonian after 1901. The measuring results of both groups are compared with the recorded perception via specific statistical methods. By observing if the output data of post-1901 cases with “Wright pattern” has a higher consistency with prospect-refuge perceptual recording of them (Hildebrand, 1991) than that of pre-1901 cases with those day’s prevailing style, we can comparatively verify the PRA measurement.

The measurement will be implemented within the inhabitable area in built function zones of house while the surrounding areas will not be sampled. Since such surrounding area is dark for half of the day and is obscured by environment for much of the year, the visual interaction between built inhabitable area and it is partially symbolic just as “overlooking postage-stamp lawns” (Twombly, 1979, 245). Instead, since artificially connected, the visual interaction between different built function zones is arguably more possible to shape the actual prospect-refuge perception because it guarantees clear information acquisition all the time and allows for possible body-gathering right after visual interaction (Ostwald, 2018). Using the above point matrix, a “relative”
PRA measurement is applied to each case considering the visual interaction within single convex space is generally restrained by other interactive acts.

4.3. MEASUREMENT RESULT

More Similar Processional Incredibility: After PRA testing, we make a data chart revealing the result of tested positions from entrance to living heart for each case. In the chart, the perception of dynamic walking positions is represented as the data of a series of successive tested points along the path based on Hildebrand’s text and diagram, while that of static positions, like the seating space near fireplace (mainly in the Prairie), the alcove (mainly in the Usonian) and the center of living room, is represented as the average data of several tested points within relevant areas to insure the most veracious regional correspondence with the place evoking relevant perception in Hildebrand’s (1991) recording. The results of all plans are compared with the expected standard result abstracted from Hildebrand’s perception recording. We set 20 percent weight for each of the five regional similarities of prospect-refuge perception. The higher percentage means the higher regional similarity. The calculation result suggests the average similarity degree of post-1901 houses is higher than that of pre-1901 houses for around 15 percentage points although some individual samples like Adams have lower similarity than the average degree of pre-1901 houses. This result generally corresponds to Hildebrand’s description about the higher processional regional similarity of prospect-refuge perception in Wright’s Prairie and Usonian house.(Figs.3,4)
Increasing Global Heterogeneity: For global trend, we make a scatter plot containing the data result of all “public livable” zones for each case. According to the implied area condition in Hildebrand’s (1991) recording, the increasing global heterogeneity of prospect-refuge is perceived in zones where all members of house owners and guests can stay comparatively long for enjoying domestic life. Therefore, the kitchen-pantry zones for servants in Victorian and Prairie houses, the bedroom zones for limited family members in all styles, and some extremely functional zones in all styles, such as heating room or storage room where people cannot stay long, are excluded from the data sampling. Based on the range of output data, a 20x20 grid is set for each plot to divide the whole value domain into 36 regional units. Statistically, each square unit in the grid can be approximated to reflect a type of obviously perceivable prospect-refuge state, since the data locating in the same unit of grid are comparatively close. Therefore, the more square units the data of a case occupy, the more diverse types of prospect-refuge perception the case can provide. The calculation result suggests the average amount of occupied “type” units of post-1901 houses is around five more than that of pre-1901 houses although some individual samples like Millard with less “type” units than average amount of pre-1901 houses exist. This result exactly reflects to Hildebrand’s description about the increasing global heterogeneity of prospect-refuge perception in Wright’s Prairie and Usonian houses. (Fig. 5)

5. CONCLUSION AND DISCUSSION
In this paper we have presented and comparatively verified a spatio-visual analysis model for measuring the prospect-refuge related perceptions in two-dimensional built space.
Figure 5. The comparative analysis for data-perception consistency of global heterogeneity between pre-1901 and post-1901 houses of Wright.

Admittedly, the present research has several technical and theoretical limitations. First, the current model mainly considers the enduring influence evoked by fixed space composition. If necessary, further work is needed by involving the lighting factor which will bring instantaneous influence on the recognition of person’s behavior, the prospect-refuge degree. Second, the model mainly considers the architectural plan. More research is needed for extending it into three-dimensional space. Third, the congruity of verification is found in the present sample size. The result involving more cases is left for further examination.

References