UNDERSTANDING DESIGN EXPERIENCE IN VIRTUAL REALITY FOR INTERIOR DESIGN PROCESS

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Abstract. Virtual reality (VR) can enhance users' spatial perception by enabling spatial design activities. Conversely, the VR environment provides more visual information for the user to process than the desktop environment, resulting in a low efficiency of the design process. This study aims to verify whether VR can have a distinctive influence on the spatial design experience compared to the desktop environment. We conducted user studies on design experience in VR and desktop environments to accomplish this goal. The results revealed that participants’ satisfaction with the design experience was higher in VR; however, the task completion was more time consuming than in the desktop environment.

Keywords. Spatial Design Experience; User Study; Design Process; Virtual Reality; SDG 9.

1. Introduction
Owing to COVID-19, space utilisation behaviour such as telecommuting has changed and has accelerated the widespread use of virtual reality (VR) technology in our daily lives. In addition to traditional video call services (e.g. Zoom, Skype), the meta-verse concept was applied to socialisation, work, or recreation in a virtual world. Specifically, meta-verse services (e.g., Roblox, Cryptovoxel, Zepeto, and Gather Town) induce general users to design spaces or objects directly in virtual reality.

Innovating the design process using virtual reality technology is not a new concept. In the early design stages, virtual reality studies were conducted that allowed detailed review and modification of architectural spaces or intuitively showed the height of surrounding buildings (Yabuki et al., 2011). In addition to research using VR's immersive sense of space, new design methods have been proposed such as supporting the architectural design process by visualising airflow (invisible) in VR (Hosokawa et al., 2016), remotely experiencing a place previously inaccessible to designers (Pletinckx et al., 2000).

VR has been widely used to improve communication between designers and clients or decision-makers (e.g. Cave Automatic Virtual Experience system for vehicle companies). In addition, VR has focused on reviewing the completed design alternatives (de Casenave & Lugo, 2017; Freeman et al., 2018; Hou et al., 2009) or
proposing a method to reveal the side effects according to the design (Yabuki et al., 2011). Design reviews in VR are sometimes more efficient and can identify more issues (Freeman et al., 2018); however, other researchers report that design reviews in VR are inefficient and detect fewer issues (Hou et al., 2009). The existing literature has shown conflicting results. Therefore, the utility of VR may vary depending on experimental settings and conditions. In literature detailing the contribution of VR in design review activities, VR was found to engage the user's spatial perception more effectively than in the desktop environment when reviewing high-complexity objects (e.g. buildings) rather than low-complexity objects (e.g. doors) classified in the theory of technical systems (de Casenave & Lugo, 2017; Freeman et al., 2018). These studies claim that VR enables an immersive and intuitive experience of the dimension, size, and shape of the target object. However, to the best of our knowledge, no studies have confirmed the specific difference between the design process considering an immersive experience in a VR environment and the design process in a general desktop environment.

Spatial design activities can be assisted by VR, which can enhance users' spatial perception. Conversely, the VR enabled immersive environment has more visual information for the user to process than the desktop environment, which may slow down the design process. Therefore, this study aims to verify whether VR can provide a distinctive influence and contribution to the spatial design experience compared to the desktop environment.

The overall design direction is determined during the early design stages and continues to be revised and developed, which makes it difficult to modify the design in the later design stages. Hence, it is essential to understand whether the VR environment can make a meaningful contribution not only in later design reviews, but also in the early stages of design. Considering these factors, we investigate the difference between designing a space in VR and in a desktop in an uncertain situation where design conditions change frequently.

By comparing the design experience of the VR environment to the desktop environment, the design process in a metaverse environment can be performed more effectively in the future. To accomplish this goal, we performed the following tasks:

1) We conducted user studies on design experience in both VR and desktop environments.
2) We conducted quantitative and qualitative analysis on the experiment results.
3) We discussed the advantages and disadvantages of both environments.

2. Related Works

2.1. SPACE PERCEPTION IN VR VS. DESKTOP

In the desktop environment, users see 3D space through the monitor screen and navigate the space by freely moving the viewpoint (zoom, pan, orbit) using the mouse and keyboard interfaces. As it is difficult for users to perceive space through their somatic sense in the desktop environment, a separate reference object (e.g. human model) or measuring tool (e.g. Tape Measure Tool in SketchUp) is needed to determine the exact distance and dimensions of the virtual object. Most 3D CAD tools provide
these functions because accurate size is essential in the design process. The desktop's omniscient point of view helps users quickly and easily explore the shapes of objects in space and their relationships. However, when experiencing virtual reality (VR) by wearing a head-mounted display (HMD), the user sees the three-dimensional virtual space surrounding him through an egocentric view. The user perceives the virtual space through the whole somatic sense while changing the viewpoint by moving his body as in the real world. Unlike viewing 3D space on a monitor screen (i.e., the desktop environment), VR enables an immersive experience of 3D space.

However, when reproducing VR through an HMD, human space perception tends to vary from that in the real world. It has been experimentally confirmed that humans perceive the distance between themselves and objects (i.e. viewer-centred depth) in VR to be closer than the actual length (Willemsen et al., 2004). This phenomenon has not yet been clarified precisely, but the leading cause is the mismatch between accommodation - the focus of each eye on the HMD's virtual image - and vergence - the location created by overlapping the virtual images perceived by both eyes - is suspected (Drascic & Milgram, 1996). According to the size-distance invariance hypothesis, the perceived underestimated depth causes the user to perceive an object's size to be usually smaller (Kelly et al., 2013). The user can recognise the space more accurately by directly moving their body in a virtual space (e.g., walking or reaching out to an object) (Kelly et al., 2013). In other words, when designing a virtual space using VR, the user needs to experience the space by directly moving their body in a 1:1 scale space for an accurate sense of space.

2.2. DESIGN IN VR ENVIRONMENTS

In architecture and automobile design, resources and time are consumed to produce a physical mock-up on a 1:1 scale. VR technology offers the advantage of evaluating the design work and revisions efficiently and quickly. VR is often used for simulating designs that are difficult to experiment with within spatial design. For example, Yeom et al. (2021) confirmed how green wall design affects the user's cognitive state through a VR experiment. Hong et al. (2019) investigated how the window-wall ratio of a building affects occupant satisfaction. Both aforementioned papers used VR technology to confirm the responses the building user received as it is impossible to experiment with actual buildings. The 1:1 scale model in the VR immersive space provides a much better alternative to reviewing the final design than in a desktop environment.

Researchers have been studying whether the design review process using VR provides better usability than the desktop environment for two decades. Studies have explored whether VR users can complete design reviews faster or discover more design issues than in the desktop environment. However, existing studies have reported contradictory results. According to the experimental results of Freeman et al. (2018), the VR environment allowed participants (i.e., reviewers) to complete a given task in significantly less time. In addition, users found more design issues in the VR environment than in the desktop environment. However, the experiment of de Casenave & Lugo (2017) reported that the 3D model review was completed faster in the desktop environment than in the VR environment, and there was no significant difference in the design errors found. Many studies still differ on whether the design
review process in VR shows a better time and a greater number of identified design issues. A clear advantage of the design review process in VR is that it improves human spatial perception (Horvat et al., 2019). Compared to the desktop environment, VR can naturally and realistically interact with the 3D model and allow full use of human spatial understanding (Hou et al., 2009).

In addition to design reviews conducted for the late design phase, new attempts to utilise VR technology for design concept development have also been proposed. Many design tools that operate in a VR environment have been released to general users (e.g., Tilt Brush by Google, Gravity Sketch, VR Sketch). Lee et al. (2018) proposed a method of customising the dimensions and configuration of desks and shelves to fit the body conditions of the end-user in a VR environment, free from physical constraints. Thus, design reviews and design activities in the virtual world are gradually becoming common. However, the usefulness and characteristics of the design action itself in the VR environment remains relatively unexplored. Therefore, this study will comparatively analyse the characteristics of design behaviour in a desktop environment and in a VR environment, revealing the differences between the two.

3. Methods

We conducted a comparative experiment to determine the difference between the VR and desktop environments in the interior design process. Interior design is one of the design domains in which designers first utilised the 3D CAD system. Owing to high complexity in interior design process, it becomes necessary to judge the shape and size of furniture, such as sofas and tables, while also determining the positional relationship of each in the space. To review the difference between the two environments, we conducted an experiment on arranging furniture in virtual and desktop environments.

3.1. EXPERIMENTAL SETTINGS

The experiment required the participants to create an interior design based on the design brief. The participants were asked to decorate an apartment's living room and kitchen space in both the desktop environment and the VR environment (figure 1-a). The living room and kitchen area are approximately 43.3 m², and the details of the space are shown in figure 1-b. The clients for the experiment were a family of three, and design requirements (figure 1-c) were included in the design brief.

The participants were instructed to design using SketchUp Pro 2021 (SketchUp) in the desktop interface (DI) and the 3D model of the living room and kitchen scaled to real-life dimensions were provided in advance (figure 2-a). In addition, 3D models of various furniture items were also supplied as a component library (figure 2-c; 20 chairs, 8 sofas, 8 tables, 6 bookcases, and 7 lights). Users were able to easily position in 3D space by drag-and-drop in SketchUp's component window (red box in figure 2). The participants selected furniture in accordance the design brief from the furniture library and then designed the space using select, move, scale, rotate, and erase functions. Participants were able to change the viewpoint (orbit, zoom, and pan) using the mouse's wheel button and the dimensions could be measured directly using the measure tool. A desktop interface with a 27-inch monitor was used, and the participants sat at a desk and performed tasks with a mouse and keyboard.
The participants were asked to design using VR Sketch in the VR environment. VR Sketch is a program that allows 3D modelling to be performed in a VR environment through a consistent interface with SketchUp. The same design brief, 3D model, and furniture library as in the desktop environment were provided. In addition, participants could select, move, scale, rotate, erase, and measure tools even in the VR environment. Users can orbit, zoom, and pan using a two-handed controller and explore the 3D space by moving their bodies to different locations in space and changing their viewpoints. VR Sketch provides a unique teleport tool that moves the viewpoint to the location pointed to by the user as a teleport point, and at the same time, it allows the user to view the 3D model on a 1:1 scale. Oculus Quest 2 was used in this experiment, and VR design was carried out in a space of 3.5 m x 4.5 m.

To explore the design experience differences between the two environments, each participant was asked to perform the same design task in both the VR and desktop environments. To minimise the learning effect bias, half of the participants first performed in the VR environment, and the other half in the desktop environment. Next, the environments were reversed and the participants were given the same design task, but they were instructed to work toward achieving different results than they had achieved in the previous environment. Unlike the previous environment, we intended to analyse their judgments on design changes in different environments. There was no time constraint in either environment. Before designing in the VR environment, a tutorial session explaining the essential functions of VR Sketch (e.g., insert components, move, copy) was held for approximately 10 min.
After completing the design tasks, the participants completed a questionnaire survey on their design experience in both environments. The questionnaire consisted of the System Usability Scale (SUS) (Brooke, 1996) and satisfaction questions about design results (Table 1). Responses were received on a 5-point Likert scale for each item, with one being 'strongly disagree' and five 'strongly agree'. Semi-structured interviews were then conducted. The experiment took approximately 1 hour in total.

### Table 1. Items of Satisfaction Questionnaire

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<th>S</th>
<th>Question</th>
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<tr>
<td>S1</td>
<td>I am satisfied with the quality of the design output.</td>
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<tr>
<td>S2</td>
<td>I am satisfied with the time it took to complete this task.</td>
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<tr>
<td>S3</td>
<td>I am confident that the outcome of this assignment was creative.</td>
</tr>
<tr>
<td>S4</td>
<td>I am confident that the results of this assignment are convincing.</td>
</tr>
<tr>
<td>S5</td>
<td>I am satisfied with the ease of working on this assignment.</td>
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Participants were recruited from interior design and industrial design majors who can use SketchUp with visual acuity (or corrected visual acuity) of 20/20 or higher, and four participants participated in the experiment (mean age = 27.3 y; SD = 3.2; one female). They all had an average of 3.1 years of experience using SketchUp (SD = 2.3), and all had prior experience with VR devices. One of them owned a VR device and used it more than once a week, while the remaining were infrequent users of VR devices (two people less than once a year, one more than once a year).

### 3.2. RESULTS AND DISCUSSIONS

Regardless of the experimental sequence, the task completion times were longer in VR than in DI. The average task completion time for the VR environment was 27.8 min.
(SD = 3.2) while that for DI environment was 18.75 min (SD = 1.0). With a difference of approximately 10 min, the VR work took approximately 48% longer than the DI.

The results of the SUS and satisfaction questionnaire are shown in figure 3. All SUS and satisfaction results did not have normality (Shapiro-Wilk test; p > .05). Therefore, we did not perform a statistical analysis. The mean SUS score of VR was 85.0 (SD = 13.1) and that of DI was 68.8 (SD = 13.6). The mean SUS score for both environments was calculated using the method described by Brooke (1996). An SUS score of 68 indicates the top 50% or average system usability. The experiment participants evaluated the usability of the DI environment as average and that of VR environment as above average.

In addition, in the satisfaction results, the participants rated their work experience higher in VR. In particular, it showed the most significant design satisfaction compared to DI in the ‘persuasiveness of the results’ item. Participants were confident that their results in the VR environment were designed based on more rigorous evidence. In VR environment, all participants were able to visually check the size and shape of the space and furniture in a 1:1 scale space while selecting furniture and adjusting its size and location. Although it was possible to directly check the scale of the space and furniture with the Tape Measure Tool in the desktop environment, it was difficult to judge whether the size of the table or the width of the space was suitable for the human scale only with the numerical value. Following are the parts of the participant responses in the post-interview.

P1: "During the design process, it was helpful to 'feel' the size of the table directly."

P2: "Feeling a sense of space on a 1:1 scale gave me the confidence that I was doing well on my own."

P3: "VR allowed me to evaluate and modify my designs in real time. … Checking the 1:1 scale directly helps to make a better decision."

P4: "Even if I look at the same furniture, the feeling is different (between VR and DI environments) … It influenced my design decisions."
The participants' design also reflected the characteristics of the VR and DI environments (figure 4). For example, in the VR design, P1 resized the height of the living room table (the original height of the table component was 800 mm) to 710 mm (figure 4-b). After arranging the table and chairs, P1 resized them to 710 mm by bending the knees and checking the height of the table from the perspective of sitting on the chair. However, P1 did not resize the height of the table in the DI work to 800 mm. Considering that the recommended table height for adults is 710–760 mm, recognizing the actual size of furniture in the VR environment affected the design of P1. In another case, P3 adjusted the height of the bar table in the kitchen to be higher than that in the DI by matching the height of the bar stool in VR (figure 4-b). The natural sense of space in VR influenced the size of the furniture and the confirmation of the movement. In the DI result of P2, the aisle width next to the kitchen table was 960 mm, but in the VR result, the desk was rotated 90° to secure a wider circulation (aisle width 1380 mm). In addition, as in DI, when P2 arranged the bookshelf and P2 viewed the living room from the kitchen, P2 checked the side of the bookshelf to see that the window was not visible. Then P2 moved the bookshelf to the opposite side.
(figure 4-b). In the post-interview, P2 answered the following:

“I tried to make it the same as what I did on the desktop in VR, but in reality, the space was too small... When looking from the kitchen, the bookcases covered the windows, so the space seemed small. So, I moved the bookshelf to the other side.”

In the two design results of P4, there are differences in the colour and style of the selected furniture.

“When I checked it with VR, (the bar table in the kitchen) did not match the colour of the wall. So, I switched to a black bar table and a white stool.”

Comparing the results of the two work environments, it can be confirmed that the participants used a 1:1 scale sense of space for furniture arrangement and size determination in the VR environment. Although they could check the exact dimension in DI with the Tape Measure Tool, it was more useful to check the actual size than the exact figure. This determines that the VR's accurate spatial sense made participants more confident in their designs.

4. Conclusion and Future Works

This study analysed the differences in spatial design experience and design outcome depending on the VR and desktop environments. The user study results revealed that the design task completion time was longer in the VR environment than in the desktop environment. However, design satisfaction with design experience in VR was significantly higher than that in the desktop environment. Specifically, the reliability and persuasiveness of the design outcome created in the VR environment were higher than those in the desktop environment. This shows that immersive settings lead to a more rigorous design experience by allowing designers to review their work-in-progress design from various perspectives. In this study, the participants conducted short design tasks (approximately 40 min per participant); however, some participants reported nausea owing to prolonged use of the head mounted display after the study. Therefore, the results of the VR design experience may vary depending on the duration of the user study.

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