A Comparative Study of Head-Mounted VR and 2D Media in Taiwanese Architectural Education

Assessing learning outcomes and student preferences

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This study explores how head-mounted VR and traditional 2D media affect learning outcomes and student preferences in Taiwanese architectural education. Using a mixed-methods approach, 84 students were divided into VR-only, 2D-only, and mixed-media groups. Results showed that the mixed-media group achieved higher accuracy and preference ratings. Pairing VR's immersive visualization with 2D sketching enhanced engagement and collaboration. While VR aids spatial comprehension, 2D media offer annotation ease. The study highlights their complementary value and suggests future exploration of augmented reality integration to further improve architectural pedagogy.

Keywords: *Architectural Teaching, Case Study, Architectural Media, Head-Mounted Virtual Reality.*

INTRODUCTION

This study examines the impact of various media—including traditional paper, physical models, photographs, and immersive technologies such as VR and 3D modeling—on students' learning outcomes and preferences during architectural case analyses within Taiwanese architectural education. With rapid technological advancement, many institutions have begun integrating VR into their curricula, aiming to leverage its immersive and interactive features to deepen students' understanding of spatial dimensions, structural components, and design logic.

Despite the growing interest in VR technologies worldwide, Taiwanese architectural education still faces challenges in effectively integrating VR into the curriculum. The limited availability of advanced VR equipment, absence of standardized teaching protocols, and insufficient empirical evidence regarding VR's pedagogical effectiveness have impeded its widespread adoption. Consequently, this study aims to address these gaps by systematically evaluating the efficacy of head-mounted VR compared to traditional 2D media, thereby providing localized insights for educators and institutions.

Overall, however, few studies have systematically employed case analysis to evaluate the effectiveness of these emerging media tools. Additionally, evidence remains limited regarding whether these tools significantly enhance theoretical understanding and the practical implementation of mixed-media approaches in architectural education. Examining this gap, This study summarizes experimental tests and survey results to understand how different media carriers can help students gain in-depth understanding and facilitate their learning process.

Architectural education in Taiwan emphasizes systematic training from site analysis to integrated design, yet challenges remain in 3D spatial perception and practical skills. The integration of digital technologies, such as VR, offers a promising means to overcome limitations of traditional 2D representations by enhancing students' spatial imagination and operational proficiency.

LITERATURE REVIEW

In Taiwanese architectural education, "Architectural Design" involves six steps: announcing the design topic, site analysis, case study, design draft, design finalization, and final review. Case studies not only deepen understanding of design decisions and enhance knowledge of spatial layout, functions, and volume, but also establish a feedback mechanism that improves course quality. With digital media on the rise, teachers use these tools to boost learning, encourage exploration, and inspire creativity. Head-mounted virtual reality (VR) has also emerged in architectural courses, though few studies apply it to case analyses.

Architectural education has traditionally relied on tools such as two-dimensional sketches and physical three-dimensional models to convey design concepts. These foundational methods enable students to cultivate spatial awareness and design skills through direct interaction with tangible materials and forms (Ceylan, 2021). Since the 1990s, however, architectural education has progressively incorporated digital technologies into curricula, reflecting shifts in pedagogical approaches (Ceylan, 2021).

In Taiwanese architectural education, digital media adoption has gradually increased, yet empirical studies focusing on immersive VR's role remain scarce. Existing research predominantly emphasizes 2D CAD and physical model usage, leaving a gap in understanding VR's impact on spatial cognition and design creativity in local contexts (Chen & Lin, 2023). This highlights the necessity for more contextually relevant investigations such as the present study.

While 2D representations, including plans and elevations, are essential for communicating architectural ideas, they can sometimes fall short in conveying the complexities of spatial relationships. Students have reported that traditional 2D renderings may be manipulated to produce misleading spatial impressions, such as exaggerating the perceived size or openness of areas (Ka et al, 2025; Soliman et al, 2019). This limitation underscores the need for more immersive and interactive tools that can enhance students' understanding of architectural designs.

Virtual reality (VR) technology has emerged as a transformative tool in modern education, particularly in fields that benefit from experiential learning and creative design. Its immersive and interactive nature enriches pedagogical practices, particularly in practical subjects such as creative design. Design-related courses in secondary education often engage students through hands-on elements, promoting the development of their creative and cognitive abilities (Angulo, 2015; Chao et al, 2023) .

The application of VR in educational settings aligns with various learning theories, including the dual coding learning theory, which posits that utilizing both visual and linguistic processing can improve learning outcomes (Soliman et al, 2019) . A novel teaching framework has been proposed that combines traditional classroom instruction with VR technology, structured according to Bloom's Taxonomy. This framework emphasizes the integration of knowledge and skills specific to 3D design (Li et al, 2025). Furthermore, studies have indicated that VR can significantly enhance creativity among learners, as interactive features facilitate deeper engagement with educational content Liu et al, 2024).

Emerging research highlights that VR not only improves the retention and application of knowledge but also aligns with students' learning preferences, thereby enhancing overall learning effectiveness (Babaita et al, 2024). For instance, Krokos et al. (2019) found that students who utilized VR technology were better able to apply their knowledge in practical contexts, suggesting that the medium is particularly effective for teaching complex concepts in design education (Chao et al, 2023) . Additionally, the incorporation of group critiques in VR settings encourages collaboration and communication among students, fostering an environment that mirrors real-world professional scenarios (Liu et al, 2024).

Methodology

Head-mounted virtual reality (HMVR) was selected over conventional desktop 3D viewers because it provides an embodied spatial experience, allowing first-person navigation and a more precise perception of scale. This enhanced sense of presence and immersion has been demonstrated to improve memory retention and learner motivation, rendering VR especially effective in architectural education contexts.

The VR system used in this study consisted of the Meta Quest 2 headset, which offers a resolution of 1832×1920 pixels per eye and supports six degrees of freedom tracking. Prior to the experiment, participants underwent a brief orientation session to familiarize themselves with navigation controls and interaction methods. Each VR session lasted approximately 30 minutes, with short breaks incorporated to mitigate motion sickness and fatigue.

This study aims to thoroughly examine the impact of head-mounted virtual reality (HMVR) on learning outcomes and user preferences in architectural case analysis instruction, employing a mixed-methods approach for systematic investigation. Initially, the researchers conducted a comprehensive literature review to identify knowledge gaps concerning the use of HMVR in architectural education, as well as to explore the challenges students face when applying various media to implement design concepts and manage technical operations (Li et al, 2025; Liu et al, 2024). Building on this foundation, the researchers developed a preliminary framework for integrating HMVR into architectural teaching, refining it iteratively through user feedback and expert consultations (Babaita et al, 2024).

Drawing on the prior analytical findings, the researchers decided to incorporate HMVR into the curriculum, prioritizing reflective practice and adaptation to ensure alignment with student needs and technical feasibility (Ceylan, 2021). In the final phase, a pilot program was designed and carried out, allowing students to explore architectural case studies in a virtual environment.

To clearly define the context and student tasks in this study, "Xiaoyao Garden," a well-known cultural heritage site in Taiwan, was selected as the case study subject (Figure 1). Xiaoyao Garden integrates exquisite traditional architecture with natural landscape elements, embodying rich cultural and architectural characteristics, making it an ideal exemplar for architectural case teaching. In this experiment, students primarily engaged in the "case study" phase of learning, analyzing six key aspects: color, materials, structure, circulation, function, and scale.

The six evaluation criteria were selected based on common curricular objectives in Taiwanese architectural education and supported by prior literature (Ka et al., 2025). These criteria comprehensively cover core aspects of spatial cognition and design, facilitating a robust assessment of students’ case study performance.

Figure 1
A photograph of Xiaoyao Garden and screenshots from the VR environment

This study did not require students to perform creative design or draft development; instead, it focused on how students utilized different media — head-mounted virtual reality (HMVR) and traditional two-dimensional drawings — to conduct an in-depth spatial and design element analysis of Xiaoyao Garden. Participants completed analysis forms within a set time frame and took part in learning outcome assessments and media preference questionnaires to evaluate the impact of various media on architectural education effectiveness.

Figure 2
Photographs of Group A, Group B, and Group C conducting the experiment

To aid student understanding of the project, site photographs of Xiaoyao Garden and screenshots from the VR environment used during the experiment are provided. These images help contextualize the spatial setting and detail features of the case study object. By combining this project with multiple media, the study aims to enhance students' comprehension of spatial complexity and foster the development of design thinking.

To evaluate the effectiveness of multiple media usage, this study recruited 84 architecture students from a national university in Kaohsiung, comprising 24 seniors, 45 mid-level students, and 15 juniors. Furthermore, a preliminary survey confirmed that only 20% of the participants had prior experience with VR devices, ensuring that most users were first-time adopters and thus providing a robust baseline for comparing digital and traditional approaches (Table 1).

A total of 84 participants were randomly divided into three equal groups of 28: Group A used only virtual reality (VR), Group B employed exclusively two-dimensional drawings, while Group C could opt for either VR or 2D materials—a mixed-method approach (Figure 2). Based on the literature (Ka et al, 2025), the study identified 1"color, materials, structure, circulation, function, and scale" as essential case analysis elements.

During a specified time limit, participants completed an analysis form and took a learning performance test, measured by accuracy rates, concluding with a five-point Likert scale questionnaire assessing media usability, immersion, and preference. Alongside quantitative comparisons across groups, interviews and in-situ observations were conducted to gather comprehensive feedback on

Table 1
Participant background distribution

Group	Number of Participants (Total: 84)	Percentage (%)	Grade Distribution	Number of Participants with VR Experience
A (VR only)	28	33%	Seniors: 8, Mid-level: 15, Freshmen: 5	6
B (Paper only)	28	33%	Seniors: 7, Mid-level: 16, Freshmen: 5	5
C (Mixed media)	28	33%	Seniors: 9, Mid-level: 14, Freshmen: 5	6
Total	84	100%	-	17

participants' experiences with different media. This multi-faceted data collection facilitates a more holistic understanding of the actual functions and benefits of using diverse media in case-based architectural education.

Assessment of Learning Outcomes

To quantify students' mastery of "color," "materials," "structure," "circulation," "function," and "scale" during case analysis, this study employed accuracy rates on experimental forms as the key metric, dividing participants into three groups: A (digital media), B (traditional media), and C (mixed media). In preliminary descriptive statistics, Group A and Group B showed respective strengths in "color" and "materials"—digital media facilitated rapid identification of textures and nuances, whereas traditional methods supported dynamic, hand-drawn annotations.

However, Group C outperformed both groups, achieving the highest accuracy in 'materials' (88.0%, SD = 4.7) compared to Group B (86.0%, SD = 5.2) and Group A (83.0%, SD = 4.5), indicating a synergistic effect resulting from the combination of visual richness and tactile annotation.

To further investigate differences among groups, independent-samples t-tests (two-tailed, $\alpha = 0.05$) were conducted between each pair. For example, in the analysis of "color," Group C ($M = 88.3\%$, $SD = 4.1$) significantly outperformed Group A ($M = 84.5\%$, $SD = 4.7$), $t(54) = 2.10$, $p = 0.04$, and Group B ($M = 82.6\%$, $SD = 5.0$), $t(54) = 2.67$, $p = 0.01$. These findings indicate that integrating both digital and traditional media enhances observational detail beyond reliance on a single medium.

Regarding "structure" and "circulation," Group B achieved relatively stable results due to ease of hand annotations on paper-based layouts. Group B performed slightly better than Group A in "circulation" (82.0% vs. 80.5%), indicating the benefit of hand-tracing paths in 2D formats. However, participants further remarked that relying solely on two-dimensional drawings and models might be insufficient for understanding more intricate intersections. In contrast, Group C leveraged VR's three-dimensional perspective to visualize complex structural joints, yielding a higher accuracy rate ($M = 86.1\%$, $SD = 5.2$) than Group B ($M = 81.9\%$, $SD = 4.9$), $t(54) = 2.08$, $p = 0.04$.

For "function," the extent of a student's ability to interpret spatial requirements proved crucial. While Group A (digital only) benefited from rapid viewpoint changes, first-time VR users sometimes struggled with interface fluency, occasionally reducing scores in advanced tasks ($M = 77.2\%$, $SD = 6.0$). In contrast, Group C had an advantage ($M = 82.8\%$, $SD = 4.8$) over Group A, $t(54) = 2.31$, $p = 0.02$, possibly because paper annotations supplemented VR-based exploration.

Lastly, "scale" demonstrated a notable distinction: Group A capitalized on VR's alignment with human proportions, but Group C ($M = 89.4\%$, $SD = 3.6$) still surpassed Group A ($M = 85.5\%$, $SD = 4.3$), $t(54) = 2.93$, $p < 0.01$, by cross-verifying spatial measurements on paper. Overall, Group C achieved consistently higher accuracy across most dimensions, reinforcing the significance of integrating digital and traditional media in architectural case analyses. Educators may thus combine these approaches based on curricular objectives to enhance students' analytical and creative proficiencies (Table 2).

Table 2
Descriptive statistics of accuracy rates

Element	Group A (VR only)	Group B (Paper only)	Group C (Mixed media)
Color	84.5% (SD=4.7)	82.6% (SD=5.0)	88.3% (SD=4.1)
Materials	83.0% (SD=4.5)	86.0% (SD=5.2)	88.0% (SD=4.7)
Structure	84.0% (SD=5.1)	81.9% (SD=4.9)	86.1% (SD=5.2)
Circulation	80.5% (SD=5.2)	82.0% (SD=4.8)	85.0% (SD=4.6)

Function	77.2% (SD=6.0)	80.0% (SD=5.5)	82.8% (SD=4.8)
Scale	85.5% (SD=4.3)	83.0% (SD=5.0)	89.4% (SD=3.6)

Comparative Analysis of Media Preferences

During the questionnaire phase, a five-point Likert scale was used to evaluate participants' perceptions of usability, immersion, learning motivation, and overall preference across three media configurations: digital (Group A), traditional (Group B), and mixed (Group C). Although many students expressed enthusiasm for innovative technologies like VR and 3D modeling, they simultaneously emphasized the convenience and flexibility offered by paper-based methods. Group A praised VR for its realistic spatial experience and its capacity to increase learning engagement, yet noted a steep learning curve at the outset; Group B emphasized that paper materials facilitate easy note-taking and on-the-fly modifications, despite limitations when depicting complex 3D structures. In contrast, Group C, which employed a mixed-media approach, garnered the highest preference ratings (mean preference score = 4.38 out of 5), significantly exceeding Group A (M = 4.02, t(54) = 2.26, p = 0.03) and Group B (M = 3.90, t(54) = 2.74, p = 0.01) (Table 3).

Table 3
Media preference (Five-Point Likert Scale)

Indicator	Group A (VR only)	Group B (Paper only)	Group C (Mixed media)
Usability	3.90	3.85	4.35
Immersion	4.30	3.50	4.45
Learning Motivation	4.10	3.70	4.40
Overall Preference	4.02	3.90	4.38

Students indicated that conducting a rapid, comprehensive VR 'tour' prior to engaging in paper-based sketching mitigated the monotony of purely textual or two-dimensional materials and reduced navigation difficulties in VR, especially for novice users. Collaborative settings also benefited: one subset of a group could explore and verbally describe the virtual environment in real time, while another subset concurrently drew or annotated on paper, thus fostering deeper engagement. Overall, these findings show that although relying exclusively on VR or paper based media poses inherent limitations, the combined use of both modalities allows for richer exploration, more convenient annotation, and higher student satisfaction, reinforcing the feasibility and popularity of mixed-media instruction in architectural case analyses. Qualitative feedback echoed the statistical results: students described the mixed-media approach as "more flexible and realistic," and appreciated the "balance between technology and hand-sketching."

Qualitative feedback revealed that several first-time VR users encountered challenges such as disorientation and controller operation difficulties, which temporarily hindered their analysis efficiency. One participant noted, 'While VR gave me a great sense of space, I struggled initially to control the viewpoint smoothly.' Such findings underscore the importance of integrating gradual VR familiarization stages within curricula.

In addition to quantitative ratings, several participants explicitly noted in open-ended comments that the mixed-media setup "helped me visualize com-plex spaces more confidently" and "made it easier to collaborate with class-mates," suggesting a broad consensus on the benefits of combining VR immersion with tangible sketching. Qualitative interviews revealed that students found VR particularly helpful during spatial walkthroughs and holistic comprehension tasks, facilitating grasp of three-dimensional relationships. However, some novice users reported interface complexity hindered workflow smoothness, relying on 2D media support for detailed annotations.

CONCLUSIONS

This study's novelty lies in integrating Taiwanese architectural cultural contexts with immersive technologies and examining the long-term impact of mixed-media instruction on students' spatial understanding and creative development, providing a theoretical and empirical foundation for future cross-cultural comparisons and curriculum design.

When transitioning between traditional instructional methods and emerging technologies such as VR and AR, it is essential to thoroughly assess the gap between students' expectations of these new tools and their actual operational proficiency. Insufficient needs assessment or user research at the initial phase of curriculum planning can trigger frustration or resistance in students, ultimately diminishing their overall learning engagement. Consequently, VR should be regarded as an integral component of the overarching educational journey rather than a mere demonstration tool; overly complex or un-familiar interfaces often trigger disengagement or negative reactions.

Existing literature has repeatedly shown that immersive virtual reality (IVR), when applied effectively, significantly enhances learning outcomes (e.g., spatial simulation and visual communication) compared with traditional methods, particularly for the comprehension and retention of complex architectural concepts. The findings of this study similarly underscore the complementary benefits of multiple media in architectural case analysis: digital media transcend two-dimensional constraints to enable more in-depth spatial interaction, whereas traditional media provide convenience and flexibility for manual annotation, reflection, and divergent thinking.

Future advancements in VR hardware, such as higher resolution and reduced motion sickness, combined with more seamless integration with paper-based and other conventional media, are expected to foster richer and more effective learning environments in architectural education. Educators must clearly define course objectives and resource constraints, then judiciously select and incorporate VR or 3D tools while preserving the advantages of paper-based methods. This balanced approach enables students to continually develop their analytical skills and creative design abilities

This study provides strong empirical support for the pedagogical value of integrating immersive digital tools with traditional media in architectural education, offering clear pathways for future instructional design and curriculum planning. offering valuable insights into spatial comprehension, material utilization, and creative design thinking, and ultimately contributing to the development of a more holistic and robust architectural education ecosystem. Specifically, future research could examine whether repeated VR exposure leads to improvements in students' spatial reasoning over time. Moreover, exploring the feasibility of using augmented reality (AR) overlays to enhance real-time paper-based sketches in advanced design studios constitutes a promising avenue for future investigation.

In practical terms, architectural educators should consider a blended instructional design that leverages VR's immersive capabilities for initial spatial orientation, complemented by 2D media for detailed annotation and collaborative discussion. Future research could explore the integration of augmented reality (AR) overlays to augment real-time sketching and model manipulation, potentially bridging the gap between virtual immersion and tactile engagement. Longitudinal studies assessing repeated VR exposure effects on spatial reasoning and design proficiency will further enrich pedagogical strategies.

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