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VR headset vs. PC screen as virtual learning tour interface for Chinese architecture heritage investigation

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Abstract

In design education, integrating digital tools has revolutionized pedagogical approaches. This study examines the impact of VR HMDs and PC screens on learning ancient Chinese architecture using a virtual tour. Involving 22 students, it assessed simulator sickness, user experience, and spatial awareness. Results show VR had a more positive spatial learning experience but the same learning outcomes. VR enhances presence but increases simulator sickness. The study underscores VR's potential and limitations in ancient Chinese architectural education, suggesting future research directions.

Keywords: virtual reality (VR), digital learning, ancient architectural education, head-mounted display (HMD), PC screens

1. Introduction

In recent years, the emergence of digital learning and information and communications technology (ICT) has ushered in a transformative era in education, offering new avenues for immersive and interactive learning experiences across diverse domains (Sayaf et al., 2021). This technological paradigm shift extends to architectural design education, particularly in exploring ancient architecture (Ummihusna and Zairul, 2022). Architectural heritage, integral to the preservation of cultural heritage, encapsulates the historical activities of humanity and the memories of cities. The term "architectural heritage" finds its origins in the Venice Charter, encompassing historical monuments and sites (Krishna Menon, 1994). Among the diverse domains of architectural scholarship, the study of ancient architecture occupies a pivotal position, acting as a crucible for comprehending the evolution of design, construction methodologies, and the cultural underpinnings influencing architectural aesthetics over the ages (Del and Tabrizi, 2020). The exploration of ancient architecture provides students with a historical perspective, design inspiration, and a profound understanding of architectural evolution (Clarke et al., 2020). It instils in them a sensitivity to cultural and contextual factors, fostering the ability to design with a global perspective while being acutely aware of preservation and restoration requirements (Del and Tabrizi, 2020).

Architecture students seek in-depth knowledge of firsthand architectural history, fostering a profound comprehension of architectural nuances and historical significance (Clarke et al., 2020). Unfortunately, the decay of historical sites and preservation concerns limit physical exploration (Cheng et al., 2004). Traditional resources like literature and photos inadequately convey spatial identity (Ji et al., 2018). In response to these constraints, students employ 3D digital models to satiate their scholarly curiosity and nurture their design sensibilities (Banfi et al., 2019). In modern education, the fusion of virtual environments and architectural teaching is promising. (Bevilacqua et al., 2022). The utilization of virtual reality headsets or personal computer (PC) screens constitutes a potent means of transporting students to digital realms where they can partake in a profoundly immersive learning experience (Moneta, 2020).

However, the educational effectiveness of these virtual interfaces requires thorough examination. Students' quest for architectural knowledge must harmonize with technology to bridge the gap between history and contemporary learning.

Several prior studies have explored the use of immersive virtual reality (VR) technology in architectural education. For example, Chan, Bogdanovic, and Kalivarapu (2022) investigated its use in remote architectural history teaching by simulating the Pantheon historical structures, providing students with a unique experiential engagement with architectural heritage but lacking a comprehensive assessment of educational impacts (Chan et al., 2022). Similarly, Capecchi et al. (2022) combined serious gaming with VR for architecture education (Capecchi et al., 2022). Angulo and de Velasco (2013) explored immersive simulations of general architectural spatial experiences, emphasizing the affective appraisal of space, aligning with part of our study's objectives (Angulo and de Velasco, 2013). Also, a previous study (Zhao et al., 2020) compared three different investigating modes for place-based STEM, highlighting that immersive virtual reality is more effective than the desktop mode in knowledge acquisition. However, this study is not set in the context of architectural education and is an exploration of natural sites.

Prior studies have often focused on the application of these technologies in isolation or within limited contexts without a comprehensive comparison of their impacts on student engagement, space knowledge acquisition, and retention in the architectural domain. There is a research gap in systematically comparing the effectiveness of VR headsets and PC screens as media for visualizing serious games in learning. This underscores the necessity for studies comparing the pros and cons of VR headsets and PC screens in architectural education through virtual tours.

This study seeks to address the identified gap by evaluating VR headsets versus PC screens in ancient Chinese architectural education. It analyzes participant experiences in a VRchat-based virtual scenario to understand how these interfaces affect learning outcomes, engagement levels, and the educational value of serious games in the architectural domain. With 22 participants, it aims to enhance the understanding of technology's role in architectural education and its impact on learning.

2. Background

2.1. The transformative potential of visualizing ancient architectural knowledge

The digitization of architectural heritage, transforming data into cultural inheritance, is a crucial form of knowledge visualization with implications beyond only preservation (Morlando et al., 2012). It plays a central role in education, enhances virtual exhibitions, supports scientific research, and offers various opportunities (Bekele et al., 2018). This burgeoning field, nested within the broader realm of data and information visualization, has become a potent tool for making collective knowledge more accessible (Zhang et al., 2022).

Knowledge visualization as an academic discipline was first conceptualized by Eppler in 2004, aiming to enrich knowledge dissemination and foster innovation through visual representation (Eppler and Burkhard, 2004). Its core purpose is to make complex concepts understandable and readily attainable. It employs various visual formats, from charts to interactive interfaces, to simplify intricate concepts and facilitate data exploration (Bygstad et al., 2022). Knowledge visualization not only alleviates cognitive burdens but also serves as a potent instrument for storytelling, knowledge management, and data-driven research (Eppler, 2011). Creating interfaces tailored for visual communication is a vital aspect of this discipline, streamlining knowledge exchange (Besançon et al., 2021). Computer screens are the predominant interface for representing ancient architectural knowledge. However, in recent years, Virtual Reality (VR) technology has gained significant ground in this field, revolutionizing knowledge engagement and visualization (Zhang et al., 2022).

2.2. The immersive realm of virtual reality (VR) technology

Virtual Reality (VR) is a revolutionary shift in human-computer interaction, creating immersive 3D environments through sensor technologies (Murphy et al., 2009). Through a plethora of sensors encompassing visual, auditory, and tactile stimuli, users find themselves ensconced within a virtual realm, where real-world experiences transpire, and interaction with the digital milieu takes on multifaceted dimensions (Murphy et al., 2013). VR stands out from traditional desktop interactions by combining high immersion and interactivity (Pallavicini et al., 2019).

The depth of immersion relies on creating a detailed, vivid, and realistic illusion of a virtual environment (Slater and Wilbur, 1997). Surrounding and matching are key aspects distinguishing desktop from VR immersion (Dincelli and Yayla, 2022). Surrounding involves obscuring the physical world, including the field of view (FOV) and display types (Slater and Wilbur, 1997). Head-mounted displays (HMDs) or surround projections should provide a significantly heightened sense of surroundings (Miller and Bugnariu, 2016). Matching focuses on the harmony between user cues and displayed information, striving for precise emulation of real-world experiences (Markowitz et al., 2018). A wealth of empirical evidence underscores the capacity of HMDs to bestow a more profound sense of presence when compared to traditional desktop interfaces (Buttussi and Chittaro, 2017). This enhanced presence immerses users authentically in the virtual world, influencing emotional experiences (Slater and Wilbur, 1997). Significantly, it wields a transformative influence on users' emotional experiences, immersing them in an alternate reality that, despite its digital essence, resonates with a striking sense of genuineness (Kim et al., 2014).

2.3. Technical characteristics of PC screens

In architectural education, especially for virtual tours, the technical features of PC screens, like high resolutions and refresh rates, are key to presenting detailed architectural content effectively. Unlike VR, PC screens' HD or 4K resolutions enhance the depiction of intricate architectural details, while their refresh rates ensure smooth motion, reducing visual fatigue and keeping users engaged (Higuera-Trujillo et al. 2024). Their color accuracy and contrast further bring out the true colors and lighting of ancient structures (Shin 2019). The widespread accessibility and user-friendliness of PC screens also make them a viable option for incorporating serious games into architectural learning, highlighting their role as a valuable educational tool (Higuera-Trujillo et al. 2024).

2.4. VR technology's role in architectural heritage education and research

VR technology's heightened presence significantly influences emotional and cognitive aspects, ushering in elevated engagement and understanding, especially in architectural education (Makransky et al., 2016, Kim et al., 2014). However, the effectiveness of VR interfaces in architectural heritage education, encompassing exhibitions, the depth of their impact on exploration, and their utility in architectural research remains an intriguing subject of investigation (Moralıoğlu and Aktaş, 2021). While the allure of VR technology in architectural heritage exhibition, exploration, and research is indisputable, a significant gap exists in the realm of comprehensive research focused on ancient Chinese architecture, leaving unanswered questions about its unequivocal educational effectiveness when compared to traditional PC screens. Consequently, further inquiry is imperative to acquire a holistic comprehension of the potential advantages and limitations associated with the integration of VR technology in architectural heritage contexts. In this dynamic convergence of knowledge visualization, design education, and architectural heritage, a promising future takes shape via this research, characterized by a synthesis of tradition and innovation poised to empower a new generation of learners and researchers in their exploration of architectural history, design principles, and the immersive potential inherent in VR technology.

3. Methods

3.1. Study design

This study employed a between-group design comprising two conditions in which participants engaged with a virtual architectural heritage site either through (a) a VR Head-Mounted Display (HMD) or (b) a PC screen. The assignment of participants to these conditions followed a counterbalanced system, ensuring a balanced distribution across both. Apart from the choice of display system, the tasks and questionnaires were consistent across both conditions.

3.2. Experimental setup

The study utilized the Oculus Quest 2 VR HMD and a laptop, with VRChat serving as the experimental platform for both configurations. A meticulously recreated virtual representation of Nanchan Temple in Shanxi, China, was employed in the study. Architectural models were generated using modelling software, with reference to architectural plans, interiors, and section drawings. These models were further refined in Autodesk Maya and subsequently integrated into Unity scenes. These customized scenes were then incorporated into the VRChat accounts (Figure 1).

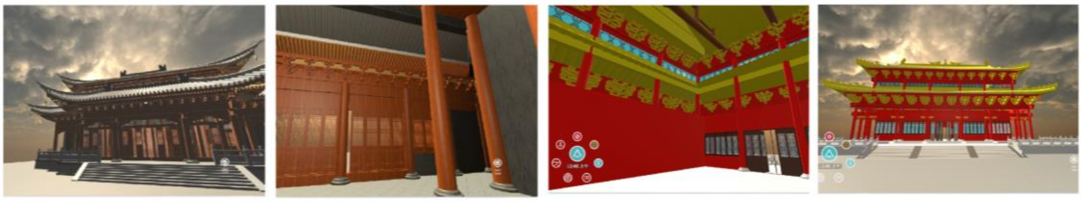

Figure 1. Virtual scene construction

3.3. Procedure

The study involved 22 graduate students with an average age of 24.7 years (SD = 3.1). All participants reported no known mental or physical impairments and possessed normal or corrected-to-normal vision. After providing informed consent, participants completed a pre-questionnaire with demographic data and the Simulator Sickness part. They familiarized themselves with the assigned interface, received background information on Nanchan Temple, and then engaged in a 10-minute virtual tour. Following the tour, participants assessed simulator sickness and completed additional questionnaires (Figure 2).

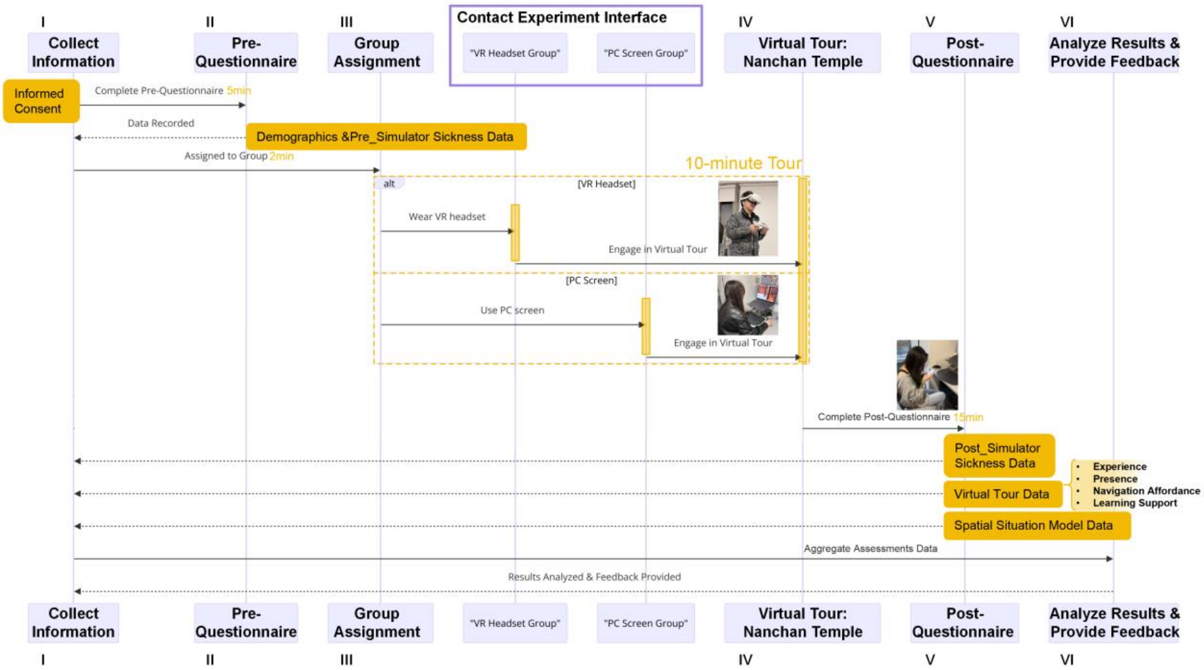

Figure 2. Experimental sequence diagram

3.4. Measures

Sutcliffe and Gault (2004) created a VR evaluation scale focusing on naturalness and compatibility, later adapted by Kabassi et al. (2019) for virtual tours into four key dimensions: VR experience, perception of presence, navigation, and learning aspect. Our study expanded this, focused more on educational enhancement (Bekele et al., 2018), and introduced evaluations for simulator sickness and domain suitability, enriching the assessment of user experiences.

3.4.1. Simulator sickness part (SS)

The Simulator Sickness Questionnaire (SSQ), developed by Kennedy et al. (Kennedy et al., 1993), assesses simulator sickness (SS) with symptoms such as nausea and dizziness. Participants completed pre- and post-SSQs to measure SS changes (ΔSSQ = post-SSQ - pre-SSQ) before and after engaging with the virtual environment.

3.4.2. VR experience part

The perceptive and cognitive part, adapted from Schrepp et al.'s User Experience Questionnaire (UEQ), assesses user experience along six dimensions: attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty (Schrepp et al., 2014). The UEQ provides a multidimensional view of interactive experiences.

3.4.3. Presence part

Presence, in this context, pertains to the sensation of being situated within a natural physical environment. Factor analysis of the Presence revealed a tripartite structure, encompassing spatial presence, involvement, and realness. These factors encapsulate the sense of inhabiting a virtual environment, engagement with it, and its perceived realism.

3.4.4. Navigation affordance part

This part delineated four primary dimensions to assess navigation affordances based on a comprehensive literature review and an examination of technical capabilities.

3.4.5. Learning support part

The Learning Support part, originally designed for educational aspects of virtual tours, expanded to three dimensions: learning promotion, richness in information availability, and knowledge retention. The assessment framework for evaluating VR headsets and PC screens in education combines principles from the Technology Acceptance Model (Perceived Usefulness and Ease of Use) (Marangunić and Granić 2015) and Kirkpatrick's Four Levels of Training Evaluation (Reaction, Learning, Behavior, Results) (Kirkpatrick and Kirkpatrick 2016), incorporating insights from immersive learning and multimedia studies (Beck et al. 2023). This approach provides the structure for assessing both objective outcomes and subjective experiences.

3.4.6. Spatial situation model part

Inspired by the MEC Spatial Presence Questionnaire (Vorderer et al., 2004), the Spatial situation model part assessed participants' mental representations of the virtual space environment, aiding in understanding their processing of spatial information in VR environments and mental map formation.

3.4.7. Demographic part

The demographic part collected basic personal details and inquired about prior VR experience and familiarity with Chinese architecture.

4. Results

4.1. Simulator sickness part (SS) score

We conducted independent two-sample t-tests to compare the SSQ scores between the VR HMD and PC screen groups, with the prerequisites of normality and homogeneity of variance met. The VR group exhibited significantly higher levels of simulator sickness compared to the PC group (M±SD; PC: 0.8±2.2; VR: 9.6±7.1; $t(20) = -3.88$, $p = 0.002$) (Figure 3).

4.2. VR experience part score

We employed independent two-sample t-tests to contrast the VR Experience Scores between the VR HMD and PC screen groups while ensuring the normality and homogeneity of variance assumptions were satisfied. Our analysis revealed no discernible differences between the two groups (M±SD; PC: 91.6±5.0; VR: 91.8±6.8; t(20) = -0.07, p = 0.944) (Figure 3).

4.3. Presence part score

Independent two-sample t-tests were executed to compare the presence scores between the VR HMD and PC screen groups, with the criteria of normality and homogeneity of variance fulfilled. Participants in the VR group achieved higher scores, although the difference was not statistically significant (M±SD; PC: 64.4±10.2; VR: 73.0±10.3; t(20) = -1.97, p = 0.063) (Figure 3).

4.4. Navigation affordance part score

We conducted independent two-sample t-tests to compare the Navigation Affordance Scores between the VR HMD and PC screen groups, ensuring normality and homogeneity of variance assumptions were met. Participants in both groups exhibited similar scores (M±SD; PC: 28.5±2.5; VR: 28.7±2.1; t(20) = -0.27, p = 0.787) (Figure 3).

4.5. Learning support part score

Independent two-sample t-tests were used to compare the learning support scores between the VR HMD and PC screen groups, with normality and homogeneity of variance assumptions met. No significant differences emerged between the two groups (M±SD; PC: 23.5±3.9; VR: 25.1±6.1; t(20) = -0.75, p = 0.464) (Figure 3).

To enhance the statistical significance, we conducted a segmented analysis. First, focusing on knowledge retention, assess participants' judgments in architecture-related details. Using two-sample t-tests and adhering to normality and variance assumptions, results indicated similar correctness rates in this category for both groups (M±SD; PC: 10.8±1.5; VR: 9.1±2.2; t(20) = 2.26, p = 0.033).

In examining learning promotion, and information availability and richness, particularly viewer interest, we employed a two-sample t-test for a comparative analysis between the VR HMD and PC screen groups. Adhering to normality and variance assumptions, the results showed a clear pattern: the VR HMD group assigned significantly higher scores (M±SD; PC: 8.6±1.7; VR: 4.5±1.9; t(20) = 5.79, p = 0.000). So, VR scores slightly higher in this section because of better learning promotion and richness in information availability.

4.6. Spatial situation model part score

Independent t-tests were used to compare SSMQ scores between the VR HMD and PC screen groups, meeting the assumptions of normality and homogeneity of variance. Participants who experienced VR reported marginally significantly higher SSMQ results than those in the PC screen condition (M±SD; PC: 32.6±5.9; VR: 37.0±4.4; t(20) = -1.20, p = 0.059) (Figure 3).

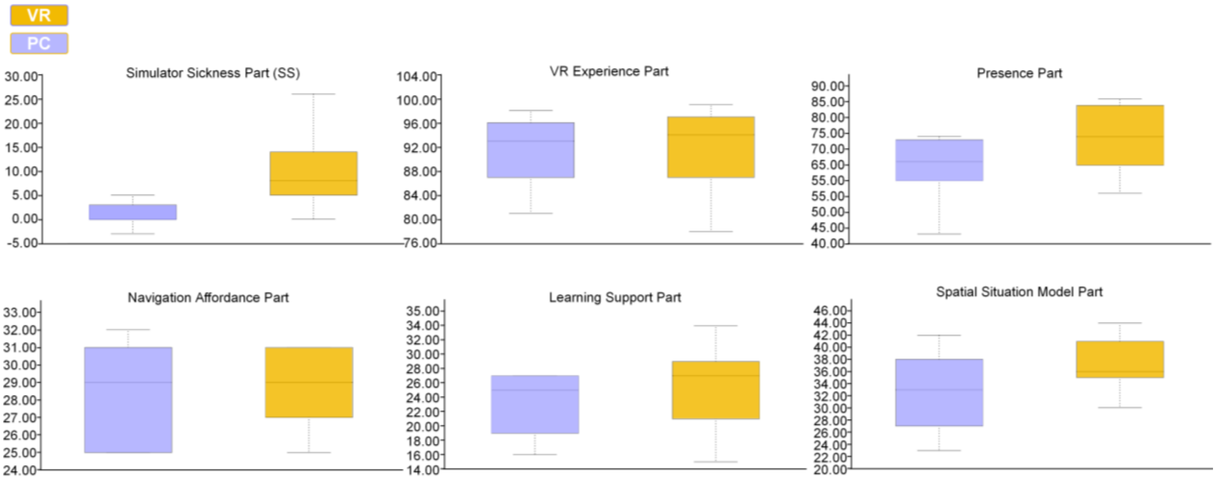

Figure 3. Boxplot of experimental results

5. Discussion

5.1. SS and Telepresence

VR HMD participants had higher telepresence but significantly more simulator sickness due to VR locomotion mode and the display field of view (DFOV) (Zhao et al., 2020). VR locomotion modes are roughly categorized as natural movement and continuous movement (Du et al., 2012). Natural movement relies on positional tracking, enhancing presence through embodied cognition, including vestibular and kinesthetic cues. In contrast, intuitive interaction involves handheld controllers or gloves, offering user agency. Both modes of egocentric access to the virtual environment can cause simulator sickness due to sensory conflicts in updating VR HMD displays (Moss et al., 2008).

The display field of view (DFOV) significantly impacts VR. Wider DFOV enhances presence but may induce more simulator sickness, magnifying visual and motion cue distortions outside the central projection area (Pausch et al., 1992). Desktops have smaller DFOV, maintained body stability and reduced simulator sickness.

5.2. User experience

Despite the VR group's increased presence, overall user experience scores, encompassing VR experience and Navigation affordance, weren't significantly higher than the PC screen group. VR enhances presence to improve emotions, engagement, and cognitive processing, aligning with prior research (Lee and Wong, 2014, Slater and Wilbur, 1997). Yet, heightened presence can intensify emotions and cause simulator sickness. So, while the VR group had a stronger presence, the user experience differences were modest.

5.3. Learning support

This study combines subjective learner perceptions and objective learning outcomes within a comprehensive evaluation framework to assess VR headsets and PC screens in architectural education. Subjective perceptions include learning promotion, richness in information availability, and perceived ease of use. Objective measures of learning outcomes include knowledge retention, especially about architectural structure details, decoration patterns, and spatial layout.

The evaluation framework revealed that both VR HMD and PC screen users excelled in learning outcomes, with VR users slightly outperforming in subjective learning perceptions. This suggests that the immersive nature of VR technology may increase motivation and fun for spatial learning, making space information more attractive. Combined with its advantages in spatial understanding, it is particularly suitable for enhancing learners' ability to visualize and comprehend complex spatial relationships, a key component of architectural education. Participants using PC screens experienced greater comfort, which correlated with previous better performance in SS, highlighting PC screens' accessibility and user-friendliness for learning content.

Nevertheless, the passion for VR environments for learning remains a subject of debate (Webster, 2016, Richards and Taylor, 2015). VR HMD users, captivated by engaging spatial information, might also prioritize other aspects over knowledge cues, indicating sensitivity doesn't guarantee better learning. Further research is needed on information acquisition and retention in virtual heritage sites.

5.4. Spatial situation model

HMDs excel in spatial perception via features like locomotion mode and DFOV, reducing cognitive load. VR's realistic scale and perspective also provide improved spatial awareness and help users grasp spatial relationships and distances between architectural elements. Stereoscopic vision is key to creating a 3D representation (Slater and Wilbur, 1997). VR's two separate, slightly offset images for each eye simulate natural perspective differences, enhancing architectural spatial understanding (Lin et al., 2008). In contrast, traditional screens lack this depth, as both eyes see the same image.

6. Conclusion

This study embarked on an exploration of the comparative effectiveness of VR headsets and PC screens as media for visualizing serious games in the context of ancient Chinese architectural education. The findings suggest that VR HMDs do not unequivocally surpass PC screens in terms of overall learning effectiveness, but slightly higher motivation was observed in the VR HMD group. They offer a more immersive and engaging experience, potentially enhancing VR HMDs in conveying spatial information, enhancing spatial models, and deepening architectural understanding. Still, this spatial awareness and emotional connection increased sensitivity does not necessarily result in improved learning outcomes. VR head-mounted displays (HMDs) enhance presence but carry an increased risk of simulator sickness compared to PC screens, which are influenced by locomotion mode and the display's field of view. That is why VR promotes emotional engagement but does not significantly surpass the overall user experience.

This research offers a foundation for further exploration into the pedagogical strategies that can leverage the unique capabilities of VR headsets and PC screens. While VR's immersive potential enhances comprehension of architectural complexities, its use must be balanced against potential simulator sickness. PC screens offer a user-friendly alternative suitable for messaging that requires less spatial sense. Their effectiveness is contingent upon the specific educational context and learning objectives. The study's value lies in Providing educators and curriculum designers with evidence-based insights into the strengths and limitations of VR headsets and PC screens, guiding the integration of these technologies into architectural education curricula. Future studies are encouraged to expand on this work, exploring broader educational settings and long-term effects to fully ascertain the potential of different interfaces in shaping the future of architectural education.

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