Data-Driven Human Factors Integration in Architectural Education: A VR-Based Experimental Course Framework for Mitigating Cybersickness via Embodied Cognition Enhancement

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Abstract:Traditional architectural pedagogy struggles to convey true spatial depth through flat media and, when VR is introduced, often neglects the cybersickness that undermines both comfort and learning. We propose a four-phase "Theory-Experiment-Analysis-Design" model integrating embodied cognition. Mirror experiments and multimodal data show enhanced embodiment reduces CS, enabling data-driven spatial interventions. In this study, a controlled VR experiment with mirror/non-mirror conditions measured physiological (EDA, HRV) and psychological (SSQ, IPQ) indicators across four stages: theoretical framing, multimodal data collection, statistical analysis, and design transformation into "Window-Mirror" interactive prototypes. Cross-disciplinary guidance ensured technical rigor. Post-course assessments (N=39) revealed: (1) 61.54% demonstrated profound SoE understanding, (2) 64.1% achieved expert VR operation proficiency, (3) 74.4% reported improved spatial interaction skills, and (4) 87.18% preferred VR environments over traditional media. However, only 41% demonstrated the ability to analyze experimental data's implications for design. The framework effectively integrated human factors into pedagogy, offering empirical CS mitigation strategies for immersive environments.

Keywords: VR-Based Architectural Education; Embodied Cognition; Cybersickness Mitigation; Multimodal Data-Driven Design

1. Introduction

With the rapid development of information technology, Virtual Reality (VR), as an emerging interactive medium, is profoundly transforming various fields such as human-computer interaction, entertainment experiences, education and training, and healthcare. Compared to traditional media (such as books, films, television), the core characteristics of VR lie in its immersiveness, interactivity, and imaginativeness. These characteristics enable users to enter virtual environments in an "embodied" manner, achieving more authentic and autonomous experiences [1]. However, VR experiences can lead to uncomfortable physical states known as Cybersickness (CS), with specific symptoms including dizziness, nausea, and oculomotor disturbances [2]. This issue severely impacts users' sense of immersion and comfort, becoming one of the key factors constraining the development of the VR industry. Especially in the field of architectural design education, which demands high levels of immersion and spatial perception, the existence of CS not only reduces learning efficiency but also hinders students' potential to fully experience and understand virtual spaces.

Simultaneously, Sense of Embodiment (SoE) as the core experience of users perceiving self-presence, owning a virtual body, and controlling its actions within virtual environments [3], is considered potentially correlated with the occurrence of CS [4]. Enhancing SoE may become an important pathway to alleviate discomfort and improve VR comfort. However, current research in architectural design teaching, particularly when utilizing VR technology for teaching the design of virtual architectural spaces (such as virtual game architectural spaces) [5], remain insufficient regarding how to proactively intervene and enhance SoE through spatial design elements, thereby optimizing user experience and mitigating CS. Based on this background, this course focuses on exploring the influence of SoE on virtual architectural space design under VR technology. Centering on this core objective, it designs and constructs an experimental teaching reform system integrating theory, experimentation, data analysis, and design transformation.

2. Background and Literature Review

2.1 VR Teaching Research in Virtual Architecture

Research on the teaching application of VR technology in virtual architectural space design and its impact on the innovation of teaching models indicates that VR technology offers new possibilities for architectural design education. Through immersive, interactive, and imaginative experiences, VR technology can effectively address the problem in traditional teaching where two-dimensional drawings struggle to fully represent physical buildings, helping students understand spatial design and architectural concepts more intuitively [1]. Furthermore, VR technology can enhance students' spatial perception abilities and increase their understanding and engagement in the design process [6].

Li and Zhang utilized the MARS virtual simulation software combined with VR headsets in a foundational architectural design course, enabling students to immerse themselves in experiencing masterpieces like those of Le Corbusier. Through dynamic observation of spatial sequences and material details, students deepened their understanding of design logic [7]; Shanti and Al-Tarazi created virtual environments of three major Christian buildings, including Hagia Sophia, for an Architectural History course. Students explored the variations in light and shadow within dome structures using VR Head-Mounted Displays (HMD), and compared construction technique differences across different periods. Quantitative surveys showed that students in the VR group scored significantly higher in architectural feature identification tests than those in the traditional image-based teaching group [8]. However, most teaching experiments focus only on technological implementation, neglecting the design for students' physiological comfort during the experiments.

2.2 VR Application in Architectural Design

The integration of Building Information Modeling (BIM) and VR can improve design visualization and support more efficient collaborative workflows. For instance, Yu et al. developed and tested a design review workflow integrating BIM and VR. The application of VR technology in landscape architecture is also gradually increasing, especially in urban planning and environmental design [9]. Chen et al. pointed out that VR provides new design perspectives for landscape architecture, particularly within the fields of computer software and applied computer science research [10]. VR is changing traditional design processes, providing designers with immersive design expression tools. Research finds that VR can offer better experiences through real-time exploration of design works [11]. Multiple studies indicate that the application of VR in education has significant effects, improving learners' motivation and design quality [12].

Currently, academic research hotspots in VR architectural design mainly focus on design processes, BIM integration, multi-user collaboration, landscape architecture, and educational applications. These studies provide theoretical support and practical guidance for the further development of VR technology in the architectural field.

2.3 Architectural Application in Game Spaces

Game spaces, as a typical and unique form of virtual architectural space, hold significant research value and representativeness. Across various fields, architectural principles play a crucial role in the design of virtual game architectural spaces. This provides a rich foundation of case studies and practical experience for conducting relevant experimental teaching.

Zhang's research points out that cyberpunk-style architecture in games primarily features cold, low-rise structures made of metal and plastic, creating a visual effect that blends decadence with futurism. Its vertically layered architectural structures shape the narrative background, influencing players' exploration paths and behavioral choices [5]. Castiñeiras López notes in his study that the recreation of ancient Greek and Roman architecture in Assassin's Creed: Odyssey enhances historical authenticity, guides player exploration and task completion, influences player action strategies through architectural details, and conveys game themes through symbolism [13]. Zonaga and Carter explore the role of architecture in constructing game worlds, highlighting that the complex structures and detailed design of steampunk-style architecture enhance visual effects, with layouts and functions influencing player action strategies, and their symbolic meaning conveying the game's ethics and values [14].

Currently, research on users' comfort experiences within immersive virtual game architectural spaces remains relatively scarce. Therefore, conducting teaching research on virtual game architectural space design under VR technology can not only fill gaps in existing pedagogical research but also provide more human-centered design guidance for virtual game architectural space design, thereby further improving the overall quality of virtual architectural spaces and the user experience.

2.4 SoE Research in Virtual Architectural Design

Architectural space serves as a crucial carrier of the virtual environment. Virtual architectural space fundamentally differs from real architectural space in terms of design logic, technological implementation, and user experience. For instance, real architecture is strictly constrained by physical laws (gravity, material mechanics) and functional requirements (lighting, ventilation), whereas virtual architectural space is entirely defined by digital rules, allowing it to break free from real-world limitations and achieve surreal structures. In terms of interaction dimensions, traditional architectural theories cannot be directly applied to virtual architectural spaces. Current research predominantly focuses on technological implementation or single-sensory experiences, with limited studies analyzing architectural space design from the perspective of embodied cognition. Embodied sensation, as one of the core factors influencing user experience in virtual environments, holds significant importance for virtual game architectural space design.

Existing research suggests a potential negative correlation between SoE and CS, indicating that enhancing SoE may be an effective way to alleviate CS [4]. However, current research primarily employs physiological measurements and psychological assessments to quantify SoE. Research on how to effectively enhance SoE within virtual architectural space design and the construction of experimental courses based on SoE remains in the exploratory phase.

Therefore, this experimental course takes "spatial design in games" as an example to explore the influence of SoE on architectural space design under VR technology.

3. Theoretical framework and Methods

3.1 Teaching Philosophy and Objectives

Adhering to the teaching philosophy of "Data-Driven Virtual Space Design Optimization," the course focuses on exploring the correlation between SoE and CS. Within the VR technology-related curriculum, the mirror exposure experiment is identified as the core teaching project. It emphasizes the guiding role of physiological and psychological data collected in the virtual environment for architectural space design.

The experiment allows students to intuitively observe and analyze the impact of SoE on CS by changing the presence or absence of mirrors. Throughout the practical process, it cultivates students' ability to collect and analyze data using VR technology, physiological measurement equipment (e.g., Ergo LAB, eye trackers), and psychological scales (SSQ, IPQ, etc.). This ultimately achieves the objective of "enhancing practical capabilities in virtual space interaction design and optimization based on experimental results."

3.2 Experimental Course Content Design

3.2.1 Theoretical Framework Construction

(1) Mechanisms of CS

Within the field of CS research, several key theories have been proposed to explain its underlying mechanisms. The earliest and most widely accepted is the "Sensory Conflict Theory" which posits that CS arises from a mismatch between sensory information and brain expectations [15]. Building upon this, the "Postural Instability Theory" emphasizes the role of postural control, suggesting that CS occurs due to the body's inability to maintain stability in the virtual environment [16]. The "Poison Theory" offers an evolutionary perspective, proposing that CS is a protective response triggered when the brain misinterprets sensory conflict as a potential poisoning threat [17]. The newly proposed "Sensory Reweighting Theory" focuses on the brain's recalibration mechanism for conflicting sensory inputs, which triggers physical discomfort when this process fails [2].

(2) Dimensions of SoE

Previous research supports the view that presence (the feeling of "being there" in the virtual environment) is negatively correlated with CS [4]. As a core element of presence, embodiment has become an important research focus.

SoE is defined as "a perceptual state arising from the cognitive system's integration of visual-motor features of an external body with proprioceptive inputs, which are then misattributed to the attributes of one's own biological body" [3]. It encompasses three key dimensions: self-location (the spatial experience of being located within a body, focusing on the relationship between self and body), agency (the feeling of controlling overall movement, encompassing actions, control, intentions, movement choices, and the experience of subjective will), and body ownership (the perception of attributing a body to oneself) [3]. Studies show that the use of virtual avatars can enhance users' subjective sense of presence, immersion, and the illusion of existence in the virtual world [18]. Therefore, researching the influence of SoE in virtual game architectural space design is crucial for optimizing virtual game environments and enhancing player immersion.

(3) Value of Mirror Exposure

Existing research proposes various methods to enhance SoE, among which visual feedback is particularly critical. Studies in real environments indicate that mirror stimulation can significantly enhance self-reference cognition [19], and empirical evidence shows that this effect is associated with enhanced self-perception. These findings collectively establish the mirror's important role as a regulator of self-awareness, capable of influencing self-representation at the perceptual level [20]. Although the psychological effects of mirrors in real environments and the impact of virtual avatars on behavioral perception have been extensively studied, their potential influence on CS has not yet been systematically investigated.

3.2.2 Experimental Teaching Model

Centering on the correlation mechanism between SoE and CS and aiming to cultivate students' ability to optimize virtual space design driven by multimodal data, a logical of "theoretical framework-experimental verification-data analysis-application transformation" was constructed. The specific teaching model is illustrated in Figure 1:

(1) Theoretical Foundation Construction and Literature Research: Systematically explain the mechanisms inducing CS in class. Analyze users' perceptual-motor coordination characteristics in virtual architectural spaces and their impact on comfort using embodiment theory. Students read relevant literature to compare and analyze experimental methods for measuring CS and SoE, clarifying the current research status and limitations, providing a theoretical basis for subsequent experimental design.

(2) Controlled Experiment Design and Implementation: Assist students in designing rigorous controlled experimental protocols around the core research question. Students learn and practice multimodal data collection methods: using biosignal measurement equipment (Electrodermal Activity-EDA, Heart Rate Variability-HRV, Respiration Rate-RESP, and eye tracking) to record physiological indicators; simultaneously, combining psychometric analysis (Simulator Sickness Questionnaire-SSQ, Fast Motion Sickness Scale-FMS to quantify the occurrence and severity of virtual motion sickness, Igroup Presence Questionnaire-IPQ questionnaire to assess SoE levels).

(3) Multimodal Data Empirical Analysis and Correlation Validation: Students integrate multimodal data through standardization to build a high-quality dataset; subsequently, perform normality tests, use Pearson correlation analysis to explore the relationship between physiological indicators and subjective questionnaires, and employ independent samples T-tests to quantify differences in physiological and psychological responses between mirrored and non-mirrored conditions, providing empirical evidence for design optimization.

(4) Output of Optimized Virtual Space Solutions: The final stage of teaching focuses on translating research findings into design

practice. Based on the experimental results concerning SoE and CS, students propose optimization cases and improvement suggestions for existing virtual architectural environments, providing theoretical support and design solutions for improving the user experience of virtual reality technology.

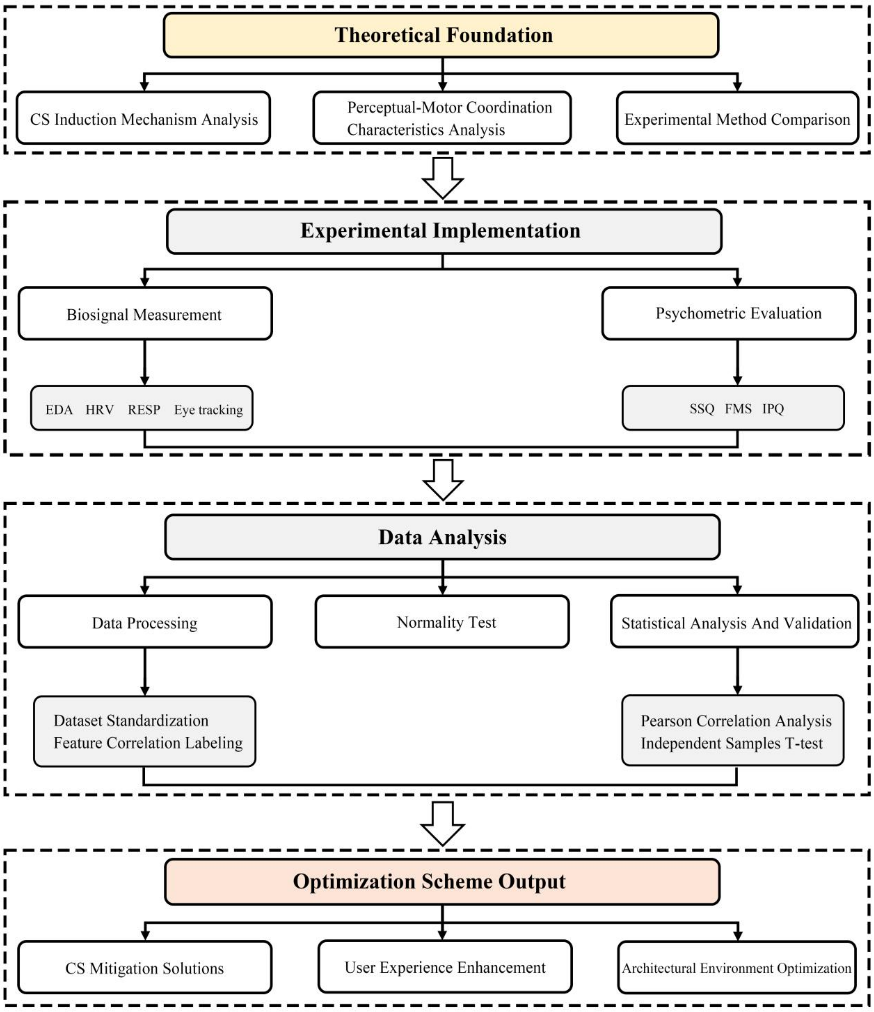

Figure 1. Experimental Teaching Model.

3.2.3 Teaching Support Conditions

(1) Technical Tools: Unity virtual environment modeling platform, HTC VR HMD, Ergo LAB physiological recorder, Tobii eye tracker, etc.

Faculty Support: Collaborative guidance from (2) Architecture (spatial design), Psychology (embodied cognition), and Computer Science (VR technology).

4. Teaching Steps and Implementation

The Mirror Exposure Experiment serves as the core of this experimental teaching course. The following elaborates on the experimental plan and methods centered around this core.

4.1 Experimental Plan Formulation

Based on a review of theories related to CS and SoE in VR environments, and aligned with the research objectives, a preliminary experimental plan on the "Impact of SoE on CS" was developed. Experimental equipment and procedural details were then confirmed through communication with technical personnel, while specific parameters including environment setup, task arrangements, and experimental grouping were determined via literature review and preliminary experiments. Finally, a detailed experimental operation protocol was established covering pre-experiment preparations, operational steps during the experiment, and post-experiment data processing and analysis procedures, thus completing the formulation of the experimental plan investigating the impact of SoE on CS.

Shantou University students were selected as the main subjects to participate in the experiment, and the main research objective was to analyze "the impact of virtual mirror exposure on SoE, CS symptoms, and multimodal physiological-psychological indicators."

4.2 Experimental Process Implementation

According to the preliminary experimental plan, Unity was used to create two virtual VR environments (with and without mirrors) to simulate a real VR space experience and ensure the naturalness and immersion of the experimental process. The virtual experimental environment is shown in Figure 2.

Figure 2. Virtual Experimental Environment

The experimental procedure consisted of three distinct stages, as shown in Figure 3: the Preparation Stage, the Main Experimental Stage, and the Final Stage. After selecting an appropriate experimental venue and equipment, students were assigned to the mirror group (M group) and the non-mirror group (N group) according to the experimental grouping. Eye movement metrics were measured using the Tobii Pro VR eye tracker, physiological data were recorded using the Ergo LAB V3.0 physiological recorder, and the influence of SoE on CS was investigated by combining multiple psychometric methods. Detailed experimental procedures are presented in Table 1.

Figure 3. Picture of the Experimental Process

Table 1. Detailed Experimental Procedures

Step	Task	Equipment	Content	Notes	Time
1	Experiment Introduction, Equipment Training	Tobii VR Eye Tracker	Experiment briefing, signing ethics consent from, familiarization with VR operation methods	Participants must abstain from caffeine, alcohol, smoking, and medication 24 hours prior	5 min
2	Wearing Equipment, Baseline Measurement	Ergo LAB Smart Wearable Physiological Recorder	Record baseline data: HR, HRV, EDA, RESP	Conducted before entering VR scene (2 min)	5 min + 2 min
3	VR Environment Navigation	Tobii Pro Wearable Eye Tracker	Record data: HR, HRV, EDA, RESP	Participants were divided into mirror group (M group) and non-mirror group (N group)	15 min
		Ergo LAB Smart Physiological Recorder	Record Data: Pupil Size, Blink Count, Gaze Duration	FMS oral questionnaire administered every 3 min (participant verbal response)	15 min
4	Baseline Measurement	Ergo LAB Smart Physiological Recorder	Record post-exposure baseline data: HR, HRV, EDA, RESP	After leaving the VR scene, test the baseline data once (2 min)	2 min
5	Subjective Psychological Assessment	"Questionnaire Star" online survey platform	Fill out the SSQ and IPQ questionnaire	Administer questionnaires after VR exposure	8 min
Note: HR-Heart Rate; HRV-Heart Rate Variability; EDA-Electrodermal Activity; RESP-Respiration Rate; SSQ-Simulator Sickness Questionnaire;					

IPQ-Igroup Presence Questionnaire;
FMS-Fast Motion Sickness Scale.

4.3 Multimodal Data Validation Results

To quantify the impact of mirror exposure on SoE and CS, we conducted independent samples T-tests and Pearson correlation analysis on multimodal datasets. Table 2 selectively presents physiological indicators with significant intergroup differences ($p<0.05$), highlighting reduced EDA and RESP, in mirror-enhanced environments. Table 3 focuses on psychological linkages, revealing critical correlations between SoE sub-dimensions (Involvement-INV, Realism-REAL) and posttest CS symptoms. Together, these statistically validated patterns provide empirical grounding for spatial design optimization.

Table 2. Independent Samples T-test Analysis of Physiological Indicators

Indicator	Time Period	Group (Mean ± Standard Deviation)		*t*	*p*
		M Group	N Group		
EDA	3-6min	2.84 ± 1.35	4.24 ± 2.60	-2.274	0.030*
	6-9 min	2.94 ± 1.24	4.08 ± 2.06	-2.253	0.031*
	9-12 min	2.87 ± 1.10	4.64 ± 2.37	-3.206	0.003**
	12-15 min	2.87 ± 1.49	4.35 ± 2.19	-2.716	0.009**
RESP	9-12min	9.48 ± 1.50	11.37± 1.62	-4.122	0.000**
Note: *p<0.05 (significant), **p<0.01 (highly significant).					

The mirror group exhibited significantly lower EDA throughout the 3-15min period ($p<0.05$), and significantly more stable RESP during 9-12min ($p<0.01$), indicating lower physiological discomfort. MPD was only significantly higher in the initial period (0-3min) ($p<0.05$), potentially related to heightened early attention triggered by the mirror.

Table 3. Pearson Correlation Analysis of Psychological Indicators

Analysis Target	Metric	r	p
SoE vs CS	INV vs SSQ - Nausea	-0.399	<0.01**
	INV vs SSQ - Oculomotor Discomfort	-0.316	<0.05*
	INV vs SSQ - Disorientation	-0.337	<0.05*
	INV vs SSQ - Total Score	-0.372	<0.05*
Mirror Exposure Effect	REAL vs Mirror Gaze Duration	0.637	<0.01**
	REAL vs Spatial Presence	0.373	>0.05
Note: All SSQ metrics are posttest scores; *p<0.05 (significant), **p<0.01 (highly significant); r>0 (positive correlation), r<0 (negative correlation); |r|>0.5(Strong correlation), 0.3<|r|<0.5 (Moderate correlation), |r|<0.3 (Weak correlation).			

The INV dimension of SoE showed significant negative correlations with all CS dimensions ($r=-0.316$～-0.399), particularly with the SSQ Total Score ($r=-0.372$). REAL was strongly positively correlated with mirror gaze duration ($r=0.637$) and weakly positively associated with Spatial Presence ($r=0.373$), suggesting that mirror exposure enhances immersion by increasing environmental realism.

These multimodal findings empirically validate that mirror exposure enhances SoE while alleviating CS, providing a physiological-psychological foundation for translating experimental insights into spatial interventions. Building on this evidence, students developed the “Window-Mirror” strategy, a dynamic interface integrating reflection and transparency, to optimize virtual social spaces.

4.4 Case Analysis of Student Design Outcomes

To verify the design transformation effect of the experimental conclusions, students applied the experimental findings and theoretical understanding to specific optimization schemes for virtual game architectural space design, based on the correlation mechanism between SoE and CS. By integrating the functions of windows and mirrors into a dynamic composite interface. This not only provides users with mirror feedback to enhance SoE but also avoids the problem of traditional mirrors fragmenting fragment architectural spatial scenes, achieving a direct transformation from data to spatial intervention. The following is presentative example of some student homework results. (Figure 4)

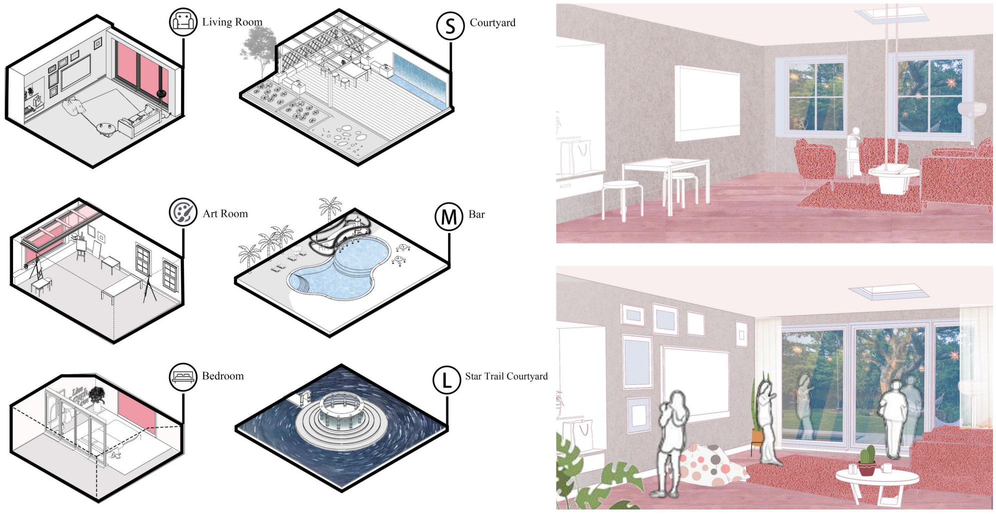

Figure 4. Axonometric Scenario of Interior Renovation

5 Feedback and Discussion

To evaluate the teaching effectiveness, questionnaires and data analysis were conducted among students participating in the experiment. A survey questionnaire was designed using "Questionnaire Star" online survey platform, and all students enrolled in the experimental course were surveyed. The questionnaire was filled out online, with students required to answer truthfully and independently. A total of 39 valid samples were collected. The analysis of the survey results is as follows:

5.1 Student Competency Enhancement Evaluation

Through chi-square test analysis, it was found that there was no statistical correlation between whether students had played games that included virtual architectural spaces and their level of understanding of VR technology and virtual game architectural spaces before the course. This indicates that the design of the experimental course is universally applicable to students with different backgrounds and does not affect the manifestation of the course's effectiveness. (Table 4)

Table 4. Chi-Square Test Results of Gaming Experience and Pre-Course VR Understanding

Question	Level	Have you played games that includes virtual architectural spaces? e.g., Black Myth: Wukong, Genshin Impact, etc.		Total	χ2	*p*
		Yes	No			
Before taking this course, what was your level of understanding of VR technology and virtual game architectural spaces?	1	3.70%	0.00%	2.56%	5.284	0.259
	2	0.00%	8.33%	2.56%		
	3	48.15%	50.00%	48.72%		
	4	29.63%	41.67%	33.33%		
	5	18.52%	0.00%	12.82%		
Note: *p<0.05 (significant), **p<0.01 (highly significant). Understanding level definitions: 1 = No knowledge; 2 = Understand basic concepts only; 3 = Some understanding (limited depth); 4 = Familiar with practical experience; 5 = In-depth research.						

Survey results on students' mastery of skills showed that: At the level of understanding SoE, 61.54% of students reported having a "profound" or "very profound" understanding of SoE in virtual game architectural spaces, indicating that the course content significantly promoted students' comprehension ability; 64.1% of students demonstrated good mastery of VR equipment, his suggests the course effectively enhanced students' knowledge and operational skills regarding VR devices; 43.59% of students stated they had "some understanding, but not in-depth" of physiological indicators and psychological scales. Subsequent teaching needs to strengthen how to specifically combine physiological indicators and psychological scales to solve virtual research problems; 89.74% of students were able to wear and adjust VR HMD devices through the experiment. However, only 41.03% of students were able to analyze the guiding significance of experimental data for design, reflecting that the practical operational effects in teaching were stronger than theoretical analysis. (Figure 5-8)

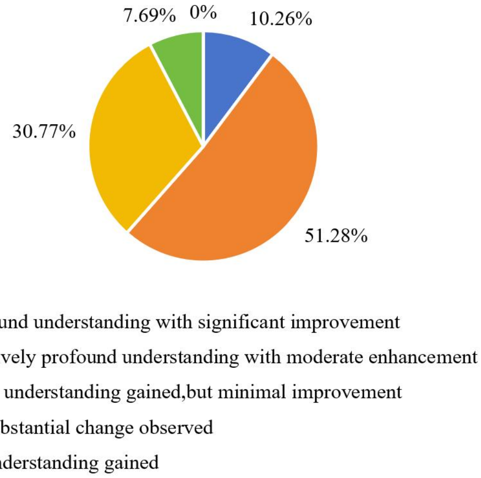

Figure 5. Post-Course Distribution of SoE Understanding Level in Virtual Spaces

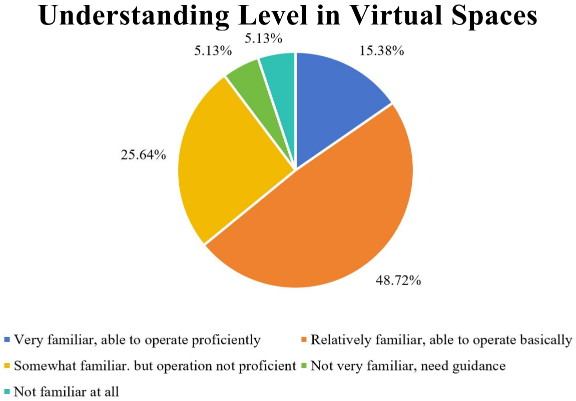

Figure 6. Post-Course Distribution of VR equipment operation proficiency

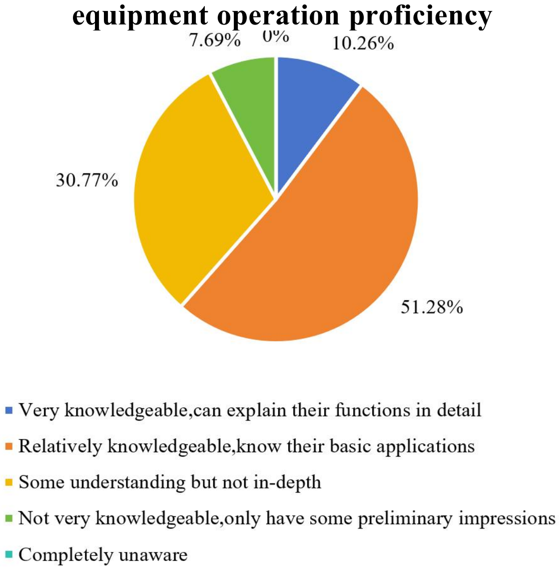

Figure 7. Post-Course Distribution of Understanding on Physiological and Psychological Scales

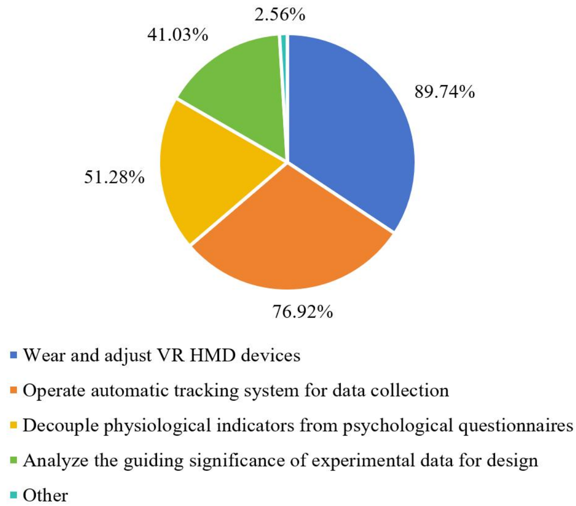

Figure 8. Proportion of Independently Completed Experimental Tasks

5.2 Virtual Environment Experience Evaluation

Students' overall evaluation of the virtual architectural space experience was positive (overall average score for environmental detail experience: 3.87, overall average score for VR overall environmental perception: 3.65). Aspects such as street layout and planning (4.0 points) and architectural color (3.92 points) within the environmental experience received high recognition, confirming the value of VR technology in enhancing spatial perception. However, "interactive experience" scored the lowest (3.49 points) in the perception of residential environments through VR, becoming a core shortcoming of the teaching, nearly 10% below the overall average. Future teaching needs to prioritize optimizing the fluency of interactive design and strengthening the perceptual intensity of the VR environment to bridge the gap between technological experience and spatial design. (Figure 9-10)

87.18% of students considered the VR scenes the most realistic and had the highest preference, proving the significant effect of VR technology in the course on enhancing students' spatial perception. Using an independent samples T-test (Table 5), a significant difference was found in the perception of realism in the VR environment between students who preferred VR and those who did not. Although students preferring VR (34) far outnumbered those in the non-preference group (5), their rating for VR realism (3.71 points) was actually lower than the non-preference group (4.0 points). This contradiction demonstrates that VR technology can provide spatial experiences surpassing traditional tools, but also reflects that the realism of the current VR scenes has not fully met students' expectations. Future teaching may need to set VR scenes at different levels to meet the perceptual needs of different students. However, due to the small sample size of non-preference VR students, the analysis results might be affected, but the significant difference has proven cognitive divergence among the groups, and subsequent verification requires expanding the student sample size. (Figure 11)

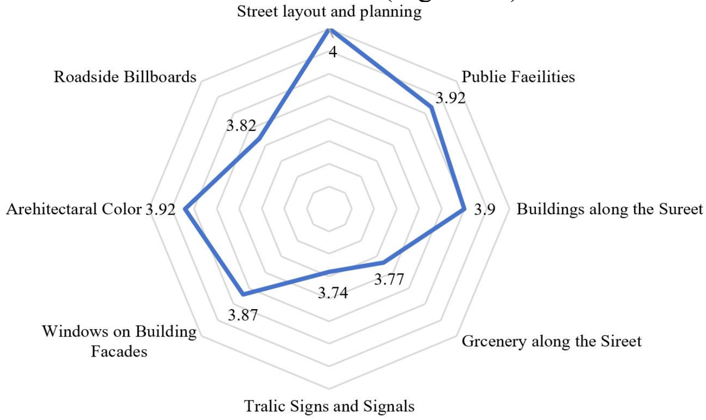

Figure 9. Architectural Environment Details Experience Score

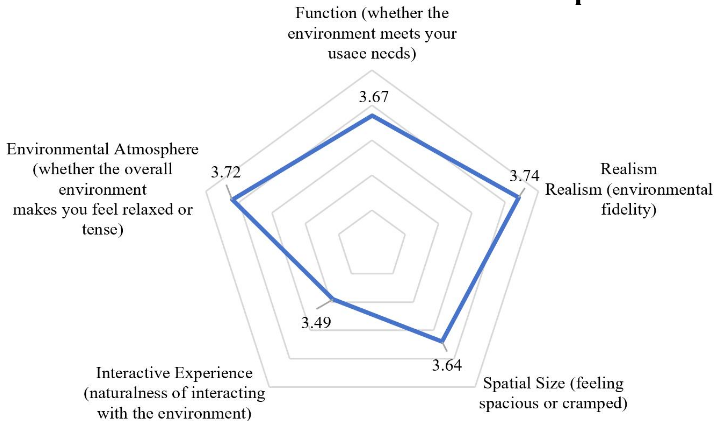

Figure 10. VR Environment Perception Dimension Score

Table 5. Independent Samples T-test on Scene Preferences and Realism Perception

	After experiencing the street architectural scene with VR, which felt more realistic compared to drawings and models? Which did you prefer? (Mean ± Standard Deviation)		*t*	*p*
	1.0 (*n*= 34)	2.0 (*n*= 5)		
In this VR environment experience, your feeling of realism regarding the architecture and the overall street environment was (Environmental fidelity)	3.71 ± 0.80	4.00 ± 0.00	-2.147	0.039 *
Note: *p<0.05 (significant), **p<0.01 (highly significant).				

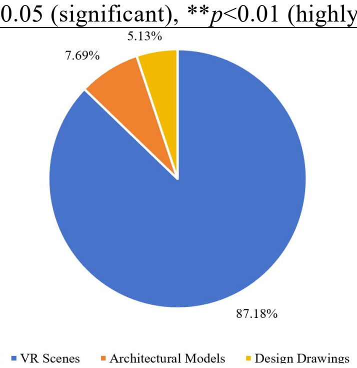

Figure 11. Preference for Architectural Space Expression

5.3 Effectiveness of Design Strategies

The "Window-Mirror" interactive design effectively enhanced students' multi-dimensional understanding of the virtual space. This was particularly prominent at the level of spatial interactive experience: 66.66% of students believed the design strategies was "quite helpful" or "very helpful" for human factors engineering (human-centered) and technology application. This directly corresponds to 74.36% of students reporting "partial improvement" or "significant improvement" in their spatial interaction and experience abilities - indicating that embodied interaction technology can significantly strengthen students' cognitive understanding of spatial experience.

However, the effectiveness at the level of technology application was weak: 69.23% of students believed the "Window-Mirror" interactive design was "quite helpful" or "very helpful" for understanding creativity, corresponding to nearly 70% of students reporting that the experiment significantly enhanced their understanding of spatial design creativity. Yet, only 53.85% of students believed the "Window-Mirror" interactive design helped them understand data-driven design technology, corresponding to only 64.1% (the lowest proportion) of students feeling that the experiment helped improve their understanding of the technological implementation and limitations of virtual spaces. This contrast reveals a key contradiction in teaching: students can understand design logic through the design strategy of "Window-Mirror" interaction, but struggle to transform technical data into design tools. (Figure 12-13)

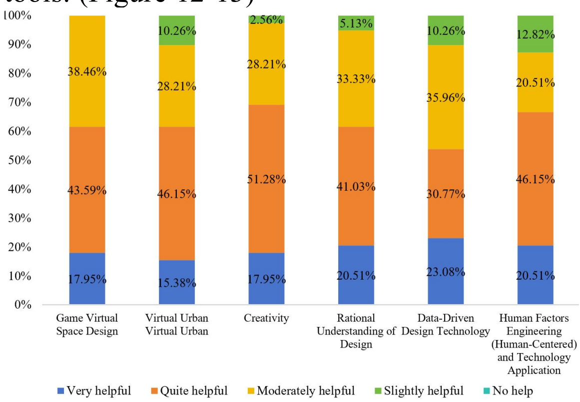

Figure 12. Cross Disciplinary Effectiveness of "Window-Mirror" Strategy

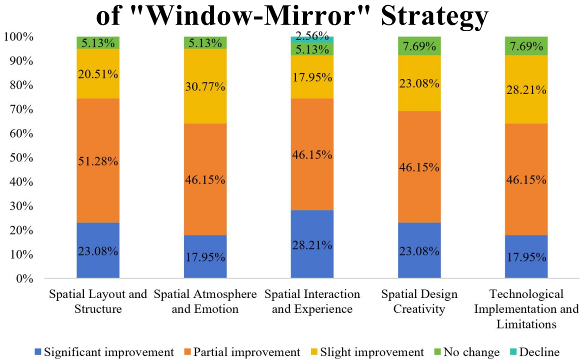

Figure 13. Enhancement Effect on Virtual Space Comprehension Abilities

5.4 Teaching Satisfaction

The teaching effectiveness of the experimental course received strong affirmation from students. Over 87% of students expressed being "satisfied" or "very satisfied" with the teaching model, with no one choosing a negative evaluation. Furthermore, 76.92% of students were willing to participate in relevant scientific research practices in the future. This positive evaluation aligns with students' perspectives on VR's substitutability for physical spatial experience. Survey results indicate that 71.79% perceived VR as offering "completely or mostly substitutable" spatial experiences. Only 7.69% viewed VR as minimally an auxiliary tool, asserting that core spatial cognition relies on physical experience. Crucially, with no students selecting "no substitution at all", these findings collectively reflect students' high satisfaction with and acceptance of VR technology integration in teaching. (Figure 14-16)

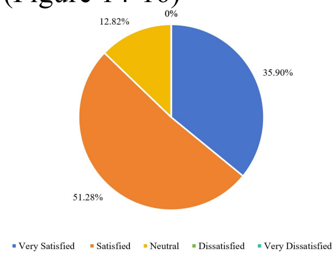

Figure 14. Student Satisfaction Evaluation of the Experimental Course Teaching

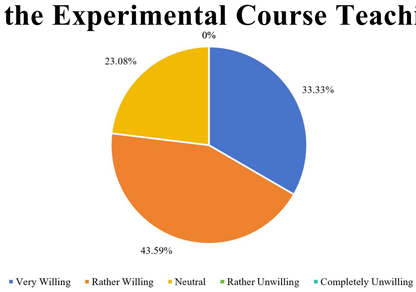

Figure 15. Student Willingness to Participate in Follow-up Research or Practical Projects

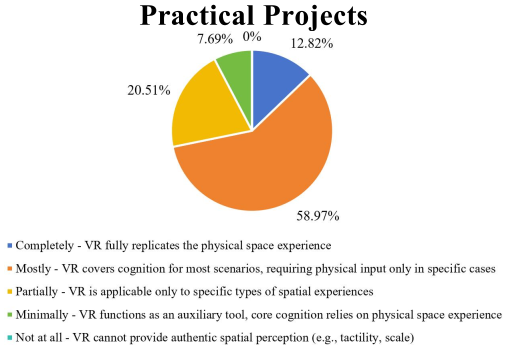

Figure 16. Student Perception Distribution of VR Substitution for Physical Space Experience

5.5 Course Optimization Direction

61.54% of students ranked "VR Equipment Hands-on Operation" first, indicating this segment was highly recognized by students. However, the data analysis and discussion segment was considered the least valuable by students, possibly because its design in the course was not deep enough or disconnected from actual design practice. Simultaneously, a significant 82.05% of students requested adding more design cases. This provides a solution for future teaching: by increasing practical cases, allowing students to see the direct guiding role of data analysis for design, which should be the primary task for course optimization. Although student evaluations of the mirror exposure experiment design segment were not high, as it is the core experiment of this course, it may be necessary to enhance student recognition by increasing explanations of its significance or improving the experimental design. (Figure 17-18)

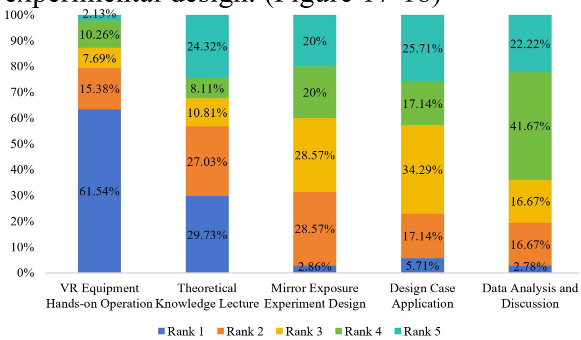

Figure 17. Students' Ranking of the Value of Course Components

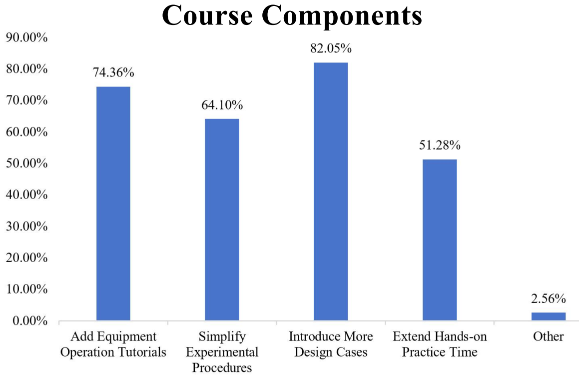

Figure 18. Priority Distribution of Course Optimization Requirements

6. Conclusion

This VR-based experimental course established a four-stage teaching model to explore how the SoE influences virtual architectural design. Through mirror exposure experiments integrating multimodal data, students quantitatively analyzed the SoE and CS correlation mechanism. Findings were translated into optimized spatial solutions, resolving the technical contradiction that traditional mirrors would fragment architectural spatial scenes.

Based on the teaching practice and evaluation data, the core conclusions of this study are as follows: Firstly, the VR experimental course significantly enhanced students' experience and understanding of virtual space, as evidenced by the majority of students demonstrating profound SoE cognition in virtual game spaces, proficiency in VR equipment operation, and positive environmental detail ratings, demonstrating the effectiveness of VR technology in strengthening architectural spatial perception. Secondly, the "Window-Mirror" strategy successfully realized evidence-based design of virtual space-through multimodal data analysis in the mirror exposure experiment, it validated the mirror's enhancement effect on SoE and alleviation of CS, with most students confirming that this strategy improved their application capability in human factors engineering, completing the design loop from experimental evidence to spatial optimization. Finally, students showed high satisfaction with the VR teaching model and widespread recognition of its instructional substitutability. However, future efforts should address the demands of the majority of students by expanding diverse VR experience scenarios for architectural spaces, enhancing students' understanding of both real and virtual spaces, and strengthening interdisciplinary integration mechanisms for translating data analysis into design implementation.

This experimental course directly addresses the key issue of CS in VR technology applications, providing a replicable teaching solution for alleviating virtual space comfort challenges. It breaks through the limitations of traditional architectural teaching that emphasizes "visual aesthetics," establishing an innovative path of "human factors technology data-driven design." It promotes the transformation of students' design thinking from subjective experience towards an empirically supported practical model, offering new ideas and directions for the future development of architectural design education.

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References

[1] Chen X, Xiao C, Xu H. (2024). Measures discussion of virtual reality technology applied in architectural design teaching. In [Conference proceedings title] (pp. 53-58). Jiangxi Science and Technology Normal University. https://doi.org/10.2991/978-94-6463-242-28

[2] Stanney K, Lawson B D, Rokers B, Dennison M, Fidopiastis C, Stoffregen, T, Fulvio J M. (2020). Identifying causes of and solutions for cybersickness in immersive technology: reformulation of a research and development agenda. International Journal of Human-Computer Interaction, 36(19), 1783-1803.

[3] Kilteni K, Groten R, Slater M. (2012). The sense of embodiment in virtual reality. Presence: Teleoperators and Virtual Environments, 21(4), 373-387.

[4] Weech S, Kenny S, Barnett-Cowan M. (2019). Presence and Cybersickness in Virtual Reality Are Negatively Related: A Review. Frontiers in Psychology, 10.

[5] Zhang X. (2023). The application of post-humanism in digital media visual design—Cyberpunk 2077 as an example. SHS Web of Conferences, 155, 02005. https://doi.org/10.1051/shsconf/20231550 2005

[6] Carrasco-Walburg C, Valenzuela-Astudillo E, Maino-Ansaldo S, Correa-Díaz M, Zapata-Torres D. (2021). Experiential teaching-learning tools: Critical study of representational media and immersion in architecture. In SIGraDi 2021: Designing Possibilities | Ubiquitous Conference (pp. 475-486). Universidad Técnica Federico Santa María.

[7] Li G, Zhang H. (2018). [Research on teaching model of architectural spatial perception based on VR interactive technology]. Chinese & Overseas Architecture, 11, 54-56. (In Chinese)

[8] Shanti Z, Al-Tarazi D. (2023). Virtual reality technology in architectural theory learning: An experiment on the module of history of architecture. Sustainability, 15, 16394. https://doi.org/10.3390/su152316394

[9] Yu R, Gu N, Lee G, Khan A. (2022). A systematic review of architectural design collaboration in immersive virtual environments. Designs, 6(5), 93. https://doi.org/10.3390/designs6050093

[10] Chen L, Peng J, Li J. (2017). [Research progress and enlightenment of virtual reality in landscape architecture]. Chinese National Expo, 204-205. (In Chinese)

[11] Doma O O, Şener S M. (2022). An investigation of architectural design process in physical medium and VR. ITU A|Z Journal, 19(3), 631-649. https://doi.org/10.5505/itujfa.2022.77019

[12] Kidik A, Asiliskender B. (2024). XR experience in architectural design studio education: A systematic literature review. Journal of Design Studio, 6(1), 153-167. https://doi.org/10.46474/jds.1472518

[13] Castiñeiras López J. (2021). Game Studies. Aproximaciones metodológicas desde la Historia del Arte Medieval. Espacio, Tiempo y Forma. Serie VII, Historia del Arte, 9, 397-418. https://doi.org/10.5944/etfvii.9.2021.30141

[14] Zonaga A, Carter M. (2019). The role of architecture in constructing gameworlds: Intertextual allusions, metaphorical representations and societal ethics in Dishonored. Loading… The Journal of the Canadian Game Studies Association,

12(20), 71-89. https://doi.org/10.7202/1065898ar

[15] Reason J T. (1978). Motion sickness adaptation: a neural mismatch model. Journal of the royal society of medicine, 71(11), 819-829.

[16] Riccio G E, Stoffregen T A. (1991). An ecological Theory of Motion Sickness and Postural Instability. Ecological Psychology, 3(3), 195-240. https://doi.org/10.1207/s15326969eco0303_2

[17] Treisman M. (1977). Motion sickness: an evolutionary hypothesis. Science, 197(4302), 493-495.

[18] Smith H J, Neff M. (2018, April). Communication behavior in embodied virtual reality. In Proceedings of the 2018 CHI conference on human factors in computing systems. 1-12.

[19] Carver C S, Scheier M F. (1978). Self-focusing effects of dispositional self-consciousness, mirror presence, and audience presence. Journal of personality and social psychology, 36(3), 324.

[20] Bögels S M, Rijsemus W, De Jong P J. (2002). Self-focused attention and social anxiety: The effects of experimentally heightened self-awareness on fear, blushing, cognitions, and social skills. Cognitive Therapy and Research, 26, 461-472.