Quantifying the Visual Experience of Three-dimensional Built Environments

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Abstract
The object of visual experiences in three-dimensional built environments can be considered as a collection of surfaces that are recognized by the human senses. This study suggests a way to interpret mutual visual relationships of surfaces based on the visual amount of light that reflects between surfaces. For this purpose, Three-dimensional Visibility Analysis (TVA) has been created as a platform for understanding the architectural implications of visual experiences in three-dimensional built environments by classifying the visual experiences into seven indices and quantifying them. We first examined the architectural meaning of each visual index through simple models to comprehend how visual relations operate between objects' surfaces and explored the visual properties of the three-dimensional built environments and their architectural significance in them. Two types of case studies using these visibility indices were undertaken to investigate their objective meanings and to provide potential applications that might be adoptable for practical applications of the built environment, as well as to find associations with how these factors are affected by the social behavior that occurs in it.

Keywords: visibility; three-dimension; isovist

1. Introduction: The Research Context
The two images in Fig.1., showing the Basilica San Marco in Venice illustrate the characteristics of a place in certain directions that cannot be perceived through the layout in Fig.1.(a). While the layout provides a picture of the comprehensive spatial organization, it does not provide the imagery of the actual visual experience of the place that is formed through the three-dimensional shapes and facades of surrounding buildings. By comparison, although the images provide an understanding of the visual characteristics from a certain viewpoint, they do not show the full spatial organization which the layout provides.

With the advancement of computers, many experiments have been conducted since the 1970s aimed at quantitatively understanding visual experiences of three-dimensional built environments formed by surrounding buildings. This started with the work on isovist field analysis (IFA) by Benedikt (1979). His theory focuses on the visual field and the geometric properties of that visual field observed in all directions from a certain point of an architectural building or an urban city. IFA partitions the ground surface (or floor surface) of the target place into a continuous network of grids, and creates an isovist shape observed from the centre point of a grid. The comprehensive visual properties of the target place are then derived from analysing the geometric characteristics of this isovist shape. Building on this study, Batty (2001) and Conroy (2001) researched the relationship between perception of place and its potential use and social characteristics.

Hillier (1996a), on the other hand, asserted that the analysis of 'spatial configuration' formed by the visual relationship of the whole place precedes that of isovist or isovist fields. Space syntax, a

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Fig.1. St. Mark's Square
theory and methodology suggested by Hillier and his team proposes various quantitative indices that express characteristics of the place by incorporating mathematical graph theories in spatial relationship studies. The visual experience of place that has been qualitatively evaluated so far, was quantitatively identified through isovist and space syntax interpretive methods.

For a more detailed analysis of architectural and urban built environment, Batty (2001) and Turner et al. (2001) developed visibility graph analysis (VGA). VGA divides two-dimensional convex areas and isovists into a grid of certain-sized squares, and uses the grid as a basis for the derivation of various indices. Then, the visual relationships between the grid units are expressed in a graph and used to calculate the various quantitative indices of space syntax such as connectivity, depth and integration.

The two-dimensional isovist, formed by intersecting the visibility line projected horizontally from the eye level with the surrounding objects or buildings, is the focus of visibility analysis. While an isovist considers visibility of all directions in 360 degrees, it does not recognize visual relationships of three-dimensional shapes of buildings that meet occluding surfaces of walls. As exemplified in the image of St. Mark's Square in Venice, visitors have a strong three-dimensional visual experience through the perception of form, size, and direction of buildings and facades that are within their viewpoint.

Most studies of three-dimensional visibility have employed volumetric isovist space as the target of analysis, or utilized the digital elevation model (DEM) for three-dimensional earth surfaces. In a recent representative study by Morello and Ratti (2009), an 'isovisimatrix' was established based on whether voxel space, a three-dimensional volumetric space that is divided equally into a grid, is visible from the ground. In other words, three-dimensional isovist measurement is computed in the isovisimatrix by counting the frequency at which the visibility lines, projected from all points from the ground to the building, penetrate each voxel space. This study provides a way of conducting visibility analysis on building facades, as it is possible to remove those voxel spaces from the rest of the open space, and analyse the voxel spaces of building facades.

The study by Koltsova et al. (2013) differentiates itself from previous studies by attempting visibility analysis using actual observable targets within an architectural environment from a pedestrian or user perspective. Their study conducted a visibility analysis of the target building facade from a single point on the ground. The modelling method proposed here shared the basic notions used by them and enhanced the modelling technique to provide a comprehensive view reflecting all of the locations of the ground between building facades. Since practical architectural environments observed by pedestrians or building users are a combination of ground surfaces, building facades and roof surfaces, a quantified modelling procedure of the visibility analysis must be defined to reflect a diverse view on visual relationships such as those between different building facades, between building facades and the ground surface, and between the sky and the ground surface.

An architectural space has been typically regarded as a three-dimensional volume formed by adding depth (z-axis) to a two-dimensional surface with a width (x-axis) and a height (y-axis). However, Gibson (1986, p.148) points out that, although defining space as a Cartesian coordinate system is a useful method mathematically, it is an abstract figure and a mathematical expression of a non-existent space. This shows that empty spaces which can be expressed geometrically, might be difficult to experience visually. Therefore geometric volume can be an abstract concept, and an elaborative modelling method for everyday space that can be visually experienced and facilitates visual information exchanges.

Gibson (1950, p.228) regarded visual experience in our everyday lives as compositions of three-dimensional physical variables that provide visual stimulations. The visual experience of three-dimensional objects is essentially the perception of light reflected from the object's surface. These objects are visually perceived through combinations of multiple surfaces that reflect light, and can be perceived through surfaces that become their background surfaces, such as the ground or floor surface, the surface of wall and ceiling.

The visual experience of three-dimensional built environments is derived from these three types of surface relationships and their arrangements (Gibson, 1986, p.148). This places the focus of visibility analysis on surfaces or facades that can be visually experienced and provide visual information. Therefore, visibility analysis of three-dimensional built environments in this study targets the visual information derived from the relationships between surfaces, and not from volumetric spaces.

A conceptual framework of how to descriptively measure the visibility relationship between surfaces of the ground and buildings was introduced for the first time in the authors' earlier research (Chang and Park, 2011). This work mainly dealt with the discrete process of computation technique as well as descriptive algorithms to demonstrate the visibility relationship. This feasibility study eventually led to succeeding research in view of two points in particular: one is the interpretation of implicit meaning of visual relationships in the three-dimensional built environments in architectural terms, and the other is the verification of the descriptive methodology in real life situations.
This research should be read as a comprehensive platform for gathering the thread of the previous works including Chang and Park (2011) and (2016). The latter is about the visibility data tracing technique developed to find out the exact location of the visibility point which shifts its location on the computer screen in accordance with zooming-in or out of the model.

2. Formation of Three-dimensional Visibility Indices

Table 1. shows three-dimensional visibility indices describing the ways of exchanging visual information between ground and building surfaces, and their interpretations of spatial meaning. Surfaces on the ground and building facades are tessellated into smaller units on which the visibilities of vertices are measured. The capital letters G and B followed by V in the notation of indices denote the visible surface of ground and building facade respectively, from a location either on the ground or building facade. A small letter subscript g (g) refers to a viewpoint location on the ground, and subscript b (b) likewise refers to building facades. |G| and |B| are the size of the valid ground surfaces and facade surfaces respectively.

Since the surfaces of each unit are based on a triangular face consisting of three vertices, the 'size of surface' indicates the number of vertices of each surface. ‘Valid space’ is the location that has higher visibility than 0, and thus it is a surface unit that is visually exposed to at least one viewpoint. Areas such as the floor surface inside a building, the hidden area of ground below the building floor, and the outer facades of a building on the very edge of a model (or system), can all be considered as non-valid areas when an open urban area is the target of visibility analysis.

2.1 Openness

Openness is defined as the visibility of the ground surface from a viewpoint on the ground surface. It is the size of the visible amount of open area from the ground surface and has been commonly used, as in the relevant studies, and often corresponds to the two-dimensional isovist area. 'Openness' in this study designates the ground surface as a flexible surface, and allows for modifications in the height of a visibility point under varying circumstances.

2.2 V-density

The study by Penn et al. (1998) confirms the close relationship between the pedestrian movement flow rates of a street and the height of buildings along that street. It could be inferred that the size of the building facades observable from the ground surface is connected to the number of building users, and is also related to the pedestrian movement flow rates on the adjacent street. V-density is the visibility of surrounding building facades from the viewpoint of g on the ground. Building facades are visual elements that have a huge impact on the sense of spatiality from a viewpoint on the ground surface.

| Table 1. Three-dimensional Visibility Indices |
|-----------------------------------------------|
| Indices | Mathematical expressions | Diagram |
| Openness (VG): the visibility of open space on the ground |
| VG = | {g} | G = the number of G, | |
| | | | |
| V-density (VB): the visibility of surrounding building facades from the ground |
| VB = | | B = the number of B, | |
| | | | |
| Navigability (V'): the degree of navigation showing movement patterns on the ground |
| V' = | | G+B = the number of G+B, | |
| | | | |
| V-occlusivity (VB): the visibility of surrounding building facades from the facades |
| VB = | | B = the number of B, | |
| | | | |
| Landmarkability (VG): the visibility of open space on the ground from building facades |
| VG = | | G = the number of G, | |
| | | | |
| Urbanscapes (VS): the degree of surrounding visible urbanscape |
| VS = | | G+B = the number of G+B, | |
| | | | |
| 3D Legibility (3DL): the degree of clarity of urban space experience |
| 3DL = | |

G = The set of valid ground units
B = The set of valid facade units of buildings
G = { v ∈ G: v is visible from g }, where g is a vertex point in G
B = { v ∈ B: v is visible from g }
G = { v ∈ G: v is visible from b }
B = { v ∈ B: v is visible from b }
v denotes the vertices constructing the surfaces in the model

2.3 Navigability

Navigability expresses the amount of visibility on the ground and on building facades from a specific point on the ground surface. Thus, from a viewpoint on the ground, it is the amount of all visible areas on all surfaces that the eye can focus on. Subsequently, this measurement is computed as a ratio of visible areas to total valid areas from a viewpoint on the ground. It is the total number of valid visible areas of the ground and the valid building facades.

As in the case of Cullen’s (1961) series of sketches, a person navigating the city explores the cityscape as a series of visual experiences through movement or walking towards his or her destination. This indicates that 'navigability' within an urban space is closely related to the combination of isovists of the ground and facades that can be visually observed from all viewpoints on the ground.
2.4 V-occlusivity

V-occlusivity is the visibility of all surrounding building facades from a viewpoint on a building facade. The amount of visibility measured here can be interpreted as the inverse level of visual occlusivity created by surrounding building facades as observed from a viewpoint on a building facade. The level of visibility from buildings is largely affected by the shape and arrangement of the surrounding buildings.

Studies by Fisher-Gewirtzman et al. (2003, 2005) describe the visual openness of surrounding areas from a certain height of a building as a three-dimensional volume. Meanwhile, visual openness is defined by measuring the amount of visible surfaces of all the surroundings in this study. It is similar to the method employed for measuring the amount of visible area from the ground. The measured level of visibility can be expressed from the respective viewpoints, on which the building facade would be color-coded.

2.5 Landmarkability

The amount of visible area on the ground surface seen from a building facade is, in other words, the amount of visible area on a building facade seen from the ground surface. Thus, this can be expressed as the degree of Landmarkability of the building facade. This index quantitatively shows the ease with which a building can be visually observed apart from its surroundings (more accurately, its surrounding ground surface), a quality that Lynch (1960) describes as a characteristic of landmarks. The Landmarkability of buildings within important spaces in cities such as plazas can be expressed quantitatively on the corresponding building facade. Landmarkability can be calculated as an average derived from all building surfaces, in accordance with individual facade or specific location within each building facade.

2.6 Urbanscapeness

Urbanscapeness combines the aforementioned V-occlusivity and Landmarkability values and captures the level of visibility of a built environment as viewed from a point on a building facade. Urbanscapeness is the amount of visibility on the ground and surrounding building facades from a building facade, whereas Landmarkability is the amount of visibility on the ground from a building facade. Therefore, Urbanscapeness can be considered as an integrated Landmarkability index, where it measures the visibility of all surfaces in the area (both the ground surface and building facades) from a building facade.

2.7 3D Legibility

The 3D Legibility suggested in this study is defined in Table 1., and is shown as the single measurement value for representing the visual relation to the site. The assumption was made that this index could show how much the configuration of the city connects to other visible spaces as a whole, and attempts to find a firm ground to support this assumption. The concept of Lynch’s (1960) legibility provides an intuitive way of illustrating the process of visual experience of urban cities, and is still valid. The 3D Legibility suggested in this study, which is inspired by Lynch’s concept, could offer a far more elaborate value to provide an understanding of the visual relationship of three-dimensional urban city.

As Gibson (1950, 1986) states, a visual experience of a city is an exchange of visual information between surfaces that can be perceived. Visual relationships formed between all surfaces within an urban area (such as the ground surface and building facades observed from the ground, and the ground surface and building facades observed from the building) define the experience of a city.

3. TVA Analysis of Simple Orthogonal Shape Models

Fig.2. shows the results of applying visibility indices to four simple orthogonal models and analysing them using TVA. These models can be divided into Type A and B based on the shape and arrangement of buildings. Type A has a differently sized ground surface. It has the same shape and layout of buildings but there is a huge difference in the building density. Type B uses the same square-shaped buildings but in different heights and configurations. Both Type A and B exemplify the huge impact of building density on the visibility analysis.

The number of vertices of $|G|$ in Model 1 is similar to that of the building facade $|B|$ ($|G| =1,579, |B|=1,678$). Model 2 has the same layout configuration as Model 1 but the size of its ground surface is around three times larger ($|G|=6,407, |B|=2,377$). Models 3 and 4 of Type B have a much more drastic difference between the size of the ground surface and that of the building facades than Models 1 and 2 of Type A. This is specifically designed to observe the effect of density on the level of visibility under the condition of minimizing the impact of building forms on that of visibility. In the case of Model 3, the number of visible spaces on the ground surface is 324, whereas the number of visible spaces on the building facade is 5,416. This is reversed as $|G|=2,549$ and $|B|=320$ in Model 4. Only valid visible areas are considered in the calculation.

These visibility tests on the hypothetical simple models have shown a reliable trend that could be generalized, but require more sophisticated tests in real life situations especially considering that the larger the ground surface is, the greater the mean visibility values become. This trend implies that the degree of visibility decreases as a building’s density rises, and vice versa. It is especially noteworthy to read the trend regardless of the four models’ differences in spatial configurations.

3.1 Openness

Model 1, where the size of the valid visible area of the ground and the building facade is similar, has a Mean Openness($\bar{V(G)}$) value of 0.243514. In contrast, Models 2 and 4, where the size of the ground surface is
much larger than the size of the building facade, which means more visibility is secured from all locations, has relatively higher Mean Openness values of 0.627030 and 0.684981, respectively. Model 3 with high-rise buildings has a Mean Openness value of 0.120027, the lowest value of the four models. These results are in accordance with the tendencies observed in the real world, and concur with preceding study results on visibility analysis.

3.2 V-occlusivity

The color on building façades in four models illustrated in Fig.2.(a) represents the value of V-occlusivity. In examining closely the mean values of each building, a relatively large difference between I-shaped building-I of value 0.243514 and L-shaped building-L of value 0.477893 in Model 1 is identified despite the similarity of size. This resulted from the shape and layout of the building. The building-L has two inner facades that are mutually visible, raising the overall visibility value, unlike cubic-style building-I, which has no mutually visible facades. These visibility analysis results verify that the visibility of the whole building can be largely affected by the building’s form and height even with buildings that are of the same scale.

3.3 V-density / Landmarkability

Fig.2.(b) shows the V-density of the ground and the Landmarkability of a building’s facade. Results show that the ground and facade surfaces are in a mutual and symmetrical relationship. V-density on the ground surface is greatly affected by the location and direction of the building compared to Openness. Landmarkability is largely affected by the form of the open space on the ground surface compared to V-occlusivity. This symmetry is clearly shown in their respective average values. Mean V-density ($V_{BG}$) and Mean Landmarkability ($V_{GB}$) are the same value in all four models of Fig.3. The mean value of V-density and Landmarkability is higher in a sparse layout with a large area of ground surface such as in Model 2 and Model 4.

3.4 Navigability / Urbanscapeness

When the ground surface and the building façades are similar in size as in the case of Model 1 shown in Fig.2. (|G|=1,579, |B|=1,678) (c), the Navigability on ground surface incorporates the analysis results

| Type | Model | Openness ($V_{G}$) | V-occlusivity ($V_{B}$) | Landmarkability ($V_{GB}$) | Urbanscapeness ($V_{GB}$) |
|------|-------|--------------------|------------------------|--------------------------|--------------------------|
| A    | Model 1 | $|G|=1,579$ $|B|=1,678$  |
|      | 3DL = 0.196816  |
|      | $V_{G}$ = 0.243514 |
|      | $V_{B}$ = 0.344864 |
|      | $V_{GB}$ = 0.210668 |
|      | $V_{GB}$ = 0.212477 |
| B    | Model 2 | $|G|=6,407$ $|B|=2,377$  |
|      | 3DL = 0.493442  |
|      | $V_{G}$ = 0.627030 |
|      | $V_{B}$ = 0.477893 |
|      | $V_{GB}$ = 0.366007 |
|      | $V_{GB}$ = 0.316643 |
|     | Model 3 | $|G|=324$ $|B|=5,416$  |
|      | 3DL = 0.123858  |
|      | $V_{G}$ = 0.120027 |
|      | $V_{B}$ = 0.172185 |
|      | $V_{GB}$ = 0.178687 |
|      | $V_{GB}$ = 0.125466 |
|     | Model 4 | $|G|=2,549$ $|B|=320$  |
|      | 3DL = 0.636405  |
|      | $V_{G}$ = 0.684981 |
|      | $V_{B}$ = 0.404321 |
|      | $V_{GB}$ = 0.467013 |
|      | $V_{GB}$ = 0.450928 |

Fig.2. TVA Analysis of Simple Orthogonal Shape Models
of V-density and Openness evenly. However, when there is a large difference in scale between the ground surface and the building facades, the index of the larger-sized surface has more influence on Navigability. Urbanscapeness measures the total visibility from all building facades and reflects the characteristics of both V-occlusivity and Landmarkability. Moreover, as observed in the analysis of Navigability, the disparities in visibility due to the differences between ground surface and building facades in scale are also reflected in the building facade visibility analysis.

Table 2. 3D Legibility of Two Models According to the Scale of Building Height

| Height | Model 1 | Model 4 |
|--------|---------|---------|
| 1      | 0.196816| 0.636405|
| 2      | 0.192602| 0.605648|
| 5      | 0.182205| 0.539273|
| 10     | 0.177415| 0.472633|

3.5 3D Legibility, 3DL.

3D Legibility reflects the ratio of visible spaces on the ground and building surfaces to the total number of visible spaces. Thus, 3D Legibility will have a value closer to the mean values of Navigability and Urbanscapeness if the ratio of visible spaces between the ground surface and building facades is similar, as illustrated in Model 1 (Fig.2.). However the 3D Legibility depends on spaces that are dominant in size when there is a huge disparity in scale. Table 2. shows the changes in 3D Legibility when the heights of the buildings in Models 1 and 4 are adjusted to twice, five and ten times the current height. With other conditions kept constant, when the height of the buildings is increased, 3D Legibility tends to decrease. This tendency needs to be interpreted in relation with a visual understanding of everyday experiences comparing high-rise and high-density environments with low-rise and low-density ones.

4. TVA Analysis of a Village in London

We made a choice to use the Barnsbury site in London where the correlations between pedestrian movements and spatial attributes had already been examined by Hillier (1996b) and Penn et al. (1997). These studies have shown that the configuration of urban grid structures is the main generator of pedestrian's movement patterns. We can assume that such a social behavior of movement is essentially affected by how much pedestrians can see and be seen from a certain location. It is this three-dimensional visibility relationship that is reflected on the spatial configuration.

The number of pedestrians flowing through per hour at each point location presented in the axial map in the existing study of Hillier(1996b) was taken to explore via TVA. The visibility indices values for each point of the locations where the pedestrian movement flow was counted and presented in the map was selected on the ground that was created in a three-dimensional model (Fig.3.).

This case study independently investigates the visibility indices of ground, not of the building façade, as the pedestrian movement flows represent the social factors of the street. The final result integrated 6 indices for the whole area, which is shown in figure (b). The St. Andrews church is enlarged in (c), and the Landmarkability of this building is shown in (d). The differences between Urbanscapeness and Landmarkability can be confirmed by observing the differences in color of the roofs of the church in (c) and (d). Since pedestrians walking down the street at ground level can see less than virtual eyes in a building facade, the colors of Landmarkability show much lower values.

Table 3. Correlations between Pedestrian Movement Flow and Each Visibility Value Computed in TVA

| Zone   | Openness | V-Density | Navigability | Observations |
|--------|----------|-----------|--------------|--------------|
| A      | .772     | .776      | .784         | 22           |
| B      | .812     | .902      | .869         | 11           |
| C      | .910     | .882      | .905         | 21           |
| D      | .272     | .309      | .292         | 13           |
| E      | .842     | .857      | .858         | 25           |
| F      | .768     | .819      | .799         | 18           |
| Entire | .775     | .792      | .792         | 110          |
| D excluded | .814 | .834      | .833         | 97           |

The simple correlation of the logarithm of pedestrian movement flow with each visibility index value is shown in Table 3. Most zones showed a strong positive correlation except Zone D which was covered with public parks and open spaces. We first compared this correlation value using different visibility indices. When comparing Openness with V-Density, it was found that V-Density had a closer relationship to pedestrian movement flow in most zones excluding Zone C. It also shows that Navigability, which is the visibility to ground and facades of buildings, of all zones except Zone C also had a higher correlation with pedestrian movement flow rates. This might imply that the measuring of visibility values on the ground alone which is often used as a similar figure as two dimensional isovist areas can be enhanced to extend our view of sight to the real three dimensional world so that vertical views of objects in our world of sight are also taken into account to the study of this area.

Looking into zone D on the map and the street view, which has no relation to the pedestrian movement flow, the question from where this odd behavior is coming arose. Looking closely into the source data in the map, the area near Richmond Ave, and Thornhill Road all have little pedestrian movement and seemed to be quiet residential areas. However the relation to the proximity of public parks with pedestrians may not bear the sole responsibility for the variation from the other trends. To clarify this issue we compared the entire site with the site excluding Zone D. Comparing the results with those presented by Hillier (1996b) in which the correlation value with the integration-3 axial
line analysis was .85, a correlation of visibility indices from TVA was found that nearly approached them.

This case study was intended to ascertain whether visibility indices could be one of the social factors that are included in current configurational models. Although it does not reach the reputation that previous studies achieved in the field of axial line map analysis, it still clearly showed a high correlation with each of the visibility values when building facades were considered.

5. Conclusion

The objects that human eyes genuinely focus on are surfaces (Gibson, 1950, 1986). Light travels from a point on a surface into the eyes through volumetric spaces. Volumetric worlds are filled with the scattering of light coming from all directions and distances reflected from every surface, providing ways for light to travel to the eye which creates vision allowing us to understand the world. This study proposes TVA as a method for quantifying the visual experience of the built environments through the analysis of visual relationships between surfaces within it.

Seven visibility indices are defined to quantify the mutual visual relationships between ground surfaces and building facades. The brief description of core algorithms for computing visibilities in between two point locations in the three-dimensional built environments with necessary procedures to set the model to be analyzed were presented. They showed the results of the analysis on the corresponding surfaces to facilitate the comprehension of various visual experiences. 3D Legibility was used to quantify the level of visual understanding of an urban space as a whole, as suggested by Lynch, and can be expected to be useful in improving urban space design. The increased difficulty in understanding visual relationships with an increase in building density and building size, if experienced in real-life situations, may be examined through interpretations of the 3D Legibility of a hypothetical model in a real city.

We verified that the relation to social behavior such as pedestrian movement flow could be explained via the visibility of point locations on the streets at the level of a fine grain. These were compared with previous work made with axial map analysis that showed great promise. Outcome values were lower than those done in axial map, but still showed a positive and strong correlation to pedestrian movement flow with fine details in the area. This opens up the potential possibility for a review of architectural and urban design as they relate to visibility. We look...
forward to investigating various social factors in relation to visibility as defined in the study using the TVA model.

Even though 3D Legibility shows the visibility of the whole space as a quantified value through the synthesis of all visual relationships between the surfaces of the three-dimensional space, it is limited in its ability to reflect the spatial configuration of the space, such as 'Intelligibility' suggested by Space Syntax. Wayfinding behavior can be cited as an example of a method to easily measure the level of understanding of a built environment in a complex building or urban space. It is important to remember that for wayfinding behavior, spatial configuration elements, such as space layout, are also important in addition to visual elements, such as signage and landmarks (Chang and Penn, 1998; Peponis et al., 1990). In order to utilize 3D Legibility as an index closer to reality in the future, it is important to explore ways of considering visual observation and spatial configuration simultaneously as Dalton and Bafna (2003) have attempted.

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