COMPUTATIONAL METHOD FOR MAPPING QUALITY OF ARCHITECTURAL SPACE

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Abstract. The key aim of this paper is to develop a computational method for mapping architectural space used for visual openness analysis. We suggest that the result will offer possibilities for quantitative design analysis particularly on spatial quality influenced by architectural elements. The proposed method consists of two stages: determination of subdivided enclosed spaces and measuring quality using visual openness parameters on each subdivided enclosed space. We advise new approach to determine subdivided enclosed spaces on architectural plan by determining two factors: bounded space and circulation space. Computational procedures applied to analyse architectural plan and then determine map of subdivided enclosed space by analysing relationship of these two factors. The concept underlying this method is that architectural space is composed of subdivided enclosed spaces, which each of them have distinct physical properties and therefore become possible to develop mapping of evaluation regarding the quality of architectural space. Our finding on orthogonal architectural plan provides ranking index of subdivided enclosed spaces that could help for analysing spatial quality of architectural space.

Keywords. Architectural space; subdivided enclose space; quality mapping; computational method.

1. Introduction

This study focuses on the architectural space as a result of the arrangement of architectural elements. There are two main approaches to architectural spatial modeling: One considers space we experience as a product of our perception and movement, and the other regards the space as an entity resulting from the arrangement of its boundary elements. A space as defined by later argument
is the void between physical boundaries where its existence is independent of
the user’s presence. Based on this principle, we further regard architectural
space as a fixed entity because its basic property can be modeled and meas-
ured similar to other physical objects.

For this purpose, we develop a method for modeling subdivided enclosed
space of architectural plan. Our method is derived from the following
approaches: We first evaluated previous methods of computing architectural
spaces and then investigated the relationships between space, circulation path
and elements of architectural design. We developed new rules of application
based on our findings.

2. Architectural space and the experience in the space

Architectural space is experienced not just by attributes of its boundaries. The
variability in the interior (enclosed space) and exterior (enclosure) comprise
the essence of architecture (Arabacioglu, 2010). Several architects (Alexander,
1977; Rasmussen, 1959; Lawson, 2001; Bentley, 1985) as well as psycholo-
have found that the experiences in the same space can vary with the changes
in architectural design elements such as colors and transparency.

Another aspect of architectural space is that architects always compose
space according to the boundaries and inter-relationships between the archi-
tectural elements and planned activities. March and Steadman (1971) used
network graph to denote topological relationships between rooms – which
room gives access to another, which room is adjacent to another. Péna (2001)
suggested that the matrix relationship of activities should be constructed to
model adjacency of spaces regarding designated activities. Both studies had
used basic mathematical model of spatial configuration in order to understand
relationship between spatial design and activities.

Our model of enclosed spaces is the elaboration from previous study by
Gross (1977), Koile (2001) and Sora (2008) with the advancement of having
a map configuration of what we named as subdivided enclosed space inside a
set of interior space. We believe that each area of subdivided enclosed space
expresses distinct spatial qualities that are significant for spatial quality analy-
sis and further design elaboration.

Here, we developed an elaboration model for computing architectural
space quality by developing a map of subdivided enclosed space. We gener-
ated the subdivided enclosed space by analyzing two main factors: bounded
area and circulation area.
3. Previous studies on spatial mapping
The concept of classification of enclosed space dates back to 1977 when M.D. Gross built a model to measure the level of spatial intensity by the number of solid boundaries (Gross, 1977). According to his study, an enclosed space is classified by adjacent walls and its numerical scale depends on the number of adjacent walls. An enclosed space can be defined by the following simple procedure: first, draw extension lines from walls, and second, construct perpendicular lines at the wall endpoints.

Koile (2001) proposed territoriality as one model for determining enclosed space in which each region is defined by its enclosure territory. Basically, the region is formed by the overlapping of territorial lines within the space. The architectural space, according to this method, is a juxtaposition of territory, circulation and use-space models; the latter is an attribute model assigned by the architect.

Through this approach, it is possible to generate an analytical model of an architectural space in which each region represents a space influenced by architectural elements.

In addition, Koile’s model represents the concept of dividing the space into subsets of enclosed spaces using perpendicularly linear projections from the edges of each element. This model can accommodate solid element such as walls that form space as well as other elements such as doors that form circulation paths and spaces.

4. Subdivided enclosed spaces
In the context of architectural plan, we determined an interior space as a unit analysis. An interior space is a space comprised of enclosures, enclosed space and circulation path. We named this area as bounded area (Figure 1).

![Diagram of spatial mapping](image)

*Figure 1. Unit of analysis*
A bounded area comprises of rectangular-type arrangement of enclosed spaces which depend on the configuration of architectural elements at the enclosure. Our computational method is then, develop configuration of enclosed spaces based on sequential rules by considering relationship between bounded area and path. Bounded area is part of unit of analysis where enclosed spaces are to be determined. The bounded area may enclosed by opaque boundaries (walls), openings (windows or doors) and other architectural elements. A path is a circulation connector inside the bounded areas. Circulation gates such as door and path form a circulation space in the bounded area.

For determining subdivided enclosed space, Our computational method works over importer CAD data. Since the input is in polygon form, the process begins by analysing the elements of the polygon. Based on this data, program executes sequential procedures and defined rules to create layout of enclosed spaces. The sequential procedure is significant to ensure hierarchical level of enclosed spaces. At the final result, we have the bounded area which comprises of hierarchical subdivided enclosed spaces delineated by territorial lines.

4.1 METHODS AND RULES

All computational process are conducted using Grasshoppper script in Rhino. Our semi-automatic method for computing subdivided enclosed spaces works in the following sequential procedures:

1. Establish L-shaped enclosed space by computing co-linearity of the boundaries and create virtual L-shaped lines to delineate the area. The co-linearity test between two polygons is performed using determinant operation by extracting maximum and minimum points of each input polygons. If determinant is not equal to zero then two polygons are not co-linear and further, program creates L-shaped area from each center point.

In example, determinant operation of three points: \( P(x_p, y_p) \), \( Q(x_q, y_q) \), and \( Z(x_z, y_z) \) is as follows:

\[
(X_p(Y_q - Y_z) - X_q(Y_p - Y_z) + X_z(Y_p - Y_q)) = 0
\]  

(1)

2. Define horizontal and vertical axial lines based on the geometry of the bounded area and create virtual axial lines. Determination of axial lines is significant to provide guideline for next procedure. The creation of boundary polygon is necessary as an input for this procedure. Afterward, program detects its center point using this equation:
Area of boundary ($A$) = \[
\frac{1}{2} \sum_{i=0}^{n-1} (x_i y_{i+1} - x_{i+1} y_i)
\] (2)

Moreover, the coordinate of the center point is as follows:

\[
Center X = \frac{1}{6A} \sum_{i=0}^{n-1} (x_i y_{i+1} - x_{i+1} y_i)(x_i + x_{i+1})
\] (3)

\[
Center Y = \frac{1}{6A} \sum_{i=0}^{n-1} (x_i y_{i+1} - x_{i+1} y_i)(y_i + y_{i+1})
\] (4)

Later, program creates line from center point perpendicular and terminates at boundary polygon.

3. Determine and create virtual extension lines from each edge of the openings and circulation path (i.e. window and door) perpendicular to each virtual axial line.

4. Divide initial enclosed space by making extension lines from the edge of L-shaped area to the nearest virtual line.

5. Establish center point of each divided enclosed space.

The result of this computational process is the configuration of subdivided enclosed spaces as illustrated in Figure 2.

Figure 2. Graphical example of computation of subdivided enclosed space; a) Initial plan; b) Determination L-shaped enclosed space; c) Circulation area using axial line; d) Determination area of opening territory by extending its edges perpendicular to axial line; e) Determination of extended area by extending L-shaped edges perpendicular to the nearest lines; f) Center points of the subdivided enclosed spaces.
5. Model of visual openness index

Window is an architectural element that provides visual, light, and air connection between indoor and outdoor environments. In modeling visual openness, we consider the window as the source of its influence. This visual openness influence is received by each of subdivided enclosed space we determine earlier in a different level considering their layout in a bounded area. There are three factors that influence the magnitude of this influence: distance to the window, ratio of the area of the window with area of the adjacent wall, and ratio of area made by a given point of subdivided enclosed space with the edges of window area and area of the bounded area. The significance of this index is that it can express the visual influence of enclosed space with such qualitative and quantitative attributes attached such as privacy, natural light, and air.

5.1 METHOD

The term visual openness index refers to the level of visual influence at a reference point as a result from procedural computation using three variables:

1. Visual distance; refers to the distance from a given point to the openings
2. Transparency index; refers to the ratio of opening area and adjacent wall area
3. Viewing area; refers to the ratio of area potentially seen from a given point to the window area and bounded area

As a reference point represents enclosed space area, the visual openness index expresses influence of particular architectural elements layout to the configuration of subdivided enclosed spaces. The function to model the relationship of three variables is based on the exponential decay function where influence of visual connection decrease exponentially over distance:

\[
VO_i = (tr)(va_i) \exp \left( \frac{-d_i^2}{d_i} \right)
\]

(5)

Where: \( VO_i \) = Visual Openness index at \( i \); \( tr \) = transparency index; \( va \) = viewing area index at \( i \); \( d_i \) = distance from \( i \) to the opening. Figure 3 illustrates this model:
6. Experiment and result

We developed procedural rules for spatial mapping and visual openness analysis using script programming in Grasshopper. The input is CAD polygon. For the experiment, we used the architectural plans of Kaufmann House (Falling Water house) by Frank Lloyd Wright (Figure 3).
Table 1 illustrates results of subdivided enclosed spaces in different interior layouts. Magenta lines indicate L-shaped area; Green lines indicate axial lines; Cyan lines indicate circulation area; and yellow lines indicate territory area.

<table>
<thead>
<tr>
<th>Room 1: Three doors and two windows</th>
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<tr>
<td>![Room 1 Diagram]</td>
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<table>
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<tr>
<th>Room 2: Two doors and one window</th>
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<td>![Room 2 Diagram]</td>
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<th>Room 3: One door and one window</th>
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<td>![Room 3 Diagram]</td>
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Table 1. Procedural steps to develop map of subdivided enclosed spaces

Following this result, we conducted visual openness analysis using the formula (5). The result displayed in Figure 5 and Figure 6:

![Figure 5](image)

**Figure 5.** Diagram shows visual openness ranking of all points in three different rooms. On average, room 1 has high level of visual openness while room 2 has low level of visual openness. As a whole, all subdivided enclosed spaces in all rooms have adequate visual openness level and only about 14.4% has lowest visual openness level.
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7. Summary and discussion

We presented a methodology for mapping architectural space by generating subdivided enclosed spaces. The procedures follow the below mentioned sequential rules applied to polygons of architectural plan: determination of L-shaped enclosed spaces; establishment of axial lines; determination of circulation space; and determination of subdivided enclosed space.

Generating subdivided enclosed space provides a visual cue to help designers or users develop more accurate spatial configuration. Based on this model, we develop computation of architectural space quality using visual openness as a parameter. The result on visual openness index provides an analytical cue to quantify the quality of architectural space in each area of subdivided enclosed space.

We propose that this computational design analysis will improve our understanding of organizing architectural space by a quantitative approach rather than a qualitative or subjective approach. The advancement may lead to generate a signature of an architect based on his/her spatial configuration over spatial parameters as demonstrated preliminary in this paper.

As a method to compute enclosed spaces, the proposed model has limitations that will be the focus of our future investigation. They include using
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rectangular-based plan as model for analysis. We are aware that for future improvement there are some significant factors need to be addressed such as: rules for territory-based settings and elaboration on visual openness model by combining computational model with empiric-based model using human vision as well as their personality trait. The later is considered by the hypothesis that architectural space is experienced varies depends on the dominant personality trait.

References

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