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Using Virtual Reality to Enhance Learning Performance and Address Educational Resource Disparities in Architectural History Courses

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Abstract: Field surveys are an important component of architectural history courses, but they are challenging for students with limited resources or geographical constraints. This paper aims to explore the potential of virtual reality (VR) technology as a solution to this problem by testing its impact on student learning performance in an architectural history course. Dule Temple, a heritage building, is used as a case study to construct a VR environment with options for ground-based or free movement modes. A total of 102 third-year architecture students participated in the study, experiencing the VR environment and completing a survey. From the results, the VR scene's level of detail achieved high levels of satisfaction. For learning performance, the results present the remarkable interestingness and effectiveness of VR in architectural history education. VR provides a comprehensive learning experience, enhancing the understanding of historical context, architectural styles, and spatial relationships. These findings show VR's transformative potential as an educational medium, complementing and, in some respects, surpassing traditional approaches such as field surveys, 2D materials, and physical scale models. However, the study emphasizes that VR should not entirely replace traditional teaching methods. Instead, combining the strengths of VR and conventional techniques offers a balanced and effective strategy for architectural education. VR offers a transformative approach to address the imbalance of educational resources and realize sustainable education.

Keywords: virtual reality; architectural history; sustainable education; heritage building; educational resource

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1. Introduction

In recent years, virtual reality (VR) has emerged as a transformative force across various industries [1]. While formally defined in 1992, the concept of VR has undergone significant evolution, with contemporary definitions characterizing it as an interactive medium that immerses users in computer-generated environments, amplifying sensory feedback to create a heightened sense of presence. VR is a fundamental technology that facilitates the creation of immersive, realistic user experiences. It enables the simulation of environments that users can perceive and interact with as though they were physically present [2]. The history of VR reflects ongoing technological advancements and the growing integration of virtual experiences into everyday life. Today, VR technologies have found widespread applications across diverse sectors, including entertainment [3], education [4], and specialized field [5–7].

In the educational realm, VR is increasingly utilized for business training, as well as within higher education and schools [8]. The 1980s witnessed a surge in interest in VR for professional education and training, with the 1990s introducing notable initiatives such as Science Space Worlds, marking VR's early integration into higher education. The significance of VR in educational settings lies in its capacity to provide immersive experiences that traditional pedagogical methods cannot easily replicate. VR enables learners to engage with complex scenarios and environments that might be otherwise restricted by physical constraints. For instance, it facilitates virtual fieldwork, reducing the necessity for physical excursions while enhancing the educational experience [9]. Moreover, VR offers educators the ability to customize instructional content to accommodate diverse learning styles and individual needs, further enriching the learning process [10,11].

In architectural education, VR offers notable advantages, particularly in subjects that rely on spatial and temporal understanding [12]. Architectural history courses, which often require the memorization and comprehension of 3D building components and the sequential development of structures, can be challenging due to their theoretical nature [13]. The large volume of factual information students are expected to retain can make the learning process overwhelming and disengaging. VR, however, offers a promising solution by providing immersive experiences that facilitate a deeper grasp of historical contexts and architectural details [14]. By engaging multiple senses, VR enhances interaction, spatial awareness, and imagination, transforming the learning process into a more dynamic and enjoyable experience. This shift from passive, one-dimensional instruction to active, bidirectional engagement significantly improves students' cognitive processes, enhancing both retention and comprehension [15]. VR's ability to immerse students in historical environments fosters a more profound and efficient understanding of architectural history, making it a valuable tool in overcoming the challenges of traditional learning methods.

VR has increasingly been integrated into architectural education. Sun et al. [16] explored the role of user interface (UI) design in VR applications for architectural education, aiming to enhance student engagement. Their experiments, conducted with 120 students, revealed significant variations in learning interest and performance based on different UI designs. Ibrahim et al. [17] investigated the impact of VR on architectural history classes and found that VR significantly enhanced students' analytical and critical thinking skills. Similarly, Shanti et al. [18] highlighted the potential of VR as an additional learning tool for architectural theory, promoting an immersive, blended learning experience that broadens students' perspectives. Chan et al. [19] examined the use of VR for teaching architectural history, using the Pantheon in Rome as a case study to assess the effectiveness of VR for remote learning, demonstrating positive student learning outcomes. While recent studies have focused on the use of VR to enhance student motivation and satisfaction, particularly in architectural education, there is still a need for further research on the specific impacts of VR on learning performance in architectural history courses.

Quantitative methods are crucial for evaluating students' learning performance in VR settings [20]. Increasing empirical research in cognitive and computer sciences has focused on understanding the human and technological factors that shape spatial perception in virtual environments. Since the fundamental element of VR is the user, and its definition hinges on the user's sense of presence within a virtual world, it is essential that assessments of VR's effectiveness be based on measures of user experience and performance. The success of any virtual environment is determined by how closely it replicates the perceptual processes that occur in the real world, allowing users to perceive virtual environments in a similar way to physical spaces. Additionally, the benefits of any new technology or tool can only be meaningfully assessed through comparison. Comparative evaluation studies are considered more reliable than self-assessment methods, as they introduce an objective

perspective, providing a clearer understanding of how VR compares to traditional learning methods in enhancing educational outcomes.

Therefore, this research investigates how VR tools influence students' learning performance in architectural history courses, particularly in terms of interestingness and effectiveness. It examines whether VR technology can address challenges posed by limited access to educational resources, such as field surveys and physical models, in architecture education. Additionally, it explores whether VR potentially contributes to addressing educational resource disparities. The structure of the paper is shown as follows: Section 2 provides the theoretical basis and Section 3 shows a case study of Dule Temple. The methodology is shown in Section 4. In Section 5, the results are provided. Section 6 gives the discussion.

2. Theoretical Basis

Virtual reality (VR) holds significant potential as a sustainable and cost-efficient tool in education. Despite extensive research into its application in architectural education, there remains a lack of agreement on how VR can be systematically integrated into existing curricula as an instructional approach. Furthermore, the role of VR in overcoming the persistent challenges faced in architectural education has yet to be clearly defined. This highlights the urgent need for a comprehensive review to evaluate the effectiveness of VR technologies and to establish practical frameworks for their adoption within architectural education.

2.1. Learning Theories and the Role of VR in Architectural Education

In architectural education, students engage in solving a sequence of design problems, emphasizing "learning by doing" rather than analytical problem solving [21]. Instructional strategies encompass a broad range of techniques employed by educators to enhance students' comprehension and mastery of course material. The "Situated Learning Model," developed by Jean Lave and Etienne Wenge [22], emphasizes immersion in activities and the application of problem-solving skills in real-world learning scenarios. This model forms the basis for approaches such as experiential learning and learning by doing, both of which highlight the preference for active participation and hands-on experiences in fostering deeper learning among students.

Mayer's cognitive theory [23] of multimedia learning emphasizes that combining visual and verbal elements enhances learning outcomes compared to relying on text alone. This is attributed to the limited capacity of the auditory and visual channels to process information independently. The theory outlines a multi-step process: filtering relevant words and images, constructing coherent verbal and visual representations, and integrating these representations with existing knowledge. This framework highlights the value of VR technology in education, particularly in architectural history [18]. VR offers a transformative approach to learning by immersing students in interactive virtual environments, allowing them to explore historical sites in detail. It serves as a potential alternative to physical visits, enabling students to grasp the scale, significance, and intricate details of architectural heritage while contributing to its preservation [19]. Despite its potential, concerns persist regarding the effectiveness of teaching history in virtual settings. Additionally, technical and practical challenges may limit the seamless integration of VR into architectural curricula, raising questions about its viability for achieving educational goals [17].

2.2. Limitations in Architectural History Courses and VR Advantages

In traditional architectural history education, knowledge acquisition has primarily relied on images, videos, and on-site surveys [24]. While these methods are valuable, they face significant limitations. Many heritage buildings are geographically distant or

fragile, making physical access challenging or impractical. Even when accessible, students often struggle to gain a holistic understanding of the entire structure due to restricted observation opportunities. Two-dimensional media, such as photographs and videos, are effective for showcasing specific details but fall short of offering an immersive learning experience [25]. They fail to convey the dynamic interplay between buildings and their surrounding environments—an essential aspect of architectural heritage. Furthermore, reliance on static imagery can lead to incomplete spatial understanding, as students are often required to mentally reconstruct unseen parts of the structure or urban context based on limited visual information [26]. This abstraction process varies widely among individuals and may result in interpretations that deviate from the actual physical reality.

VR is emerging as a transformative tool in architectural history education, offering students an immersive and highly detailed perspective of architectural heritage [15]. With 360-degree visualization, VR enables students to experience historical sites with near-real-life fidelity, fostering a deeper understanding of architectural elements and historical contexts. By immersing students in a simulated historical moment, VR replicates the benefits of in-person visits, allowing them to closely examine architectural details and spatial relationships as they would during a physical tour of a city or site [27]. This approach also addresses logistical challenges by reducing the need for time-intensive and costly field trips, particularly to distant or international locations. Field trips have long been a cornerstone of architectural education, providing students with essential human-scale experiences. However, VR is increasingly recognized as a valuable complement to traditional teaching methods, enhancing lecture-based learning and helping students to achieve more robust learning outcomes. Despite its potential, the adoption of VR in architectural history education remains limited, highlighting the need for broader integration and research to fully harness its capabilities.

2.3. Research Target

The main target of this study is to evaluate the effectiveness and interestingness of VR as a teaching tool for architectural history education to promote the learning performance of students. By integrating an immersive VR experience, this study aims to improve students' understanding of architectural heritage, focusing on key aspects such as historical context, architectural detail, and spatial scale. Through the case study of Dule Temple, this study aims to provide empirical insights into the potential of VR to complement or exceed traditional teaching methods such as 2D materials, field investigations, and physical scale models. Finally, this research hopes to establish a balanced pedagogical strategy that uses the unique strengths of VR while maintaining the fundamental strengths of traditional educational methods.

3. Case Study

Dule Temple was selected as a case study.

3.1. Course Introduction

The course "History of Chinese Architecture" is one of the basic courses of a major in architecture (Figure 1). It aims to familiarize students with the basic historical facts of the development and evolution of ancient Chinese architecture through various teaching links and master the characteristics and methods of ancient architectural planning and design. The course content covers aspects such as architectural theory, architectural art, and architectural technology.



Figure 1. The scene in class.

One of the main parts of the course "History of Chinese Architecture" is gaining an in-depth understanding of traditional Chinese architectural forms, which is the basis for students to learn Chinese architectural culture. This part of the course not only involves the rich forms of Chinese architecture in different eras and regions but also explores the historical background and cultural driving force of its formation and evolution. Through the analysis of architectural forms, students can intuitively understand the spatial layout, structural characteristics, and decorative style of traditional Chinese architecture and deeply understand the close relationship between architecture, social culture, and the natural environment.

Through systematic analysis and case explanation, the course focuses on the diversity of traditional Chinese architectural forms and the cultural connotations behind them. For example, through the study of the major types, such as palaces, religious buildings, folk houses, gardens, and defensive buildings, students can fully grasp the overall style of traditional Chinese architecture. At the same time, the course also focuses on the interpretation of details, including the craftsmanship of the wooden structure system, the design logic of the brackets, and the cultural symbolic significance of the roof form. In this way, students can not only feel the beauty of the building but also understand its deep design intention and cultural expression.

In addition, the course emphasizes the combination of theory and practice and enables students to connect classroom knowledge with actual cases through field research, historical document analysis, and digital restoration. This teaching method not only cultivates students' observation and analytical skills but also strengthens their mastery of architectural history research methods.

Through systematic study of traditional Chinese architectural forms, students can not only master their structural characteristics and design concepts but also understand the cultural logic and value system behind these forms. For example, how architectural forms reflect the ritual ideas of ancient China, how Feng Shui concepts influence site selection and design, and how to adapt to the regional environment. This knowledge will help students to better inherit and innovate Chinese architectural culture in modern architectural design and protection practice, and it lays a solid foundation for further architectural research and practice.

3.2. Dule Temple

Dule Temple, located at No. 41 Wuding Street in Jizhou District, Tianjin, spans an area of approximately 16,000 square meters (Figure 2). Recognized as one of the first national key cultural relic protection units, it is also designated as a historical building with special protection status by the Tianjin Municipal Government. Additionally, it is situated within a designated historical and cultural block in Tianjin and holds the distinction of being a national AAAA-level scenic spot.

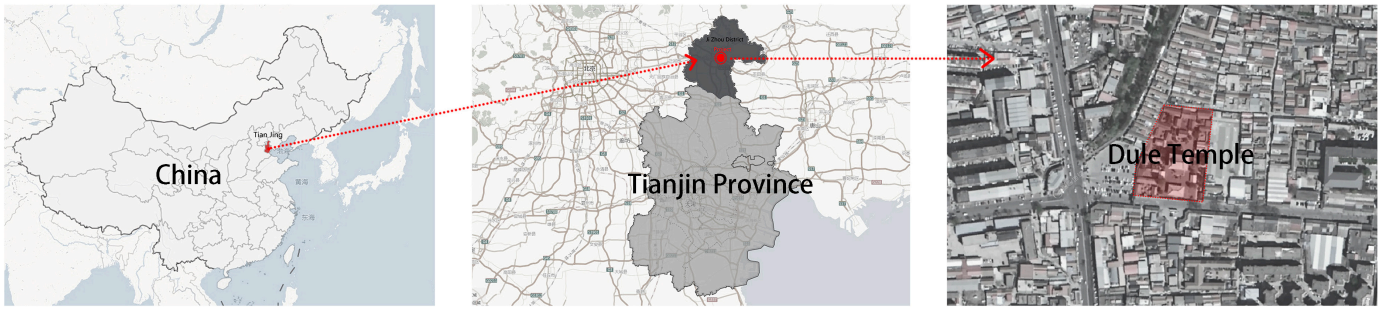

Figure 2. Location of Dule Temple.

The temple (Figure 3) is believed to have originated during the Tang Dynasty and was reconstructed in the second year of Tonghe during the Liao Dynasty (984). Among the surviving structures from the Liao period are the Shanmen (Mountain Gate) and the Guanyin Pavilio, making Dule Temple one of only three extant Liao Dynasty temples in China.



(a) (b)

Figure 3. Dule Temple. (**a**) The main building. (**b**) Indoor of the building.

The Shanmen measures three bays in width (16.63 m) and two bays in depth with four rafters (8.76 m). It features a single-eaved, four-sloped roof supported on a stone platform. North of the Shanmen lies the Guanyin Pavilion, also reconstructed during the Liao Dynasty in 984. The pavilion measures five bays in width (20.23 m) and four bays in depth (14.26 m). Externally, it appears as a two-story structure, with an additional circle of eaves at mid-height, and is crowned by a hip roof. Internally, the pavilion contains three levels, including a mezzanine, which houses a 16 m high, 11-faced Guanyin statue. The hollow structure is encircled by two levels of corridors, showcasing an innovative spatial layout and design.

Constructed as a wooden structure, the architecture of Dule Temple is characterized by its structural division into pillars, brackets, and beams. The brackets serve as the primary

load-bearing elements. The temple's architectural style is reminiscent of Tang Dynasty traditions, evident in its deep eaves and the imposing, robust design of its brackets. This combination of structural ingenuity and aesthetic grandeur underscores the cultural and historical significance of Dule Temple.

Dule Temple is the oldest wooden structure in China, with important historical and architectural significance. The selection of Dule Temple as the case in this study is mainly based on the following reasons: First, Dule Temple is a pyramid of traditional Chinese architecture, and its architectural style and craftsmanship reflect the unique charm of Song Dynasty wooden structures. Its main hall is famous for its exquisite proportions and complex bracket structure, which provides a valuable case for studying the structure and decoration of ancient Chinese architecture. Second, the rich cultural and historical background of Dule Temple not only carries religious significance but also reflects the social, political, and cultural environment at that time. Through virtual reality technology, the architectural details and historical background of Dule Temple are delivered, and students can obtain a more comprehensive understanding of the cultural connotation and contemporary significance of ancient buildings. In addition, the spatial layout and architectural details of Dule Temple can fully demonstrate the spatial structure and craftsmanship details of traditional buildings, which is very suitable for teaching architectural history courses. Through VR technology, students can carefully observe the appearance, internal structure, and detailed decoration of the building in a virtual environment and enhance their understanding and interest in historical buildings. In summary, choosing Dule Temple as a case study can not only reflect the multi-dimensional teaching objectives of architectural heritage education but also provide a specific and representative practical scenario for the application of VR in historical architectural education.

4. Methodology

This section details the construction of the VR scene, followed by an overview of the survey design and the questionnaire used to evaluate the VR experience and learning experience.

4.1. Construction of VR Scene

To deliver an engaging VR experience, this study integrated both hardware and software components. The Oculus Quest 2 platform, developed by Reality Labs, served as the primary hardware. It included a head-mounted display and hand-held controllers, enabling users to interact with the VR environment via natural head, body, and hand movements. For an optimal room-scale experience, a minimum clear area of 4 m by 4 m was recommended. Given the computational demands of rendering high-quality VR environments, the system employed met the necessary specifications to ensure a realistic and immersive experience. To evaluate the perceived realism, a participant survey was conducted, focusing on the current VR quality. The virtual scenes, depicted in Figure 4, were enhanced with an authentic soundscape, captured from the district's surroundings and integrated into the VR environment for added immersion.

The virtual model of Dule Temple was constructed using a combination of advanced modeling tools and techniques to ensure accuracy and fidelity. The process began with the collection of detailed architectural drawings and photographs of Dule Temple. These resources were used to create a base model in AutoCAD 2024, capturing the precise dimensions and layout of the structure. The model was then imported into SketchUp Desktop 2024 for detailed architectural modeling, including the intricate wood structures and ornamentation characteristic of traditional Chinese architecture. To enhance the realism of the VR experience, sounds were recorded on-site at the temple, capturing ambient noises such as wind through the wooden beams and the subtle sounds of nature in the surrounding

environment. Furthermore, the VR experience begins with an audio-guided introduction, which was pre-recorded based on the historical background of the temple and tailored to align with the course objectives. This model was subsequently exported to Unity 6, where lighting, materials, and interactive elements were added to create an immersive and educational virtual environment. This comprehensive workflow ensured that the VR scenes not only maintained architectural accuracy but also provided an engaging, context-rich learning platform.



Figure 4. VR scenes for Dule Temple.

The VR experience was designed to offer users two distinct movement modes: on-ground movement and free movement. In the on-ground mode, users navigate through the environment using the joystick on the hand-held controllers, enabling a natural and intuitive transition between locations. This mode restricts movement to ground level, providing users with a realistic, true-to-life perspective. By contrast, the free movement mode allows users to fly freely within the virtual space, granting access to a comprehensive 360-degree view. This mode is particularly beneficial for observing intricate details of heritage buildings that may be inaccessible from ground level. At the initial interface of the VR experience, users can select either movement mode. The VR environment created for this study allowed participants to navigate the renovated district and explore its underlying features in depth. At the beginning of the VR tour, there is an introduction to provide the historical context of the heritage building.

4.2. Satisfaction

The assumption of a shared understanding among individuals often proves to be less universal than anticipated, with differences emerging subtly or, at times, manifesting as significant gaps. Users inherently bring their disciplinary perspectives and subjectivities into their experiences, which can influence their perceptions and evaluations. To assess the quality of the virtual environment and the representation of heritage buildings in VR, this study incorporates the concept of satisfaction as a key metric.

Satisfaction has been extensively explored in prior research, with multiple definitions and frameworks proposed. Three primary perspectives on satisfaction have been identified [28]. The first, known as the purposive approach, views satisfaction as the extent to which a product or experience supports users in achieving their goals. The second, the actual-aspiration gap approach, evaluates satisfaction based on the discrepancy between users' current and desired states. The third perspective defines satisfaction as a multi-

dimensional construct encompassing cognitive, affective, and conative elements, which collectively shape an individual's attitude toward the subject. This study adopts the second perspective, positing that participants assess the VR experience and learning performance in VR.

Satisfaction, as conceptualized here, arises from two key categories of factors: contextual—those related to the characteristics of the virtual environment and user experience—and compositional—those associated with user demographics and predispositions. These factors influence satisfaction either directly or indirectly by shaping users' subjective evaluations of specific attributes, which in turn affect overall satisfaction.

In this study, based on satisfaction theory, we extended it to "interestingness" and "effectiveness" to evaluate the VR tool in the architectural history course. By this way, this study not only evaluates the satisfaction of VR tools but also their interestingness in enhancing the experience of heritage buildings and their effectiveness in enhancing the understanding of architectural details and context. The dual emphasis on these dimensions allows for a comprehensive analysis of how VR fosters engagement and facilitates learning, addressing both the experiential and educational aspects that are critical to its success in academic settings.

Satisfaction theory provides a robust framework to evaluate user experience by examining how different dimensions of satisfaction—cognitive and affective—contribute to overall perceptions. In the context of this study, these dimensions underpin the evaluation of VR's "interestingness" and "effectiveness" as follows:

Cognitive Dimension: This dimension pertains to the knowledge and understanding gained through the VR experience. The detailed representation of architectural elements, spatial scale, and historical context in the VR environment directly engages students' cognitive faculties. This aligns with the "effectiveness" of VR in enhancing learning outcomes, as it provides a platform for students to comprehend complex architectural concepts in a more intuitive and accessible manner.

Affective Dimension: The affective aspect relates to the emotional responses elicited by the VR experience. The immersive nature of VR, its ability to create a sense of presence, and its interactive features contribute to heightened engagement and enjoyment. This directly influences the "interestingness" of the VR tool, making learning more appealing and motivating for students.

By integrating these dimensions, satisfaction theory offers a comprehensive lens through which the strengths of VR as an educational tool can be evaluated, connecting theoretical constructs to practical outcomes in architectural history education.

4.3. Survey and Questionnaire

Pilot survey: Prior to distributing the formal questionnaire, a pilot survey and brief interviews were conducted with five architecture students. The objective of this pilot phase was to evaluate the questionnaire's suitability regarding length, clarity of terminology, question phrasing, and comprehensiveness of relevant factors. Additionally, the questionnaire was reviewed by five experts specializing in architecture education, virtual reality, educational assessment, and usability. Their feedback led to significant revisions aimed at enhancing the instrument's ability to assess the desired dimensions effectively. Modifications based on the pilot feedback included reordering questions for better logical flow and refining ambiguous items to improve clarity.

Formal questionnaire: The finalized questionnaire consisted of 34 questions organized into four sections: (1) Personal Data: Age and gender; (2) VR Experience: Users' engagement with the VR environment; (3) VR Satisfaction: Evaluations of the quality of the VR experience. In alignment with the principles outlined in key documents for

building heritage, including the Venice Charter, London Charter, Principles of Seville, and Xi'an Declaration, three critical criteria are selected to evaluate the representation of heritage buildings within the VR environment: clearness, realism, and detail [28]. The average satisfaction rating across these dimensions was used to quantify the perceived quality of the reconstruction; (4) Learning Experience: Assessment of how VR influenced participants' educational outcomes. The assessment focused on the interestingness and effectiveness of VR education compared to 2D materials, field surveys, and 1:1 scale models. Responses were recorded on a five-point Likert scale (1: Strongly Disagree, 2: Disagree, 3: Neutral, 4: Agree, 5: Strongly Agree). The questionnaire, detailed in Table 1, covered various aspects, including preferences for movement modes, discomfort levels, realism of the VR environment, and the perceived effectiveness of VR in enhancing architectural history lessons.

Table 1. Questionnaire.

Questions	
Personal data:	
Gender	Male/Female
Age	
VR experience:	
Did you experience VR before?	Yes/No
Which movement mode do you prefer?	Ground movement/Free movement
You feel dizzy or sick in VR.	1–5
VR operation is user friendly.	1–5
You encourage the use of VR in architectural education.	1–5
VR satisfaction:	
How satisfied are you with the three aspects of VR scene?	1–5
Clearness	1–5
Realism	1–5
Detail	1–5
Learning experience:	
Interestingness	
It is interesting to use VR in architecture class.	1–5
It is interesting to learn architectural heritage by VR.	1–5
It is interesting to learn architectural details by VR.	1–5
It is interesting to experience heritage buildings by VR.	1–5
It is interesting to use 2D materials in architecture class.	1–5
It is interesting to learn architectural heritage by 2D materials.	1–5
It is interesting to learn building details by 2D materials.	1–5
It is interesting to experience heritage buildings by 2D materials.	1–5
It is interesting to use field survey in architecture class.	1–5
It is interesting to learn architectural heritage by field surveys.	1–5
It is interesting to learn building details by field surveys.	1–5
It is interesting to experience heritage buildings by field surveys.	1–5
It is interesting to use 1:1 scale models in architecture class.	1–5
It is interesting to learn architectural heritage by 1:1 scale models.	1–5
It is interesting to learn building details by 1:1 scale models.	1–5
It is interesting to experience heritage buildings by 1:1 scale models.	1–5

Table 1. *Cont.*

Questions	
Effectiveness	
VR is helpful to understand architectural details.	1–5
VR is helpful to understand architectural styles.	1–5
VR is helpful to understand heritage spatial scale.	1–5
VR is helpful to understand historical context.	1–5
2D materials are helpful to understand architectural details.	1–5
2D materials are helpful to understand architectural styles.	1–5
2D materials are helpful to understand heritage spatial scale.	1–5
2D materials are helpful to understand historical context.	1–5
Field surveys are helpful to understand architectural details.	1–5
Field surveys are helpful to understand architectural styles.	1–5
Field surveys are helpful to understand heritage spatial scale.	1–5
Field surveys are helpful to understand historical context.	1–5
1:1 scale models are helpful to understand architectural details.	1–5
1:1 scale models are helpful to understand architectural styles.	1–5
1:1 scale models are helpful to understand heritage spatial scale.	1–5
1:1 scale models are helpful to understand historical context.	1–5
What else you wish to add?	

Participants: A total of 102 third-year architecture students participated in the study. The third-year students were selected for the study for the following reasons:

Course background matching: Third-year architecture students usually have taken some basic courses, such as architectural design foundation and architectural history theory, and have a certain understanding and knowledge of architectural history and spatial analysis, so they can better participate in VR learning related to architectural history and provide higher delayed feedback.

Instrumentality of learning stage: Third-year students are at a stage of transition from basic learning to advanced professional courses. At this stage, students need more complex tools and methods to assist in understanding the details and context of historical buildings. VR technology is an ideal tool for such learning.

Sample consistency: Students of the same grade can reduce the bias of experimental results caused by differences in learning stages. For example, first-year students may lack basic knowledge, while senior students may have mastered the relevant content.

Availability: Third-year students usually have the time and desire to participate in experiments because the course schedule at this stage is relatively flexible, which is suitable for additional learning activities and investigations.

All participants were informed that their involvement was voluntary, and data confidentiality was ensured. Prior to the survey, a training session on VR technology was conducted to familiarize participants with the system and minimize technological barriers. The study recorded the time taken by each participant to complete the VR tasks and the questionnaire. Survey scenes are depicted in Figure 5.

Validity test: To assess the internal consistency of the questionnaire, Cronbach's alpha was calculated. A value exceeding 0.70 is generally considered reliable. In this study, Cronbach's alpha was measured at 0.806, indicating a high degree of internal consistency among the items. This result validated the use of the questionnaire as a cohesive tool for evaluating VR-related factors and their impact on learning experiences.



(a) (b)

Figure 5. (**a**) Participants in the VR experience. (**b**) Scale model.

5. Results

5.1. Basic Information About the Participants

In October 2024, a questionnaire-based study was carried out during the architectural history class. Basic information about the participating students was gathered. The age of the participants was mostly 21 years old. There were 56 males and 46 females. The time required for students to complete the VR experience and questionnaire served as a key metric for evaluating the usability and accessibility of the VR platform in architectural history education. Prolonged interaction times may indicate challenges in navigation or comprehension, which could hinder engagement and learning outcomes. Additionally, tracking these durations is instrumental in logistical planning, such as estimating the number of VR devices required to efficiently accommodate all participants. Therefore, examining the factors influencing the VR experience duration is essential for optimizing both the system's design and its practical deployment. This study focused on analyzing the impact of individual differences, such as prior exposure to VR and architectural knowledge, on the time required to complete the VR operation.

The relationship between "Did you experience VR before?" and the time required to complete learning process in VR environment was analyzed, as shown in Table 2. The relationship did not show a statistically significant correlation (p-value: 0.041) in the independent samples t-test. For the students who experienced VR before, the mean VR operation time was 5.4 min (Std. Deviation: 1.2). For the students who never used VR before, the mean VR operation time was 5.8 min (Std. Deviation: 1.0). The findings indicated that students can efficiently adapt to VR technology following a brief introductory session, irrespective of students' prior exposure to the technology. Furthermore, the intuitive and user-friendly design of the VR interface enhances its suitability for educational applications.

Table 2. The relationship between VR experience and time taken to complete the VR tour.

Questions	Mean (Min)	Std. Deviation	Sig.
Experienced VR	5.4	1.2	
Never experienced VR	5.8	1.0	
			0.041

5.2. VR Experience

The VR experiences of students were investigated. Among the participants, 36 had no prior experience with VR technology. As for the operation, only 23.5% of participating students selected "preferred the on-ground movement mode." After the questionnaire survey, we interviewed the participants. They claimed that both movement modes were good for observing the heritage buildings, although the experiences of the different movement

modes were different. Student A mentioned "The on-ground movement mode provides an authentic perspective aligned with human-scale observation, allowing us to engage with architectural design as it would appear in real-world settings." It proves that the on-ground movement mode is particularly effective for analyzing spatial relationships, understanding the flow of movement within a structure, and assessing design elements from a pedestrian's viewpoint. By contrast, the free mode enables users to "fly" and navigate freely within the virtual space, offering an unrestricted range of viewpoints. This capability facilitates the exploration of perspectives that are otherwise unattainable, such as aerial views or close-up inspection of intricate details located at significant heights. It enhances students' comprehension of the overall form, structural composition, and hidden features of buildings, fostering a more holistic understanding of the design. By combining these modes, the VR platform enables students to gain a comprehensive understanding of architectural structures, bridging the gap between a realistic perspective and an exploratory perspective.

The survey results revealed that VR sickness remained a concern for students, as indicated by a mean score of 2.8 (standard deviation: 1.1) for the statement "You feel dizzy or sick in VR." Notably, four participants rated this aspect at the highest level (5), signifying significant discomfort during the VR experience. Despite this, the usability of the VR system was positively received; 89 participants rated "VR operation is user friendly" at the highest level (5), underscoring the device's user-friendly interface and its suitability for teaching and learning contexts. Furthermore, the statement "You encourage the use of VR in architectural education" achieved a mean score of 4.5, reflecting students' overwhelmingly positive attitudes and strong support for integrating VR into architectural history education. These findings highlighted both the promise of VR as an educational tool and the need to address issues related to user comfort.

5.3. VR Satisfaction

The evaluation of participant satisfaction with the heritage building in the VR environment encompassed three dimensions, with the mean satisfaction scores summarized in Table 3. For the clearness of the virtual environment and heritage building, the mean satisfaction score was 4.1 (standard deviation: 1.3). Realism received a slightly lower mean score of 3.9. Among the three aspects, clearness obtained a low satisfaction level, with participants expressing a preference for more refined rendered scenes. Conversely, the detail of the VR scene achieved the highest satisfaction score, with a mean value of 4.5 and a standard deviation of 0.8, reflecting consistently high approval among participants. These findings underscored the importance of enhancing visual clarity while maintaining the detailed representation that users highly value.

Table 3. VR satisfaction.

Question	Mean	Std. Deviation
How satisfied are you with the three aspects of VR scene?		
Clearness	4.1	1.3
Realism	3.9	1.0
Detail	4.5	0.8

5.4. Learning Experience

This study evaluated the perceived interestingness and effectiveness of VR as a learning tool in an architectural history course, comparing it with traditional methods such as 2D materials, field surveys, and 1:1 scale models. The results are shown in Table 4.

Table 4. Results of interestingness and effectiveness of VR.

Questions	Mean	Std. Deviation
Interestingness		
It is interesting to use VR in architecture class.	4.4	0.5
It is interesting to learn architectural heritage by VR.	4.6	0.4
It is interesting to learn architectural details by VR.	4.7	0.4
It is interesting to experience heritage buildings by VR.	4.3	0.8
It is interesting to use 2D materials in architecture class.	3.3	1.2
It is interesting to learn architectural heritage by 2D materials.	3.8	0.9
It is interesting to learn building details by 2D materials.	3.5	0.6
It is interesting to experience heritage buildings by 2D materials.	2.3	0.8
It is interesting to use field surveys in architecture class.	4.7	0.4
It is interesting to learn architectural heritage by field surveys.	4.6	0.4
It is interesting to learn building details by field surveys.	4.7	0.5
It is interesting to experience heritage buildings by field surveys.	4.8	0.4
It is interesting to use 1:1 scale models in architecture class.	4.1	0.5
It is interesting to learn architectural heritage by 1:1 scale models.	3.5	0.8
It is interesting to learn building details by 1:1 scale models.	4.6	0.4
It is interesting to experience heritage buildings by 1:1 scale models.	3.1	1.0
Effectiveness		
VR is helpful to understand architectural details.	4.8	0.4
VR is helpful to understand architectural styles.	4.6	0.5
VR is helpful to understand heritage spatial scale.	4.8	0.4
VR is helpful to understand historical context.	4.8	0.4
2D materials are helpful to understand architectural details.	4.2	0.8
2D materials are helpful to understand architectural styles.	3.8	1.1
2D materials are helpful to understand heritage spatial scale.	2.1	0.6
2D materials are helpful to understand historical context.	4.0	0.4
Field surveys are helpful to understand architectural details.	4.8	0.4
Field surveys are helpful to understand architectural styles.	4.8	0.5
Field surveys are helpful to understand heritage spatial scale.	4.8	0.5
Field surveys are helpful to understand historical context.	3.6	1.2
1:1 scale models are helpful to understand architectural details.	4.8	0.5
1:1 scale models iare helpful to understand architectural styles.	2.4	0.9
1:1 scale models are helpful to understand heritage spatial scale.	3.2	1.5
1:1 scale models are helpful to understand historical context.	2.3	0.7

The results revealed a strong preference for VR as an engaging tool in the architectural history course, with an average score of 4.5 out of 5 for the "interestingness" dimension. While field surveys achieved the highest score of 4.7, underscoring their enduring appeal and effectiveness in providing hands-on learning experiences, VR emerged as a close second, demonstrating its potential as a compelling alternative. By contrast, 2D materials scored considerably lower, with an average of 3.2, highlighting their limited ability to captivate students. The 1:1 scale models performed moderately, achieving an average score of 3.8, indicating that while they offer some degree of engagement, they may not fully resonate with students compared to immersive or interactive methods like VR.

For the question "It is interesting to use [method] in architecture class?", students rated VR highly (mean = 4.4, SD = 0.5), reflecting its engaging nature. While field surveys scored slightly higher (mean = 4.7, SD = 0.4), the logistical constraints of fieldwork limit its applicability. By contrast, 2D materials received a much lower score (mean = 3.3, SD = 1.2), suggesting that static representations lack the dynamism provided by VR. For learning

architectural heritage, VR and field surveys were equally effective (both mean = 4.6). This result highlighted VR's ability to convey historical and cultural contexts in a compelling way, rivaling the authenticity of on-site experiences. VR scored the highest for learning architectural details (mean = 4.7, SD = 0.4), on par with field surveys (mean = 4.7, SD = 0.3) and slightly ahead of 1:1 scale models (mean = 4.6, SD = 0.4). This result demonstrated VR's capacity to render intricate architectural elements with precision while maintaining an engaging environment. The 2D materials scored significantly lower (mean = 3.5, SD = 0.6), underscoring the limitations of flat, static visuals in conveying complex details. Field surveys scored the highest in this category (mean = 4.8, SD = 0.3), emphasizing their unparalleled authenticity in creating immersive experiences. However, VR also performed strongly (mean = 4.3, SD = 0.8), offering a viable alternative when physical site visits are impractical. By contrast, 2D materials (mean = 2.3, SD = 0.8) and 1:1 scale models (mean = 3.1, SD = 1.0) were less effective in providing engaging learning experiences, likely due to their lack of spatial and sensory depth.

VR demonstrated exceptional effectiveness as a learning tool in the architectural history course, achieving an average score of 4.8 out of 5. This high rating underscored VR's capacity to enhance understanding across diverse aspects of architectural heritage, including details (mean = 4.8, SD = 0.4), spatial scales (mean = 4.6, SD = 0.4), styles (mean = 4.6, SD = 0.5), and historical context (mean = 4.8, SD = 0.4). Its immersive and interactive nature likely plays a pivotal role in fostering deeper comprehension and engagement.

Field surveys followed with an average score of 4.5. Despite their authenticity and tactile learning benefits, the method received a comparatively lower score (mean = 3.6, SD = 1.2) for the question, "Field surveys are helpful to understand historical context." This shows that while field surveys excel in conveying physical and spatial aspects of architecture, they may lack sufficient contextual or interpretive elements. By contrast, the introduction of historical background at the beginning of the VR tour effectively makes up for this shortage. The 2D materials, with an average score of 3.5, revealed clear limitations in fostering an effective learning experience. The static nature of 2D materials can limit students' ability to feel spatial scale (mean = 2.1, SD = 0.6) and understand architectural style (mean = 3.8, SD = 1.1), areas in which VR significantly performed better than other techniques. The results showed that traditional materials have difficulty conveying the depth and complexity of architectural heritage. Finally, 1:1 scale models received the lowest effectiveness score, averaging 3.2. Although scale models are able to provide tactile and visual insights, their limited scope and inability to convey architectural style (mean = 2.4, SD = 0.9) or historical context (mean = 2.3, SD = 0.7) may reduce their perceived utility. This result showed that scale models are less effective than VR, which is more dynamic and interactive.

Overall, the results present the remarkable effectiveness of VR in architectural history education, providing a multifaceted learning experience that incorporates spatial, stylistic, and contextual understandings. These findings reinforce the transformative potential of VR as a primary educational medium, complementing and, in some cases, surpassing traditional methods such as field surveys, 2D materials, and scale models.

5.5. Regression Results

In this section, the key determinants of the "interestingness" and "effectiveness" of VR in the architectural history course are identified through multivariate regression analysis. The dependent variables, interestingness and effectiveness, are represented as the mean values derived from responses to four relevant questions. The independent variables are VR experience factors, including "Did you experience VR before?", "You feel dizzy or sick in VR", and "VR operation is user friendly." The results are shown in Table 5.

Notably, variables like gender and age were excluded from the analysis because they showed no significant relationship with the interestingness and effectiveness of VR in the architectural history course. The regression models demonstrated a strong predictive capability, explaining 51.6% of the variance in interestingness (R^2 = 0.516) and 42.8% of the variance in effectiveness (R^2 = 0.428).

Table 5. Determinants of interestingness of VR in the architectural history course.

	Coeff.	St. Coeff.
Constant	4.5	
VR experience		
Did you experience VR before?	0.269 **	0.156
You feel dizzy or sick in VR.	−0.450 ***	−0.173
VR operation is user friendly.	0.215 **	0.12
R-squared	0.516	

* $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

Table 5 demonstrates that all three VR experience factors were significantly related to the level of interestingness in using VR for the architectural history course. Having prior experience with VR contributed an increase of 0.27 in interestingness. VR sickness was a significant negative predictor, reducing interestingness by 0.45. Furthermore, user-friendly VR operation positively influenced interestingness, with an increase of 0.22. These results underscored the importance of user experience in enhancing the perceived interestingness of VR as an educational tool in architectural history.

Table 6 reveals that the three VR experience factors were significantly related to the effectiveness level of using VR in the architectural history course. Specifically, experience with VR contributed an increase of 0.23 to effectiveness. VR sickness served as a statistically significant negative predictor, decreasing effectiveness by 0.17. Additionally, user-friendly VR operation positively impacted effectiveness, with an increase of 0.47.

Table 6. Determinants of effectiveness of VR in the architectural history course.

	Coeff.	St. Coeff.
Constant	4.75	
VR experience		
Did you experience VR before?	0.226 *	0.125
You feel dizzy or sick in VR.	−0.165 *	−0.08
VR operation is user friendly.	0.466 ***	0.181
R-squared	0.428	

* $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

6. Discussion

6.1. VR Application in Architectural Education

Based on the survey and interviews, VR effectively delivers the level of detail required for studying heritage buildings in architectural history courses. Hartmann et al. [29] highlighted the enduring value of physical prototyping in design representation, even with the rise of digital technologies. Physical models foster active engagement but often fall short in accurately conveying textures and materials due to their simplistic design. To address these limitations, integrating material samples that reflect real-world properties proved effective, emphasizing the importance of tactile references in enhancing visualization tools. By contrast, digital solutions such as architectural computer models and VR excel in providing higher fidelity, especially in terms of material realism. VR, in particular, offers an immersive environment where students can independently explore and grasp detailed

knowledge of heritage buildings. This self-directed learning approach minimizes the reliance on teacher intervention, demonstrating VR's capacity to revolutionize educational methodologies in architectural history.

Soliman et al. [30] pointed out that VR features can influence the experience. In this study, participants also mentioned "fresh soundscapes can create a more realistic environment. It makes me feel as if they are in the actual scene of the building." This immersion can enhance students' emotional connection with the learning content. "Narration provides rich clues for learning. It helps me better understand historical and spatial contexts and supplement cognitive learning."

Immersion is a critical factor in determining the effectiveness of VR as a learning tool, particularly in architectural history education. Pirker et al. [31] demonstrated that students' sense of immersion within VR environments plays a pivotal role in enhancing their motivation and focus during the learning process. Consistent with their findings, this study also revealed that immersion within the VR setting is a critical factor influencing student engagement and concentration. In this study, we found the same conclusion. The immersive qualities of the VR environment, such as the realistic representation of architectural details, spatial scale, and interactive elements, were designed to deeply engage students and facilitate active participation. Feedback from students highlighted that the immersive experience in VR heightened their interest and enthusiasm compared to traditional methods such as 2D materials or static models. The ability to explore heritage buildings interactively allowed students to focus more attentively on architectural details and historical context, fostering a sense of presence that is typically unattainable by conventional teaching methods. Moreover, the immersive nature of VR encouraged deeper cognitive engagement, enabling students to grasp complex architectural concepts more effectively. For example, navigating through a three-dimensional reconstruction of Dule Temple helped students to understand spatial relationships and contextual significance in a way that theoretical explanations or photographs could not achieve. These findings suggest that the immersive aspect of VR is not only a key contributor to enhancing students' learning motivation and focus but also serves as a powerful medium for delivering intricate architectural knowledge in an accessible and engaging manner.

As for the theoretical impact, this study applied the cognitive, affective, and intentional dimensions of satisfaction theory to the evaluation of educational technologies such as VR, expanding the scope of application of the theory. By combining satisfaction theory with learning performance indicators such as fun and effectiveness, we provide a theoretical framework for future research on the role of VR in education. In addition, this study revealed how VR technology affects students' learning motivation and concentration through immersion and interactivity, providing a new perspective for the field of educational psychology.

As for the practical impact, at the practical level, this study provides actionable insights for educators and policymakers. The results show that VR technology can effectively make up for the uneven educational resources in architectural history courses caused by geographical limitations or lack of resources. In addition, we also put forward specific suggestions for optimizing the design of VR tools, such as simplifying the operation process and enhancing immersive sound effects, to improve their educational value. These findings not only provide guidance for college course design but also provide a reference for building a more inclusive and attractive learning environment in underdeveloped regions.

While we advocate for incorporating VR into architectural history education, this recommendation does not suggest it should entirely replace traditional teaching methods, such as two-dimensional media or field research. This view is also supported by previous work [32]. Notably, students demonstrated significant engagement and informational

insights regardless of the teaching approach employed. Consequently, the optimal teaching methods for architectural history courses should be tailored to the specific context and learning objectives of each lesson. For instance, VR excels at providing a comprehensive understanding of structural attributes, such as dimensions and spatial relationships, offering students an immersive perspective. By contrast, physical prototypes facilitate tactile interaction and hands-on exploration, fostering a different dimension of learning. By leveraging the strengths of both VR and traditional methods, educators can create a balanced and effective teaching strategy.

6.2. Bridging Educational Inequities

VR technology has shown unique advantages in solving the problem of uneven distribution of educational resources in the field of architectural history education, as mentioned above. Field research is a particularly important part of architectural history courses. It is easier to achieve in areas with rich educational resources, but it is a big challenge for areas with scarce resources or large geographical restrictions. For example, it is difficult for students in remote areas to visit historical buildings in person, thus losing their intuitive feeling of the spatial scale, detailed craftsmanship, and cultural background.

VR technology provides a solution for students in these areas to make up for the limitations of reality by constructing highly restored virtual scenes. Through VR, students can "visit" historical buildings in an immersive way and gain an in-depth understanding of their architectural style, spatial layout, and cultural connotations without compromise due to insufficient resources or geographical barriers. This virtual teaching not only breaks down the limitations of time and space but also reduces the high cost of on-site teaching, allowing more students to have equal access to high-quality educational resources. However, previous research [33] also highlighted that economic constraints present significant barriers to the widespread adoption of VR technology, particularly in regions where financial resources are limited.

In addition, VR technology also provides new possibilities for the fair distribution of educational resources. For example, the details and background knowledge of historical buildings can be collected digitally and shared to different schools through VR platforms and even cross-border educational exchanges. This will not only improve the efficiency of resource utilization but also promote diversified learning experiences and stimulate students' interest and sense of responsibility in cultural heritage protection. Therefore, VR, as an innovative educational tool, is of great significance in solving the imbalance of educational resources and has taken a key step toward educational equity in the context of globalization.

6.3. Limitations

There are also some limitations in the study. Individual differences, such as age, gender, and prior experience, could influence students' perceptions of VR. Unfortunately, our sample size was relatively small and homogeneous (all third-year architecture students), limiting the variability in demographic factors and the feasibility of subgroup analysis. Future studies could address this limitation by incorporating a more diverse participant pool and exploring how demographic variables mediate or moderate the learning outcomes and satisfaction levels in VR-based education.

It is essential to emphasize the importance of simplifying VR interactions for educational purposes, which is consistent with the view of Lampropoulos [34]. In the conducted experiment, all students had access to assistance from teaching staff, ensuring smooth interaction with the VR environment and operations. However, if students were to use the software independently, either at school or home, usability challenges could arise,

particularly for those with limited experience in operating VR systems. Such difficulties might negatively impact the educational outcomes and reduce the effectiveness of VR as a teaching tool. Furthermore, these issues could influence students' perceptions of VR, potentially diminishing its appeal and undermining its motivational value as a learning resource. Additionally, the perceived likeability of the VR experience may also be influenced by its educational focus, as the content is directly aligned with the lesson syllabus, which may limit its broader appeal.

6.4. Future Work

The integration of VR into architectural education presents significant opportunities, particularly through the development and application of VR games centered on heritage buildings. One promising direction is the creation of immersive VR games that enable students to explore, interact with, and analyze the complexities of historical architecture in an engaging and dynamic format. These games could incorporate tasks such as identifying architectural components, solving structural design challenges, or simulating restoration projects. By gamifying the learning experience, students can deepen their understanding of architectural features while fostering enthusiasm and active engagement. Moreover, an equally innovative approach involves empowering students to design and develop their own VR games focusing on heritage buildings. This hands-on process not only equips students with practical skills in VR development but also encourages an in-depth investigation of architectural history and structural intricacies. To create effective and accurate VR environments, students must study materials, construction systems, and cultural contexts in detail, thereby promoting a comprehensive and nuanced appreciation of heritage architecture. These strategies hold the potential to enhance students' technical proficiencies in VR and game design while cultivating a deeper connection to architectural heritage through active, participatory learning. Moreover, such approaches extend the applicability of VR beyond the academic environment, inspiring wider interest in cultural heritage and offering innovative ways for the broader public to engage with historical structures.

Also, we plan to further improve the VR teaching tool and its evaluation methods. On the one hand, we will embed knowledge points of architectural heritage directly into VR scenes to enhance students' understanding of historical background, architectural features, and cultural significance. At the same time, we will add interactive question-and-answer sessions so that students can instantly consolidate their knowledge in immersive learning. Thess improvements will not only help to enhance the teaching effect of VR but also collect more comprehensive feedback from students on the impact of education. On the other hand, we will add more evaluation questions about skill improvement and knowledge acquisition in the questionnaire design, especially questions related to the historical background, spatial understanding, and cultural value of architectural heritage. This will help to build a more comprehensive evaluation system, so as to explore the potential and application value of VR technology in architectural history education in depth. Through these improvements, we hope to further verify and expand the conclusions of the current study and provide more basis and guidance for future educational practice.

7. Conclusions

This study highlights the transformative potential of VR as an educational tool for architectural history courses. The Dule Temple site was used as an example to construct the VR environment to enable students to experience the heritage building, with options for on ground-based or free movement modes. A survey was conducted after the course for 102 third-year architecture students. Forty-two questions were set in the questionnaire, including personal data, VR experience, VR satisfaction, and learning experience.

From the results, it can be found that students can efficiently adapt to VR technology following a brief introductory session, irrespective of students' prior exposure to the technology. Furthermore, an intuitive and user-friendly design of the VR interface is required to enhance its suitability for educational applications. The statement "You encourage the use of VR in architectural education" achieved a mean score of 4.5 (out of 5), reflecting students' overwhelmingly positive attitudes and strong support for integrating VR into architectural history education.

For the two movement modes in the VR environment, the on-ground movement mode is particularly effective for analyzing spatial relationships, understanding the flow of movement within a structure, and assessing design elements from a pedestrian's viewpoint. By contrast, the free mode enables users to "fly" and navigate freely within the virtual space, offering an unrestricted range of viewpoints. This capability facilitates the exploration of perspectives that are otherwise unattainable.

Satisfaction with VR quality was also evaluated. For the clearness of the VR environment, the mean satisfaction score was 4.1 (out of 5). Realism received a slightly lower mean score of 3.9. The detail of the VR scene achieved the highest satisfaction score, with a mean value of 4.5.

The interestingness and effectiveness of VR for architectural learning were also assessed while learning historical context, architectural styles, architectural details, and spatial relationships, compared to field surveys, 2D materials, and scale models. The results revealed a strong preference of students for VR in the architectural history course, with an average score of 4.5 out of 5 for the "interestingness" dimension. VR also demonstrated exceptional effectiveness as a learning tool in the architectural history course, achieving an average score of 4.8 out of 5. This high rating underscored VR's capacity to enhance understanding across diverse aspects of architectural heritage. However, the study emphasizes that VR should not entirely replace traditional teaching methods. Instead, combining the strengths of VR and conventional techniques offers a balanced and effective strategy for architectural education.

Overall, virtual reality offers a transformative approach to addressing the imbalance of educational resources by providing an immersive and resource-rich learning experience.

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