SOME PHENOMENA IN THE SPATIAL REPRESENTATION OF VIRTUAL REALITY

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Abstract. Virtual reality is widely used to present architectural design space. It has also provided a solution that general public without architectural design background can easier understand complex space which has not been constructed yet. However, how much information could general public understand, while browsing design space presented by virtual reality? In this study, we have compared the experimental results from one with architectural design background and the other without architectural design background in different space factors such as form, scale, organization, circulation of space. Finally, we conclude some preliminary phenomena from the data. The phenomena could be the guidelines to the design of spatial navigation in the system of virtual reality.

Keywords. Architectural representation; Virtual reality; representational media.

1. Introduction

Le Corbusier stated that the best way to appreciate architecture is to walk through a building so that one can look at it from different viewpoints, and to view the articulation of the building(Penz, 2003). Bertol and Foel(1997) also considered that only one way of experiencing architecture is to observe a building completely and to obtain more objective experience of the building. However, the design of an architectural space that has not yet physically constructed is probably stored in the designer’s mind or in a variety of design media. Therefore, it is difficult for public laymen to understand and conceptualize the designer’s spaces. Forms of design media which have been
developed ever since the Renaissance period, are being used to scale models and perspective drawings to facilitate the communication between designers and laymen since it is difficult to communicate and portray designers’ ideas to laymen in verbal or written form (Mitchell and McCullough, 1994). In the digital age, design media are utilizing computer animation and virtual reality to represent space to people. Thanks to forms of design media, the presentation of space is now not static but dynamic, wherein people can experience visual continuity over time. In addition, virtual reality has also enabled users to interact with systems, thereby increasing the conscious experience of virtual spaces (Belleman et al., 2001).

2. Problem and objective

A single user can experience virtual reality as a form of media by using an HMD or desktop PC, and more than one user can experience it using CAVE. People can experience virtual space not just in a small frame but in a larger frame along with the sensation of full immersion as well as stereo vision (Kalay, 2004). The media for a simulator providing the full immersion sensation have also been installed so that information can be transmitted from a laboratory to a museum, making it a public media that enabled designers to communicate their ideas to visitors or users (Liu and Tang, 2003). By comprehensively surveying presentational media in architectural design, the spatial simulator has become a form of media that can present the most complete and exact spaces stored in a designer’s mind. Visitors can also browse through the images presented serially and across time, to gain a deeper understanding of the design. However, with regard to the main design content displayed, what are the differences between designers and users with regard to how they browse through spaces through the experience of virtual reality? The objective of the research is to investigate the same and different phenomena.

3. Spatial experiment

3.1. EXPERIMENTAL ENVIRONMENT

In the experimental design content, an art museum which has been designed, yet not been built, is taken as an example. The reason is that this art museum is the one open to the public and that it will relatively arouse more interest and curiosity from the public. And the spatial complexity will be greater than that of the residence houses. Figure 1 shows the relationship between the forms of the four tested spaces and their relative locations. In each experimental space,
Space A is located on the second floor in the building. Except three openings, the whole area is surrounded by the concrete walls, ceiling and floor. Space B is a big two-story stairwell. The two-dimensional form of the space is an isosceles trapezoid whose shape is almost like a triangle. It is also mainly surrounded by the concrete walls, ceiling and floor. Space C is a more irregular space with the lowest spatial enclosure in all the experimental spaces. The surrounding planes consist of only one glass shield and one concrete wall. One-fourth of the top is transparent, and the rest is composed of four exits of different sizes. The floor of the space is composed of three small floors of different levels. And, in the space interweave arrays of columns with the matrix arrangement. Space D is a rectangular space. In the space there are a column and an exit. The space is surrounded by three concrete walls and one glass shield.

*Figure 1.* The forms of the four experimental spaces and their relative locations.

*Figure 2.* The stereoscopic screen  
*Figure 3.* The joysticks
The experimental setting is mainly a rear-projection screen which can present a stereoscopic vision (Figure 2). The size the screen presents is 120 inches. The screen is used to present the design space for the experiment. When browsing the space, the subjects can go forward and backward, pan to the left and the right, and tilt up and down, through the joy sticks (Figure 3).

3.2 EXPERIMENTAL SUBJECTS

The specification of the subjects in the experiment as following:

Subject A: a student who studies in the graduate school with more than five years’ training in architecture design. But this subject is chosen from three qualified subjects who match the general principles, and has the fewest invalid data among these three subjects to be the analysis data of this experiment.

Subject B: an ordinary person who doesn’t have any training in architecture design. But this subject is also chosen from three qualified subjects.

3.3 EXPERIMENTAL METHOD

Before the official experiment, each subject first tries to browse a space which is irrelevant with this experiment to let him/her realize the interactive operation ways in this three-dimensional virtual reality as well as the concept of think-aloud protocol analysis (Ericsson and Simon, 1993), which is to narrate in the verbal way the perception generated by the spatial image in the brain and to present in the hand-painted way if it is hard to express verbally. The order of the space test is from A to D, and the space switch is through the button switch in the joy sticks.

3.4 EXPERIMENTAL ITEMS

Space is a fundamental element in the architecture, and the spatial experience is mostly acquired from visual feelings. Therefore, when a person is in a space, what he faces first is the “form” surrounded by spatial elements such as the wall, the floors, and the roof. He also has a feeling about the size of the space called the “scale”. Then, along the “circulation” stringed by each separate spatial route to another space, the “disposition” of each separate space is organized after he experiences different spaces. Hence, in the tested items, “form”, “scale”, “circulation” and “spatial organization” are chosen. In addition, four tested items will be subdivided into the affected sub-factors, which are illustrated in Table 1 (Rasmussen, 1964; Alexander, 1977; Bloomer and Moore, 1977; Krier, 1988; Zevi, 1993; Ching, 1996):
3.5 EXPERIMENTAL STEPS

1. In the process of browsing the “three-dimensional virtual reality”, when the subjects are in one of these four spaces, they are asked to tell or draw the form and scale of the space, and then to explain based on what sub-factors they decide the form and scale of that space.

2. After the subjects browse the form and scale of each separate space, they are asked to browse these four spaces by strolling (instead of switching the space via buttons). After browsing,

<table>
<thead>
<tr>
<th>SPATIAL FACTORS</th>
<th>SUB-FACTORS</th>
<th>ILLUSTRATION OF SUB-FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. form</td>
<td>shape</td>
<td>the outline of the inside/outside space</td>
</tr>
<tr>
<td></td>
<td>edge</td>
<td>define the boundary of the space which could be clear or vague</td>
</tr>
<tr>
<td></td>
<td>surface</td>
<td>the appearance of the plane; for instance, whether the feel of the material is rough or fine, whether the color is dark, and the grain, etc.</td>
</tr>
<tr>
<td></td>
<td>opening</td>
<td>the openings on the plane surface, such as the windows on the wall, and the skylight on the ceiling</td>
</tr>
<tr>
<td>2. scale</td>
<td>reference</td>
<td>In the space, if there are tables or people as reference objects, it will be easier to determine the size of the space according to these reference objects.</td>
</tr>
<tr>
<td></td>
<td>objects</td>
<td>The perspective angle influences the determination of the size of the space. An exaggerative perspective angle increases the size of the space more easily.</td>
</tr>
<tr>
<td></td>
<td>perspective</td>
<td>The distance of observation. If the distance is too far, it will not be easy to compare with the proportion of the body.</td>
</tr>
<tr>
<td></td>
<td>distance</td>
<td>The size of texture on the surrounding planes, such as the size of the formwork used for the self-consolidating concrete (SCC)</td>
</tr>
<tr>
<td></td>
<td>the size of texture</td>
<td></td>
</tr>
<tr>
<td></td>
<td>observation position</td>
<td>Observe the positions where one can observe in a space; for instance, to overlook from the sky.</td>
</tr>
<tr>
<td>3. circulation</td>
<td>path</td>
<td>the path along which one can walk</td>
</tr>
<tr>
<td></td>
<td>stairways</td>
<td>the passageways which connect the floors of different levels</td>
</tr>
<tr>
<td></td>
<td>ramp</td>
<td>two-dimensional passageways which connect the floors of different levels</td>
</tr>
<tr>
<td></td>
<td>plaza</td>
<td>public places which one can pass through at will</td>
</tr>
</tbody>
</table>

(Contd...)
4. organization properties of each separate space; for instance, the public space and the private space
main entrance and secondary entrance the entrances which connect the building and the exterior space
spatial arrangement the ways to arrange each separate space, such as the concentrated arrangement, the linear arrangement, and the grid arrangement
spatial connection the connections among the spaces, such as the interior space and the exterior space

a. Likewise, the subjects also express the spatial organization of the relevant locations in these four spaces in a verbal way or by drawing. And then, they explain on what basis they determine the sub-factors of the spatial organization.

b. Based on the spatial organization presented in the previous step, the subjects are asked to draw the circulation of these four spaces. After they finish drawing, ask them to explain how they determine what to be the sub-factors of the circulation.

4. Results and Discussions

4.1 COMPARISON OF FORMS

Table 2 shows the relevant sub-factors and the drawings made by two subjects based on how they feel about the forms of these four spaces. In this table, comparing the forms drawn by the subjects with the forms of four spaces in Figure 1, we can see that these two subjects have the same drawing regarding the number of the lines in each form. However, in the proportion of the sides of the form, what Subject A draws tends to be more similar to the form in Figure 1. Subject B is less precise in drawing the proportion of the sides of the form.

In each form drawn by these two subjects, Space A is most different from Figure 4. Subject B also makes big differences in Spaces B and D that are more closed. However, the sub-factor “edge” is the one that these two subjects use most when they judge the form. In the process of the guided tour where the screen proportion is 4 to 3 and the focal length of the camera is 28mm, it is easy to mistake the vertical wall as the wall leaning inward or to mistake the wall angle less than 90 degrees as the right angle or bigger obtuse angle, when they pan or tilt. As a result, this might be the reason why the subjects cannot grasp the precise angle of the edge. In addition, in judging the form, Subject A uses more sub-factors as the basis of judging the form while Subject B mostly focuses on the edge. The reason could be that Subject A possessing the knowledge of architecture would utilize more knowledge of architecture as the clues when observing the form.
4.2 COMPARISON OF SCALES

Table 3 shows the data speculated by the subjects and the sub-factors based on which the subjects make judgment on the scale of the tested spaces. In the scale estimated by these two subjects, the scale estimated by Subject A is more close to that of the real space while the scale estimated by Subject B is much less close. In the method of judging the scale, Subject A mainly uses people in the space or the width of exit/entrance as reference objects, then, utilizes the knowledge of architecture to know the basic height and width of a person and a door, and further estimates the scale of a space. Subject B uses a more intuitive way to perceive the size of that material through the texture of the formwork used for the self-consolidating concrete (SCC) projected from the screen, and then further estimates the scale of the space. However, such intuitive perception is more inaccurate than the estimation method in which Subject A uses more precise sizes as the basis.

4.3 COMPARISON OF CIRCULATION AND SPATIAL ORGANIZATION

Figure 5a,b show the spatial organization and circulation drawn by these two subjects after they locate these four spaces according to their self-guided tour. Compared with Figure 4, the spatial organization and circulation drawn by Subject A is more accurate. When searching for the connections between each tested space, Subject A finds out the spatial organizations of Spaces A, B, and C, by means of the “path” and “stairways”, and then finds from Space D the relative locations between Space D and three other spaces. When passing by the path(Figure 4, below Space D) beside Space D, Subject A will find the

Figure 4. The plans of the 4 experimental spaces.
“main entrance and secondary entrance” of Space C which connects the path of Spaces A and B. Hence, four spatial organizations are inferred through the sub-factor “spatial arrangement”.

The spatial organization and circulation drawn by Subject B is more different from what is shown in Figure 4. One reason is that Subject B speculates the spatial organization mainly through the “main entrance and secondary entrance” and “spatial connection”. If these four spatial organizations are not seen together but seen separately; that is, the organization between Spaces A and B, Spaces B and C, Spaces C and D, perhaps we can see that, between each organization and Figure 4, there is no big difference in space. For instance, Space A is connected with Space B simply through a path, and Space C is connected with Space D through the “stairways” and “path”. Therefore, judging from such a result, the preliminary inference is that sub-factors “main entrance and secondary entrance” or “spatial connection” can only infer separately the relationship with the neighboring space. Without these two sub-factors, it might be relatively more difficult for Subject B to infer the spatial organization. Another possible reason is that Subject B might easily get lost if there are too many turns in the circulation during the virtual reality tour.

5. Conclusion

According to the analyses and discussions about the experimental results, we can get some preliminary phenomena after the one with architectural design backgrounds and the one without any architectural design background browse the geometrical spaces in their virtual reality tours. Especially, when the space is observed by panning and tilting, the edges which judge the form of the space are easily transformed and lead to misjudgment because of the focal length and the screen proportion. What’s more, the one with the experience in architectural design will use more spatial sub-factors to determine the form, scale and spatial organization. And it is probably because of this reason that the one with the experience in architectural design can understand the space more precisely. Therefore, based on these phenomena, the representation system of virtual reality which can let the observers understand more easily and precisely what the designers would like to present can be proposed in the future studies.
TABLE 2. Two subjects do the experiments with the form in four experimental spaces

<table>
<thead>
<tr>
<th>Space</th>
<th>Subject A</th>
<th>Subject B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Drawing form</td>
<td>Sub-factor</td>
</tr>
<tr>
<td>A</td>
<td>![Image]</td>
<td>shape, edge</td>
</tr>
<tr>
<td>B</td>
<td>![Image]</td>
<td>shape</td>
</tr>
<tr>
<td>C</td>
<td>![Image]</td>
<td>shape, edge, opening</td>
</tr>
<tr>
<td>D</td>
<td>![Image]</td>
<td>edge</td>
</tr>
</tbody>
</table>

TABLE 3. The results that two subjects do the experiments with the scale in four experimental spaces.

<table>
<thead>
<tr>
<th>Space</th>
<th>Real Size</th>
<th>Subject A</th>
<th>Subject B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measurement</td>
<td>Sub-factor</td>
<td>Measurement</td>
</tr>
<tr>
<td>A</td>
<td>Length: 13.8m</td>
<td>Width: 13.8m</td>
<td>Height: 4.95m</td>
</tr>
<tr>
<td>B</td>
<td>Length: 13.8m</td>
<td>Width: 5-19.8m</td>
<td>Height: 10.35m</td>
</tr>
<tr>
<td>C</td>
<td>Length: 34.5m</td>
<td>Width: 38.6m</td>
<td>Height: 10.35-12.75m</td>
</tr>
<tr>
<td>D</td>
<td>Length: 13.8m</td>
<td>Width: 13.8m</td>
<td>Height: 4.2m</td>
</tr>
</tbody>
</table>

Length: 5m | size of Width: 7m | texture Height: 2m |
Length: 3.5m | size of Width: 6m | texture Height: 4m |
Length: 15m | size of Width: 10m | texture Height: 4m |
The longest side: 7m | size The shortest side: 4m | of Height: 3.5m | texture
Figure 5a (left) The spatial organization and circulation drawn by Subject A.  5b (right) The spatial organization and circulation drawn by Subject B.

References