Investigating Immersion and Presence in Virtual Reality for Architectural Visualization

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***Abstract*—The architecture industry increasingly relies on virtual reality (VR) for architectural visualization, yet there is a critical issue of insufficient user involvement in the design process. This study investigates the sense of immersion and presence in the virtual environment among 60 Malaysian participants aged 20 to 40. The study utilized a 1000 sq. ft. apartment with three bedrooms and two bathrooms, was replicated in a 3D model based on real-world references. Our findings show that participants were moderately immersed in the virtual environment (M = 4.86), but the lack of sense of touch, lack of detail, and interactivity within the virtual environment affected their sense of immersion in VR for architectural visualization. This study has enhanced our understanding of human-computer interaction in VR, specifically for architectural visualization, and has emphasized the importance of improving these aspects to create more effective architectural visualization user experiences.**

Keywords—Virtual environment; virtual reality; human-computer interaction; architectural visualization; sense of presence

I. Introduction

Computer simulation, such as virtual reality (VR) has become an intrinsic part in realizing the vision of Industrial Revolution 4.0 and has revolutionized the way human work, communicate, collaborate and interact with one another [1]. Within the architecture industry, VR has facilitated design, construction and management of the built environment, given its immersive and interactive visualization capabilities [2]. Professionals in the architecture, engineering and construction (AEC) industry relies heavily on visual modes of information transfer and interaction, such as sketches, two-dimensional drawings, computer imagery, visualization and simulation [3, 4].

VR has proven its value in the AEC industry, offering benefits from design reviews to construction simulations [2, 5]. Architects now have access to a variety of tools like Enscape, Lumion, Twinmotion, Unreal Engine, Chaos Vantage, and Chaos V-Ray for real-time visualization of their architectural design proposal. In the conceptual phase, VR is used to explore design ideas quickly, providing architects with a sense of proportion and scale. As projects progress, VR becomes crucial for design validation, allowing architects to experience detailed interiors and exteriors realistically [2]. This technology allows architects to make fast well-informed decisions, considering aesthetics, cost, and environmental impact. The design process, once time-consuming, now occurs in seconds.

Despite evidence showing the use of these digital visualization technology could bring significant improvement in communication, exchange and interoperability of information, there exists a lack of end-user involvement and perspective in the design process [6]. According to Lee et al. [6], to effectively use digital visualization for architectural design collaboration, it is important to ensure the effectiveness of the visualization system from the end-user perspective.

Prabhakaran et al. [4] identify some hurdles within the architecture and construction sectors concerning immersive technologies like VR. These challenges encompass deficient communication among stakeholders, primarily attributable to the nascent state of VR infrastructure. Specifically, issues such as hardware requisites, user mobility constraints, ease of operation, and device ergonomics contribute to these communication inefficiencies [4]. Moreover, our earlier findings highlight the impact of VR hardware issues on users' sense of presence, a critical aspect underscored by Prabhakaran et al. [4] to enrich immersive experiences. The sense of presence, as highlighted by is pivotal for users to truly feel immersed in the virtual environment. While simulating spatial movement on a screen is feasible, Gomez-Tone et al. [8] argue that genuine immersion requires viewers to perceive themselves within the virtual space, fostering a profound sense of presence.

This study emphasizes the importance of end-user involvement in architectural design, utilizing VR technology to delve into user experiences. By integrating human emotions into digital visualization tools, the aim is to create architecture that caters to emotional needs. Facilitating improved collaboration between architects and users, the process enriches design through digital visualization. However, there remains a gap in understanding user responses to VR immersion in architectural contexts, especially in Malaysia. This research focuses on exploring Malaysian users' immersive experiences with VR when interacting with 3D building models. The goal is to pave the way for more empathetic architectural designs that prioritize user needs.

The paper is structured as follows: it begins with a background and literature review in Section I and II, providing context for the study. Following this, the experiment conducted to investigate the sense of presence among Malaysian users in VR is detailed in Section III. Subsequently, the results of the experiment are presented, accompanied by a thorough discussion is given in Section IV and Section V. Finally, the paper concludes by acknowledging the study's limitations and offering recommendations for future research in this domain in Section VI.

II. Literature Review

A. VR and Immersive Virtual Environment for Architectural Visualization

In the context of built environment, virtual reality (VR) can be defined as the experience of feeling present in a fictitious or envisioned environment through its representation [5]. An immersive VR system requires a three-dimensional (3D model), a head-mounted display (HMD), interaction devices or controllers and software to run the program. Immersive VR enables users to immerse themselves into the virtual environment [9].

As an immersive technology, VR enables human experience in the virtual environment through the sense of presence, which is the major factor in delivering lifelike experiences in the simulated environment [5]. Realism in the immersive virtual environment via VR is considered an important element for architectural design visualization, as the main objectives of VR applications in built environment field is to facilitate visualization and simulation of the architecture design [5].

Apart from tremendous benefit as learning tool for visualization in architecture education [10,11,12,13], most VR research in the construction industry proved that the technology benefits in the decision-making during the design process among design professionals [14,15]. However, there is a considerable gap in the effectiveness of VR for design collaboration with real-end users of buildings and clients from non-design background. Thus, it is important to investigate whether the use of VR for architectural visualization could achieve the level of realism as expected by these non-design users.

However, as stated earlier it is found that there is a lack of study that investigates how users respond to the design while experiencing it in VR, especially for the context of Malaysian user. Abdul Ghafar and Ibrahim [16] stated that there is lack of emphasis given to human factor when using these digital visualization tools. Azmi et al., [7] also argue that the use of VR for visualization of housing design for homebuyers are limited in terms of touch sensation and navigation. In addition, Delgado et al., [3], supported by Lyu et al., [17] argue that despite the advancement of VR technology in visual rendering of the immersive virtual environment, other sensory simulation such as auditory, tactile, thermal, olfactory and taste remain relatively underdeveloped. These arguments highlighted the importance of exploring end-user engagement through the visual representation using VR during the design stage to determine the effectiveness of this digital visualization technique during design collaboration.

B. Emotional Intelligence in Digital Architectural Visualization

Over the past decade, emotional intelligence has been the focus of research from different disciplines of studies to explore the advantage of applying the concept to benefit their respective fields. Salovey and Grewal [18] described emotional intelligence as the skill that brings together the fields of emotions and intelligence by viewing emotions as useful sources of information that help one to make sense and navigate the social environment. As human responds cognitively and emotionally to the built environment, the use of VR to evaluate users' emotion during their immersive virtual environment experience serves as a promising framework for the future of design and research in the built environment [19].

However, user experience has been the main issue in VR for architectural visualization as VR is highly visual and does not really support other human sensations such as olfactory and haptic [7,19]. VR has the capacity to simulate the illusion of being in a place through the sense of presence, hence, it is crucial to meet the viewers' expectations, cognitive and emotional dimension of the built environment [19]. Research has shown that some design element in the built environment reflected higher sense of attraction of the brain to the surroundings, which impacts the psychological wellbeing of the inhabitants [20].

It is found that research in regard to emotional intelligence in architectural visualization within the virtual environment has not been widely studied. Thus, this paper argues the critical need for a study that investigates the synergistic relationship between VR and user experience. This study is trying to fill the considerable gap in studies that examine how the end-user, which is usually non-design professional perceive the digital simulation of an architecture design. This is pertinent to help architects to understand and improve the design of virtual spaces that has more meaning, physically and emotionally to the end-users. It is substantial to explore emotional intelligence during the design process that requires exchange of not only technical decisions but also the human experience, especially with the use of digital visualization technology such as VR.

C. Sense of Presence

Immersive virtual environment enables human experience in a given environment through the sense of presence. Presence is defined as the subjective experience of being in one place or environment, even when one is physically situated in another [21]. It has been proven by various recent research that human emotion in the virtual environment is similar to the emotion in the physical environment [7, 22, 23].

Caroux [24] indicates that while immersion would be typically related to sensory feedback that results in the sense of being surrounded by the virtual environment, presence would be more related to a cognitive psychological response that is the feeling of being in the virtual environment. Several factors affecting presence has been identified, including i) human factors - the level of experience and age [25], ii) the visual and sensory input [26], and iii) technological factors – stereopsis, field of view, and interactivity [5].

Following Paes et al., [5], identifying factors that affect presence in virtual environment is a vital step to improve the VR application in the built environment. This study aims to fully optimize the advancement of digital visualization technology in the AEC industry to ensure effective user experience in VR, especially for the context of Malaysian users. Hence, it is possible to create a new space for better discussions of design solutions between architects and end-users for a design that meet user needs. With the considerable gap in literature concerning users from Asian background in using VR technology for architectural visualization, following Azmi et al., [7], this study is focusing on the users' behavioral response in VR within the context of Malaysian user in local architectural design. In the next section, this paper delineates the experimental research methodology employed to investigate the sense of presence among Malaysian users within VR environments for architectural visualization purposes.

III. Research Methodology

This study is an empirical and relational study as most human-computer interaction studies such as Paes et al., [5]. Employing a one-group posttreatment-only pre-experimental design, the study leverages survey questionnaires to assess user experience within virtual environments. This design entails exposing a single group of participants to an intervention, followed by measurement, as elucidated by Creswell [27]. Participants engage with a VR setup simulating the interior of a house, after which they provide feedback through questionnaires to gauge their immersion and presence within the virtual environment.

A. Participants

Participants were recruited for the experiment using purposive sampling method, via advertisements distributed in social media and word-of-mouth. In order to be included in the study, individuals had to meet the following criteria: (1) Malaysian nationality; (2) aged between 20 and 40 years old; (3) not physically or mentally impaired and (4) not under serious medications for health-related problems. In regard to the sample size, a power sample analysis using G*Power version 3.1.9.7 [28] was conducted with a level of statistical significance equal to 80% with a medium effect size of Cohen's $d = 0.5$ ($\alpha = .05$). This follows similar sample size estimation by other studies in VR experiments such as Pallavicini and Pepe [29]. Result of the power sample analysis using G*Power suggests an estimation of sample size for the research design and one sample case statistical test is 27 participants. In this study, a total of 60 samples were recruited, which is more than adequate to get a high statistical power.

Based on the post-hoc power analysis to compute achieved power based on 60 samples conducted in G*Power version 3.1.9.7, the study has 99% power to detect medium-sized effect $d = 0.5$ ($\alpha = .05$). The 60 participants recruited in this study include: 33 female (55.0%) and 27 male (45.0%); mean age of 30 years old (SD: 2.81). 95% of the participants are from Malay racial background. Only two participants have the experience of using VR for architectural visualization before the experiment.

B. 3D Model and VR Apparatus

An apartment designed in Selangor, Malaysia was selected as the experiment environment. This residential unit consists of 1000 square feet of living space with three bedrooms and two bathrooms. A 3D model of an interior of a house was developed in Sketchup Pro 2019 (version 19.3). Enscape software (version 2.6.1) was used for the real-time 3D visualization and as the VR plugin for Sketchup. Fig. 1 shows the 3D model of the kitchen of the apartment in Sketchup software. Fig. 2 shows the virtual environment as viewed in VR, rendered using Enscape software.

Fig. 1. 3D model of the kitchen in Sketchup software.

Fig. 2. VR view of the kitchen rendered in Enscape software.

For the VR apparatus, HTC Vive was used. HTC Vive consists of a head-mounted display (HMD), two base sensors for tracking position and orientation, and a set of controllers were used as the VR equipment. The computer used was a Dell G7 15 7590 laptop with Intel ® Core ™ i7-8750H processor and NVIDIA GeForce GTX 1050 (4GB GDDR5) graphics card. The computer has an 8GB RAM that operates with the Windows 10 operating system. The specifications on this computer satisfy the minimum system requirements for HTC Vive. Fig. 3 illustrates the VR setup which consists of the HTC Vive head mounted device (HMD), two base stations and two controllers.

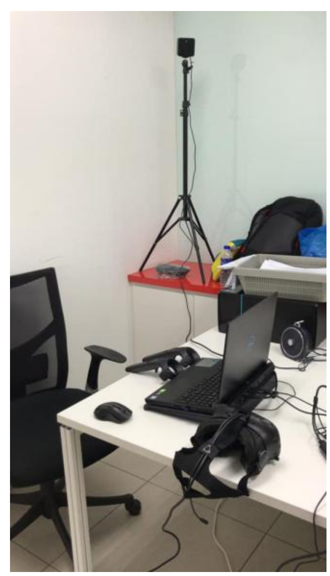

Fig. 3. VR device setup.

The HTC Vive system allows for physical movement within a minimum play area of 2 meters x 2.5 meters, hence the experiment was set to comply within this play area. The play area was setup using Viveport software. Fig. 4 shows the participants using the HTC Vive during the experiment.

Fig. 4. Participant using the HTC Vive during experiment.

C. Data Collection Instruments

The data collection instruments used in this study include:

- Demographics – the question includes their gender, age, marital status, racial background, level of education, profession and prior VR experience;
- Consent form - Before the experiment, every participants was asked to read carefully the consent form, as it is the right of every person to make informed decisions regarding their participation in a research study, after being informed of all aspects of their role in the study as required in the Belmont principle of respect for persons [30]. This research has also been approved by the Universiti Putra Malaysia Ethics Committee for Research Involving Human Subject (JKEUPM-2020-028) prior to the data collection;
- The Virtual Presence Questionnaire (VPQ) - After the participants had been exposed to the virtual environment, a Virtual Presence Questionnaire (VPQ) was given to each participant. The VPQ was adopted from the Presence Questionnaire, originally used by Witmer and Singer (1998). The Presence Questionnaire was used to evaluate the level of presence that each participant experienced during the VR experience to view the virtual environment. The VPQ developed in this study is adapted based on the instruments developed by prior research that includes Witmer and Singer [21], Westerdahl et al., [31] and Heydarian et al., [32].

The VPQ consists of nine Likert Scale-based questions (seven-point scale), two questions that requires a yes or no answer, and two open-ended questions. These questions were developed based on prior research to determine the level or immersion and presence of the participants in the virtual environment, including the level of realism of the virtual environment. The results from the VPQ would add to the understanding in regard to the participants' differences and abilities in a given virtual environment, and the characteristics of the virtual environment that may affect presence.

The two open-ended questions in the VPQ seek to obtain additional information based on the participants' experience in the virtual environment using the VR devices. In the open-ended questions, the first question invited the participants to comment on the kind of information that they think is lacking from the virtual environment; while the second question invited them to provide suggestions regarding the application of VR for architectural visualization in Malaysia. The two open-ended questions in the VPQ are:

- What kind of information do you think is lacking from the VR environment?
- What are your comments regarding the application of VR for architectural visualization?

According to Creswell [27], Neuert et al., [33], and Aithal and Aithal [34], open-ended questions in a set of questionnaires allow the respondent to express an opinion without being influenced by the researcher. The open-ended questions advantages include the possibility of discovering the responses that participants gave spontaneously, and thus avoiding the bias that may result from suggesting responses in close-ended questions such as Likert-scales [35].

IV. Result and Analysis

A descriptive statistical analyses to describe the central tendencies and variability in participants' response in this study were conducted using SPSS version 25 software package. Table I illustrates the mean and standard deviation for the participants' responses in the VPQ.

TABLE I. VPQ Questionnaire Items - Mean and SD

VPQ QUESTIONNAIRE ITEMS - MEAN AND SD		
VPQ Questionnaire Items	***Source***	***Mean (SD)***
"How physically fit do you feel today?" [a]	[21]	6.27 (0.73)
"How good are you at blocking out external distractions when you are involved in something?" [a]	[21]	5.75 (0.97)
"Are you easily disturbed or distracted when working on tasks?" [a]	[21]	3.87 (1.75)
"Did you get bored with the VR model during the viewing experience?" [a]	[31]	5.80 (1.61)
"Did the surfaces such as walls, floors, and furniture look real in the VR model when you view it?" [a]	[31]	4.95 (1.65)
"Could you orient yourself in the internal environment during the VR experience?" [a]	[31]	5.43 (1.53)
"How much did your experiences in the virtual environment seem consistent with your real-world experience?" [a]	[21]	4.95 (1.64)
"How realistic was your sense of movement around in the virtual environment?" [a]	[21]	4.60 (1.59)
"How difficult was it to understand the characteristics of the house in VR?" [a]	[32]	3.25 (1.72)
"Did you feel that the Virtual Reality (VR) model lacked information for you to understand the interior of the house?"	[31]	Yes = 55%
"Do you feel any discomfort or dizziness after the VR experience?"	[7]	No = 45%

[a.] The question response format was a 7-point Likert scale.

Findings from Table I indicates that the participants were relatively fit during the experiment (M = 6.267, SD = 0.7333). The participants were also somewhat focused during the experiment based on their responses in Question 2 (M = 5.750, SD = 0.968) and Question 3 (M = 3.867, SD = 1.751). In the virtual environment, the result showed that most of the participants thought that the textures on walls, floors, and furniture look real in the VR model (M = 4.950, on a 7-point Likert scale where 1 = “not real at all” and 7 = “very real”). The same responses also applied to whether their experience seems consistent with real-world experience (M = 4.950, on a 7-point Likert scale where 1 = “not consistent at all” and 7 = “very consistent”).

The participants also felt that they were able to orient themselves in a virtual environment (M = 5.433, on a 7-point Likert scale where 1 = “not at all” and 7 = “totally”); and that their sense of movement in the virtual environment is not much realistic (M = 4.600, on a 7-point Likert scale where 1 = “not at all” and 7 = “totally”). Of the 60 participants, 33 participants (55%) felt that the VR lacked information for them to understand the interior of the house. Finally, a majority of participants (78.3%) did not feel any discomfort or dizziness after the VR experience. The results also reveal that participants were relatively focused during the experiment based on their ratings from Questions 1 to 4. The participants also indicated that the virtual environment was moderately realistic based on their ratings from Questions 5 to 10.

A. Analysis of Open-Ended Questions

Of the 60 participants, only 33 participants (55%) provided their answers to the open-ended questions. To identify participants’ evaluation of the virtual environment from the two open-ended questions, this study deployed thematic analysis. Four main themes emerged from the participants’ answers in these two open-ended questions which are: “feel”, “detail”, “size” and “interactivity”. The thematic analysis is presented in Table II.

In the first open-ended question - what kind of information do you think is lacking from the VR model? 18 participants mentioned that they were unable to estimate the size and dimensions of the interior of the house based on their VR experience. These participants felt that it is essential for them to feel the size of the space in the architectural visualization. In addition, seven participants commented that the information about materiality and texture of materials in the house is lacking in the virtual environment. One participant commented that the VR model was unsatisfying since they were unable to touch the materials inside the house or feel the wind from the window or balconies. Two participants also commented on the lack of sense of sound and smell in the virtual model. On the other hand, five participants commented on the realism of the virtual environment that lacks detail and seems unrealistic.

In the second open-ended question, eight participants provided suggestions that the VR equipment or space provided should enable them to walk around freely in the virtual environment without being restricted. Five participants provided suggestions for a more realistic virtual environment with better resemblance of a real physical building. One participant suggested that the VR application could provide options in terms of furniture arrangement, while another participant suggested that the VR application to provide different color options in the architectural visualization.

TABLE II. THEMATIC ANALYSIS OF VPQ ANSWERS

Open-ended Question 1: What kind of information do you think is lacking from the VR environment?	
Participants’ Response	***Theme***
“I want to really feel the house to make sense of it in terms of touch and smell; I am not sure how that can be achieved virtually”.	Feel
“I can’t feel the element of wind to make sense of the open space concept of the house.	
“Physical environment is more satisfactory as there is physical touch. The feeling of walking inside a real house is not similar as in VR”.	
“I can’t imagine the quality of materials in the VR model”.	Details
“Lack of detailing in the VR model”.	
“I can’t estimate the size and dimension of space inside the virtual environment”	Size
“It’s difficult to understand the size of the room from the VR”	
“I think a lacking feature of the VR technology is that I can’t estimate the size of the house”	
Open-ended Question 2: What are your comments regarding the application of VR for architectural visualization?	
Participants’ Response	**Theme**
“Adding capability to vary household content so that it may suit different individuals (worker, students, family, big family), and having multiple household arrangement settings for the same house layout”.	Interactivity
“I would suggest a bigger space for people can walk freely while using the VR equipment”.	
“I would suggest including measurement in the VR model for potential homebuyers to realise the size of the house”.	
“It is suggested to include interactive information such as measurement (height and width) and colour options for walls or furniture”.	

V. Discussion

The study acknowledges limitations in touch and interactivity, impacting the participants' sense of presence. Issues related to hardware constraints and restricted movements contribute to a less realistic experience. Based on participants' response, it can be discerned that the participants' experience in the virtual environment are moderately natural, which results to a moderate level of immersion and presence. The authors believes that a greater degree of immersion and presence is detracted due to the lack of sense of touch in the virtual environment.

Most participants highlighted that the inability to physically touch or feel the materials within the virtual environment was a significant limitation. The authors contend that this absence of tactile interaction compromised the overall sense of immersion and presence. Furthermore, additionally, participants pointed out the unrealism in navigation, as the VR device was tethered with wires, which restricted movement and affected their ability to move freely within the virtual space. We recognized the limitations of the VR device used in this study, which requires cables attached to the HMD that limits participants' movements; hence affecting the level of realism in the virtual environment.

Apart from that, most of the participants also opined that they were unable to sense the feeling of space or estimate the dimensions or size of the house that they view in the virtual environment, which is one of the critical factors in enhancing their experience and presence in the architectural visualization. We acknowledged these findings as the most important one, considering the assumption by past literature that the virtual environment could simulate the physical world conditions with sufficient accuracy and are efficient in representing spatial information [36].

Furthermore, according to Azmi et al., [7], due to the lack of interactivity in the virtual environment, the atmospheric qualities of spaces are diminished, hence the sense of presence was lacking. The virtual environment could not simulate the physical world accurately in terms of the quality of the surrounding and its relation to human senses. This corroborates findings from [37] that suggests integrating technology capable of aligning the visual perception of virtual objects with the tactile sensations of holding and touching real objects with bare hands can significantly enhance the quality of experiences and sense of presence in virtual environments.

This study also concurs with Higuera-Trujillo et al., [19] that user experience is a vital issue that needs to be addressed. The user experience includes enhancing the capacity of VR simulation to generate the 'place illusion' and the credibility of the 3D scenarios in the virtual environment to meet the users' expectations of the simulated environment [19]. Thus, the findings in this study allows for further understanding of the current user experience in VR for architectural visualization.

VI. Conclusion

This study aims to enhance the architecture industry's adaptation to Industry 4.0 by leveraging digital visualization, particularly VR, in architectural design. The study contributes to understanding user experiences in VR architectural visualization, particularly in Malaysia. While VR has significantly improved design review and collaboration, there is still a gap in end-user involvement. By evaluating VR effectiveness from the user's perspective, this research addresses these challenges. Issues like hardware requirements and user mobility hinder seamless communication in VR architectural visualization. Additionally, the study emphasizes the importance of the user's sense of presence in VR environments. Findings from our empirical study shed light on participants' experiences, highlighting realism and challenges.

This study highlights the significant potential of VR technology to revolutionize both the real estate and architectural industries. In real estate, VR offers a more sustainable and versatile alternative to physical show units, allowing developers to enhance their marketing strategies, reach broader audiences, and provide homebuyers with a more comprehensive and immersive evaluation experience than traditional methods. In architecture, VR serves as a tool for understanding user emotions and behaviors within designed spaces, fostering empathetic and user-focused designs, with potentials to focus on groups such as the elderly or individuals with special needs.

Recommendations include enhancing VR interactivity for better user engagement. This research contributes to understanding users' needs in VR architectural visualization, particularly in Malaysia, aiming to improve design collaboration and user satisfaction. It anticipates VR technology's enhanced role in architectural visualization, aligning with users' preferences and needs. Future research directions include investigating innovative approaches to improve the realism and immersion of VR environments for architectural visualization and exploring advancements in VR hardware such as tactile gloves or body-kit to allow sense of touch in the virtual environment.

Limitation of Study

Several limitations of this study should be acknowledged. First, due to budget constraints, the study used an older version of the VR equipment, which is HTC Vive which was succeeded by newer versions of the VR headset. The HTC Vive (released in 2016) was followed by the HTC Vive Pro in 2018, and later, the HTC Vive Cosmos and Vive Pro 2 were introduced in 2019 and 2021, respectively.

Additionally, the study focused solely on the responses of participants in Malaysia that fulfil the inclusion criteria, which limits the participant pool to other nationalities with various cultural differences, which might have different perception due to cultural differences. Lastly, the absence of haptic devices meant that tactile feedback was not incorporated into the virtual experience. Future research should consider integrating haptic technology to allow users to physically interact with textures in the virtual environment, and assess its impact on emotions and behaviors.

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