Spatial Recognition Affected by Color and Texture in Architectural Space

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Abstract

In this study, we reproduced the Villa La Roche designed by Le Corbusier and the Casa Gilardi designed by Luis Barragán in a virtual environment which can control the color and texture as variable parameters. Then subjects evaluated the scale and the impression of the houses to clarify the spatial recognition characteristics affected by the color and texture. In the scale and the drawing test, the subjects wearing a VR headset evaluated the scale of the houses and drew the floor plan. As a result, there were a tendency that the Villa La Roche was recognized to be smaller, while the Casa Gilardi was recognized to be real scale or a little larger. In addition, the subjects wearing a VR headset evaluated the space impression by SD method. The results showed characteristic changes in space impression according to the color and texture.

Keywords: Spatial Recognition / Architecture / CG / Color / Texture / Virtual Reality

1. Introduction

When people experience architectural space, the color and texture of the material affect their spatial recognition. Practice of decorating architectural elements in a variety of colors is called architectural polychromy and the houses designed by Le Corbusier (1887-1965) are listed as one of the features of architectural polychromy. The houses designed by Luis Barragán (1902-1988) also have the walls of brilliant colors such as pink, red and yellow. Those houses were evaluated as a quiet and beautiful architecture with its texture. It was said that Barragán liked scraping mortar walls because the gradation due to delicate shadows enriched the expression as the finished surface of wall was more uneven.

Psychologist J. J. Gibson pointed out that density and changes in texture are important for spatial structure and depth perception[1]. In order to investigate human recognition characteristics affected by color and texture, various experiments have been conducted[2]-[4]. However, there are many parts that have not yet been clarified to evaluate architectural space. It is generally difficult to evaluate the effects of enormous patterns of color and texture in real space where people can move around freely. On the other hand, by using virtual environment, various parameters can be easily examined. Current virtual reality hardware and software enable us to move interactively in a high-quality virtual environment. A realistic building in virtual environment provides an experience close to the real building and can change the various parameters.

The purpose of this study is to investigate the characteristics of spatial recognition affected by color and texture of architectural space.
2. Method

2.1. Virtual environment creating method

In the past few years, game engines and VR headsets have become common to build high quality virtual environments and provide immersive experience. A game engine is basically an integrated development environment to improve efficiency in video game development. However, it is widely used for interactive 3D-CG application development, including VR contents and architectural visualization. A VR headset is a goggle shaped device for experiencing VR contents.

In this study, we constructed a virtual environment with the game engine called “Unity” and provide an immersive space experience with a VR headset called HTC Vive. The feature of HTC Vive is room-scale VR which allows users to freely walk around 5 meters of diagonal space with “Lighthouse” laser base stations, that include motors that literally spin the lasers in order to detect the headset’s position.

2.2. Investigated houses

The targets of this study are houses where the effects of color and texture are positively adopted in their design. We reproduced the Villa La Roche (Paris, 1923) designed by Le Corbusier and the Casa Gilardi (Mexico City, 1978) designed by Luis Barragan in a virtual environment which can control the color and texture as variable parameters. Figure 1 shows each floor plan and the target area. The floor plans and the 3D-CG model were created with reference to [5] to [8]. The color and texture of the 3D-CG model were reproduced based on the photographs and the explanation contained in the above references.

2.2.1. Villa La Roche

The color of the interior seen in the Villa La Roche is the earliest case of architectural polychromy advocated by Le Corbusier. The internal color scheme is seen in faces, openings, nonstructural elements, and is composed entirely of light pastel color. The finish is smooth. Figure 2 shows a screenshot of the virtual environment built on Unity.

2.2.2. Casa Gilardi

A variety of colors and textures are used in the Casa Gilardi. This house is regarded as a masterpiece of Barragan who tackled the color and texture design in his lifetime and answered to light and water which were the subjects of his architecture. Figure 3 shows a screenshot of the virtual environment built on Unity.
2.3. Experiment in virtual environment

Subjects wearing a VR headset evaluated the scale and the impression of the target houses in the virtual environment to clarify the spatial recognition characteristics affected by the color and texture. This experiment was conducted by using two types of space: space without color and texture (referred to as “white space”) and space with color and texture. Figure 4 shows a scenery of the experiment.

![Figure 4: Scenery of experiment.](image)

2.3.1. Scale test

In the scale test, the subjects evaluated the scale of the houses. When each subject first entered the target house, the size of the space was different from the real size (approximately 50 times larger). The subjects could control the scale of the house freely with the controller and were asked to select (1) the scale to feel “comfortable” and (2) the same scale as the real. The time limit was not set up.

2.3.2. Drawing test

In the drawing test, the subjects virtually experienced the target houses in the same scale as the real. At the same time, they were asked to draw the plan of the house on a 1/200 scale on a 5 mm squared paper. The drawing target area was a part of the floor plan and instructed as shown the gray area in Figure 1. The time limit was 10 minutes including the time for VR experience and the drawing. Wall of the floor plan was allowed to draw with a single line.

2.3.3. Space impression evaluation

In the space impression evaluation, the subjects virtually experienced the three patterns of different colors in the target house. One of them was a real color scheme. The subjects experienced each pattern for one minute, and then were asked to select the adjective pairs of 20 items that were close to the impression of the space on a scale of seven. If the impression faded away in the middle of the evaluation, it was allowed to experience the target house additionally for 30 seconds.

2.3.4. Subjects

The experiment was conducted for 18 students majoring in architecture between the ages of 22 to 26 (male: 9, female: 9 people). There was no subject who had seen the drawings of each house. The subjects were divided into three groups so that the experience in the scale test and the drawing test did not affect the space impression evaluation in which the subjects experienced the houses of three different color patterns (Table 1).

Since Group A took the scale test and the drawing test with white space, it was possible to evaluate the space impression of both the Villa La Roche and the Casa Gilardi without knowing the real color and texture. Group B took the scale test and the drawing test in the Villa Roche with real color and texture, and could evaluate the space impression of the Casa Gilardi without knowing the real color and texture. Group C reversed the target houses of group B in each test. The experiment period was December 12-20, 2016.

| Table 1: Subject Group. |
|-------------------------|
| Group | A | B | C |
| Number ID | 6 a to f | 6 g to l | 6 m to r |
| Scale Test | Roche Gilardi | Roche Gilardi | Roche Gilardi |
| Drawing Test | white c & t | c & t | c & t |
| Space Impression Evaluation | Roche Gilardi | Gilardi Roche | Gilardi Roche |
| | c & t | c & t | c & t |

Roche: Villa La Roche, Gilardi: Casa Gilardi
white: white space, c & t: with color and texture

3. Results and Discussions

3.1. Scale test results

Figures 5 to 6 show the scale values evaluated by each subject as the real and comfortable space in the VR environment (the Villa La Roche and the Casa Gilardi) that enables the subjects to change the scale freely with a controller. The subjects (a to f) experienced the white
space and the subjects (g to r) experienced the spaces with color and texture. There is no significant difference in the characteristics of perceived scale between the white space and the space with color and texture.

3.2. Drawing test results

Figure 7 shows the results of the drawing test on the Villa La Roche. The six subjects (a to f) experienced the white space and other six subjects (g to l) experienced the space with color and texture. All the subjects correctly drew the rooms and the connection between the rooms. This result shows that it is possible to recognize the spatial structure in VR environment.

However, there was a difference in the scale of each room. Between the white space and the space with color and texture, there is no significant difference. As for drawing representation, two people who experienced the white space did not draw the slope while all the subjects who experienced the space with color and texture drew the slope.

Subject f who made the drawing in the largest scale recognized all the room to be larger than the real. On the other hand, subject h who made the drawing in the smallest scale recognized all the room to be smaller than the real. Subject h especially evaluated the real and the comfort scale to be largest in the scale test. In other words, subject f has a tendency to recognize the space to be small in the Villa La Roche.

Three people out of 12 evaluated the real scale correctly in the Villa La Roche. The other nine people answered the scale larger than the real scale. On the other hand, seven people out of 12 evaluated the real scale correctly in the Casa Gilardi. The other three people except f answered the scale smaller than the real scale. There were tendencies that the Villa La Roche was recognized to be smaller, while the Casa Gilardi was recognized to be real scale or a little larger.

Regarding the comfortable scale, there was a variation in the evaluation rather than the real scale, and the comfortable space might depend on the individual. At the Villa La Roche, six subjects evaluated the comfortable scale to be larger than the real scale, two subjects evaluated that to be smaller, and four subjects evaluated that to be same. On the other hand, at the Casa Gilardi, five subjects evaluated the comfort scale to be larger than the real scale, five subjects evaluated that to be smaller, and two subjects evaluated that to be same. There was no significant difference between the Villa La Roche and the Casa Gilardi.

Figure 5: Scale test result of Villa La Roche.

Figure 6: Scale test result of Casa Gilardi.

Figure 7: Drawings of Villa La Roche.
3.3. Perceived distance in drawing

According to the drawing test on the Villa La Roche, Figure 9 shows the results of the comparing the perceived distance and the real distance of (1) to (10) shown in Figure 1.

![Figure 9: Perceived distance of Villa La Roche.](image)

The above figure shows the results of the subjects (a to f) who experienced the white space, and the below figure shows the results of the subjects (g to l) who experienced the spaces with color and texture. There is no significant difference in the characteristics of perceived distance between the white space and the space with color and texture. There is no effect of color and texture on the subjects (f, k) who tended to evaluate longer than the real distance and the subjects (b, h) who tended to evaluate shorter.

As the measured distance increases, the error tends to increase. In addition, since the distance of (5) in the bridge and the dining room is the longest distance, the variation in the perceived distance also increases, and the perceived distance of the white space slightly varies.

According to the drawing test on the Casa Gilardi, Figure 10 shows the results of the comparing the perceived distance and the real distance of (1) to (7) shown in Figure 1.

The above figure shows the results of the subjects (a to f) who experienced the white space, and the below figure shows the results of the subjects (m to r) who experienced the spaces with color and texture. In the case of the Casa Gilardi, the perceived distance tends to be shorter.
in the white space than the real distance. The space with the long aspect ratio especially tends to be shortly evaluated.

Figure 10: Perceived distance of Casa Gilardi.

3.4. Space impression evaluation

Figures 11 to 14 show the results of spatial impression by the SD method when the subjects wearing the VR headset experienced the virtual environment of the Villa La Roche and the Casa Gilardi. When a part of color scheme was changed in each house, the impression changes were indicated. Table 2 shows the factor analysis result of spatial impression. For each house, the 12 subjects evaluated three color patterns (n=72). The number of the factors was set to four. We call the three factors “Evaluation”, “Potency” and “Activity” as proposed by Osgood[9]. In addition, we call the forth factor “Scale”.

In the Villa La Roche, R-C0 (Figure 2) has the real color scheme. R-C1 (Figure 12a) and R-C2 (Figure 12b) have changed parts of wall color. Figure 15 shows the average factor score of the four factors. There was significant difference of the “activity” factor (p<0.05) between R-C0 and R-C1. R-C1 has the inverted hue of the red wall receiving sunshine and the shaded blue wall without changing the brightness and the saturation. This change focuses on the color planning related to sun light derived from Corbusier’s discourse[5] “… the dark wall is blue, the wall full of light is red. …” As a result, R-C1 provided “activity” factor effect change.

R-C2 has the wall of the west in the picture gallery where the color closed to ultramarine changes to complementary orange type to verify the effect of enlarging the distance between walls by “thin ultramarine wall” which is one of architectural polychromy theory[5]. Compared to
significant differences of the “activity” factor (p<0.01) and “scale” factor (p<0.05) between G-C0 and G-C2. G-C2 has the frosted glass where the color changes to complementary blue to verify the impression from the corridor filled with yellow color by colored frosted glass as a filter that is a representative lighting style of Barragan. As a result, G-C2 provided “activity” and “scale” factor effects change.

On the other hand, G-C1 has the color exchanged with column and wall to verify the psychological effect of the red column standing in the pool and the blue wall illuminated by oblique rays. They gradually come closer as the
subjects go through the corridor and approach the dining. Compared to G-C2, there was no significant change in impression.

In the space impression evaluation in a virtual space of the existing two houses, the advancing and receding effects of colors did not appear so clearly compared with the experiments using miniature model[4]. One of the reasons is that the VR technologies used in this experiment enabled to move freely in a visual environment by stereoscopic images with a wide field of view. The experience is considered to be closer to reality than that using miniature model in which the point of view was fixed.

4. Conclusions
This study investigated the characteristics of spatial recognition affected by color and texture in architectural space. The findings are as follows. There were tendencies that the Villa La Roche was recognized to be smaller, while the Casa Gilardi was recognized to be real scale or a little larger. There were some shortages of drawing on the white space. In the case of the Casa Gilardi, the perceived distance tended to be shorter in the white space than the real distance. The space with the long aspect ratio especially tended to be shortly evaluated. In the Villa La Roche, inverted hue of the red wall receiving sunshine and the shaded blue wall provided “activity” factor effect change. In the Casa Gilardi, the frosted glass where the color changed from yellow to complementary blue provided “activity” and “scale” factor effects change.

The VR technologies used in this study enabled to move freely in a visual environment by stereoscopic images with a wide field of view. The experience is considered to be closer to reality than that using miniature mod-

el or photo images. Since real-time 3D-CG rendering can also change the color and texture easily in architectural space, the experiments using VR is effective to clarify human spatial recognition characteristics.

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