A Methodology to Evaluate the Effectiveness of Designers' Cognitive Process when Using Multi-user Virtual Reality

Adlin Shaflina binti Azizo[1*], Kherun Nita binti Ali[1], Noorminshah binti A.Iahad[2], Norhazren Izatie binti Mohd[1], Mohd Azwarie bin Mat Dzahir[1], Nafisah binti Abdul Rahiman[1]

[1]Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia
[2]Azman Hashim International Business School, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

[*]ashaflina2@graduate.utm.my

Abstract. This paper proposed the mixed-mode methodology to evaluate the effectiveness of the cognitive process when using Multi-user Virtual Reality (VR) in the design review sessions. The research explains that the design review is an essential part of the planning process. It evaluates the client's requirements against the designers' design before the construction starts. Quality communication among the designers and clients plays a central role in enhancing the output of the design review session, apart from the quality in visualisation during the presentation. A multi-user VR system with a head-mounted display allows users to fully immerse into the virtual environment (VE) during the design review process and subsequently achieve quality discussion and decision-making. This paper describes the process of data collection in quantitative and qualitative methods, where questionnaires will be distributed to determine the state-of-the-art of the designers' cognitive processes when they are involved in the design review session. Parallelly, an experiment on the use of multi-user VR during a design review session will be conducted. Users (Designers) will be interviewed before and after the experiment. Finally, multi-user VR's effectiveness will be identified by comparing the findings from both quantitative and qualitative methods.

1. Introduction

A design review is a process where the project's design is evaluated and criticised against its requirements. It is an integral part of the construction industry where the designers and clients exchange information and evaluate the requirements during the design review session.

The construction process typically takes a long time to plan and is costly, depending on the construction period and the client's needs. In the process, design review is crucial to promote good, cost-effective, and efficient design because it provides unbiased, independent advice when designing new buildings, landscapes, and public spaces [1]. Therefore, having a good quality design review session will involve a quality cognitive process.

The cognitive process includes the way of thinking, knowing, remembering, judging, and problem-solving. During the design review stage, the designer's emotion or cognitive process plays a significant role in determining the proper decision-making. Due to the client's difficulty in understanding the designer's design, the designer must explain or review the plan with the client during the design review stage to prevent misunderstandings or mistranslation.

Despite their technical background in the construction field, virtual reality (VR) systems can facilitate collaboration by improving communication and access to data for all clients [2]. Nevertheless, VR is still relatively new in Malaysia. However, it is regarded as one of the new trends in digital innovation [3] that can potentially change the way the construction industry operates and increase clients satisfaction. The user is placed "within" an environment, which can provide a greater sense of immersion than non-immersive VR [4] by using the VR gear and having a connection with the Virtual Environment.

This paper aims to propose the methodology to evaluate the effectiveness of the cognitive process in the design review session in multi-user Virtual Reality (VR). A convergent parallel mixed methods is adopted in this research. The researchers combine the elements of qualitative and quantitative approaches to research, such as the use of qualitative and quantitative points of view, data collection, analysis, or inference techniques for the broadest purpose of comprehensiveness or profound understanding [5].

In the following section, this paper discusses the literature review and proposed methodology. First, the literature review presents the cognitive processes, including the qualities involved to get a good design review session and the theory for the research. Next, the proposed methodology section discusses the proposed methodology used for the research and presents the flow chart of the research. Lastly, the paper is concluded in section 4.

2. Literature Review

In the design review, multi-user Virtual Reality (VR) is introduced to integrate the workflow into the 3D model and bring designers and clients together. Multi-user VR is where the users' shared experiences, communicate and interact in the same virtual space. The users are placed in the room with the head-mounted display to view the virtual building environment for the design review session. This technology enables users to read each other's bodies and moods while also transforming early-stage design and development by allowing clients to enter the virtual environments to evaluate the design requirement during the design review session.

Furthermore, VR can determine users' cognitive processes and personality characteristics for problem resolution [6]. The cognitive process is the way designers think or solve problems during the design review. Cornelia and Bauer [7] agree with this statement, as VR is immersive and allows users to feel and express their emotions, behaviour, and a variety of other senses. Therefore, the analysis of users' emotions and individuals during the design review session with VR can improve the quality of the meeting and lift the burden of designers from debating the construction and development process with their clients. The visual realism of the multi-user VR may influence the design review session evaluated. In research by [8], the authors found that reviewing the design with VR is effective because the discussion is based on a visualised design in realism, not on traditional media such as a regular slide presentation or 3D drawing. Thus, the research proved that the visualisation during the presentation affects the design review.

2.1 Cognitive Processes

Cognition means mental processes that contribute to knowledge and comprehension. These cognitive processes include thinking, knowledge, collection, evaluation, and problem-solving. These functions include language, fantasy, perception, and planning at a higher level. According to [9], an immersive virtual reality system could improve decision-making during design review by enhancing the user's cognitive performance in communicating design ideas. As a result, high-end technology can help with design reviews and considerably assist clients in understanding the designs. Hence, this research emphasises the cognitive processes to identify the designers' way of thinking, communicating, and problem-solving. Furthermore, the cognitive process can help to identify qualities that influence the evaluation of design reviews.

This paper selects the cognitive load theory (CLT) as the research concept theory for the methodology section. The cognitive load refers to the amount of the cognitive that can be held at a

specific time, especially during the interaction or discussion that requires the user to think or process the information.

2.2 Virtual Collaboration Quality

An advanced visual can attract people to communicate before discussing or deciding regarding the system or other stuff. According to [10], visual representation is the main feature of the presented work before it can commence. Thus, the development of a VR system allows for the visual representation during the configuration process for the client by solving the problems and fixing the communication crisis before it occurs. Data visualisation is more efficient in communication and understanding [11] than using the traditional architecture design process [12], which is by writing or drawing. While the process of discussion usually leads to the decision-making or exchanging ideas regarding discussion topics [13]. During the design review session, discussion among the designers and clients becomes a central part of negotiating about design, delivering the idea or thought, and the decision-making. Thus, to achieve the objective, there are four types of quality in Virtual Collaboration Quality covered in this research which are communication quality, decision quality, discussion quality, and visualisation quality. Figure 1 shows the Virtual Collaboration Quality to enhance the design review session.

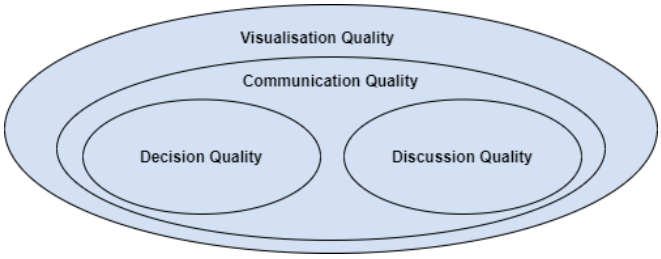

Figure 1: Virtual Collaboration Quality

The review of the previous paper is essential in the research as it can reveal the crucial data to help the current research. Table 2 shows the previous studies related to the Virtual collaboration Quality.

Table 1. Previous studies related to the Virtual collaboration Quality

Author	Communication Quality	Decision Quality	Discussion Quality	Visualisation Quality
[14]		•		
[15]				•
[16]		•	•	
[17]	•			
[18]				•
[19]		•		
[10]	•			•
[20]	•			•

3. Proposed Methodology

This proposed methodology is based on the convergent parallel mixed methods design shown in Figure 2. Figure 3 illustrates the proposed flowchart of the proposed research methodology that was designed according to the research's objective. As stated by [5], mixed-method research is a research type where researchers combine elements of qualitative and quantitative approaches to research such as the use of

qualitative and quantitative points of view, data collection, analysis, or inference techniques for the broadest purpose of comprehensiveness or profound understanding.

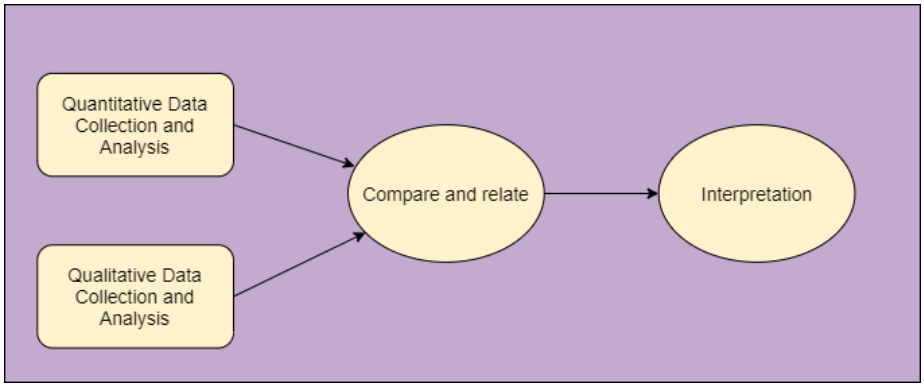

Figure 2: The convergent parallel mixed methods design [21]

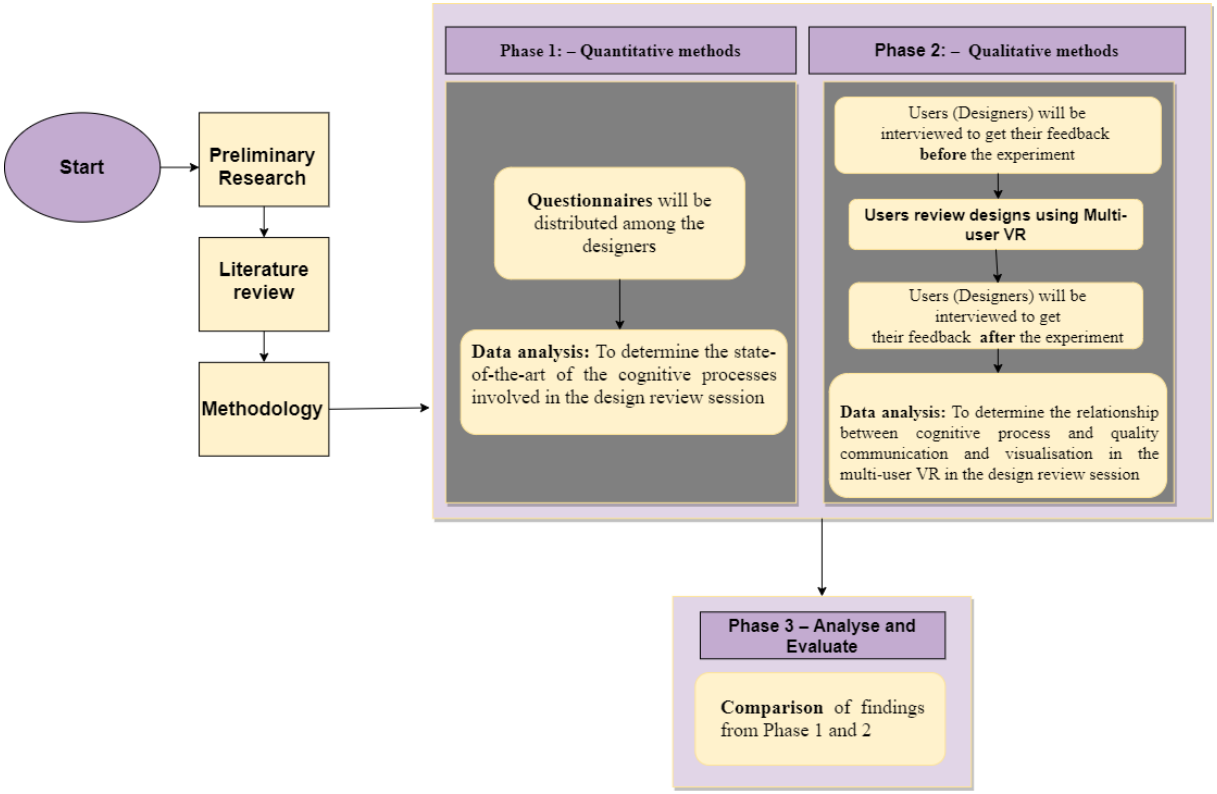

Figure 3: Proposed flowchart of the research methodology

Phase 1 – Quantitative methods
On this phase, the questionnaire survey will be distributed randomly among the designer. The data will be collected and analyses to determine the cognitive processes involved in the design review session. The data obtained from the designers and clients will be used to make inferences about the qualities of the traditional design review.

Phase 2 – Qualitative methods

The data will be collected before and after the experiment by collecting the interview feedback regarding the multi-user Virtual Reality (VR) in the design review. The primary purpose of this experiment was to validate the experimental setup and methodology. Hartmann and Graaf [22] concluded that the client would gain confidence and empowerment to further contribute to building the design solution by providing feedback. Thus, this method determines the relationship between cognitive process and quality communication and visualisation in the multi-user VR in the design review session. Users will be participating in the interview session before and after the experiment, to get their validity and respondent towards cognitive process, including the qualities in multi-user design review VR. Below is the following example for the interview feedback question:

1) How was the VR experience? Can you explain how did you feel in the virtual environment? [23]
2) Was there anything that made it easier or harder to interact in the virtual environment?
3) What do you think about other designers during the interaction?

Phase 3 – Analyse and Evaluate

The quantitative and qualitative data will be analyses to compare the cognitive process and qualities involved during the normal design review session and the multi-user VR design review. Hence this phase was proposed to evaluate the effectiveness of the cognitive process in the design review session in multi-user VR.

4. Conclusion

Factors such as visualisation quality, communication quality, discussion quality, and decision-making quality are the measures used to evaluate the effectiveness of the cognitive process when using multi-user VR in the design review session. Thus, the mixed-mode methodology is proposed for the research where two phases, i.e., quantitative and qualitative, will be conducted concurrently. Interviews before and after using multi-user VR and questionnaires are the data collection techniques adopted for the research. Finally, findings from both methods will be compared for the final result of the research.

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6. References

[1] Mathers J, Illman S, Brady A and Geraghty D P 2013 Design Review Principles and Practice *Des. Counc.*
[2] Ventura S M, Castronovo F and Ciribini A L C 2020 A design review session protocol for the implementation of immersive virtual reality in usability-focused analysis *J. Inf. Technol. Constr.* **25** 233–53
[3] Wong Y Y R, Wong P L, Wong P W and Goh C P 2020 The Implementation of Virtual Reality (VR) in Tertiary Education in Malaysia 1–6
[4] Wu H, Cai T, Luo D, Liu Y and Zhang Z 2021 Immersive virtual reality news: A study of user experience and media effects *Int. J. Hum. Comput. Stud.* **147** 102576
[5] Schoonenboom J and Johnson R B 2017 How to Construct a Mixed Methods Research Design *Kolner Z. Soz. Sozpsychol.* **69** 107–31
[6] Selivanov V V, Selivanova L N and Babieva N S 2020 Cognitive Processes and Personality Traits in Virtual Reality Educational and Training **13**
[7] Cornelia A and Bauer M 2020 The Potential of Immersive Virtual Reality for Cognitive Training in Elderly 614–23
[8] Liu Y, Ph D, Castronovo F, Ph D, Asce A M, Messner J, Ph D, Asce M, Leicht R, Ph D and Asce A M 2020 Evaluating the Impact of Virtual Reality on Design Review Meetings **34**
[9] Paes D and Irizarry J 2018 A Usability Study of an Immersive Virtual Reality Platform for

Building Design Review: Considerations on Human Factors and User Interface *Proceeding Constr. Res. Congr. 2018* **1996** 148–57
[10] Hamrol A 2015 Immersive City Bus Configuration System for Marketing and Sales Education Immersive City Bus Configuration System for Marketing and Sales Education
[11] Cham H, Malek S, Milow P and Ramli M R 2020 Web-based system for visualisation of water quality index
[12] Yildirim T 2012 Comparison of Traditional and Digital Visualization Technologies in Comparison of traditional and digital visualization technologies in architectural design education
[13] Gjerde M 2017 Informing design review : Discussion of the findings of a visual preference study in New Zealand *Procedia Eng.* **198** 562–9
[14] Torda A 2020 CLASSIE teaching – using virtual reality to incorporate medical ethics into clinical decision making 1–8
[15] Graf H and Stork A 2018 CAE / VR Integration – A Qualitative Assessment of Advanced Visualization for Interactive Conceptual Simulations (ICS) in Industrial Use *VIRTUAL, Augment. Mix. Real. Appl. Heal. Cult. HERITAGE, Ind. PT II 10TH Int. Conf. VAMR 2018, PT II* **1** 260–71
[16] Moser I, Chiquet S, Strahm S K, Mast F W and Bergamin P 2020 Group Decision-Making in Multi-User Immersive Virtual Reality **23** 846–53
[17] Roupé M, Johansson M, Maftei L, Lundstedt R and Viklund-tallgren M 2021 Virtual Collaborative Design Environment : Supporting Seamless Integration of Multitouch Table and Immersive VR **146** 1–16
[18] Jamei E, Mortimer M, Seyedmahmoudian M, Horan B and Stojcevski A 2017 Investigating the Role of Virtual Reality in Planning for Sustainable Smart Cities 1–16
[19] Goulding J, Nadim W, Petridis P and Alshawi M 2012 Construction industry offsite production: A virtual reality interactive training environment prototype *Adv. Eng. Informatics* **26** 103–16
[20] Balali V, Noghabaei M, Heydarian A and Han K 2018 Improved Stakeholder Communication and Visualizations: Real-Time Interaction and Cost Estimation within Immersive Virtual Environments *Constr. Res. Congr. 2018* 522–30
[21] Demir S B 2018 A convergent parallel mixed-methods study of controversial issues in social studies classes: A clash of ideologies Kuram ve Uygulamada Egit. Bilim. 18 119–49
[22] Hartmann T and Graaf R De 2017 Supporting Design Reviews with Pre-Meeting Virtual Reality Environment **22** 305–21
[23] Shi Y and Du J 2018 Social Influence on Construction Safety Behaviors : A Multi-User Virtual Reality Experiment