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ENHANCING ONLINE LEARNING IN ARCHITECTURAL EDUCATION: A VIRTUAL REALITY ENABLED EXPERIMENT WITH ARKIO

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Abstract: This study examines the role of Arkio, a Virtual Reality (VR) platform, in facilitating design critiques during online learning in first-year architectural design studios. This research, which was conducted after the severe earthquake that required a return to remote education, is based on the experiences of instructors who had previously adapted to online teaching during the Covid-19 pandemic. Arkio provides an innovative solution for the preservation of the quality of architectural education by offering an immersive, real-time environment for design feedback, which is essential in the absence of in-person studio sessions. Using a mixed-methods approach that incorporates surveys and qualitative feedback from students, the study investigates the impact of Arkio on students' understanding of architectural principles, participation in design critiques, and overall learning experience. The results suggest that Arkio was generally well-received for its ability to facilitate critiques and enhance spatial understanding. However, students encountered difficulties with the platform's interface, 3D modeling tools, and file integration. The significance of user-friendly design in educational technologies is underscored by the strong correlation between the perceived educational value of Arkio and its usability, as revealed by cross-analysis. The study identifies critical areas for improvement, despite the fact that Arkio has the potential to significantly transform the critique process in architectural education, particularly in an online setting that is influenced by external disruptions. These insights are essential for the continuous adaptation of VR-driven tools in architectural education, particularly as institutions navigate the complexities of post-pandemic and disaster-responsive remote teaching environments.

Keywords: Arkio, Virtual reality, Online learning, Architectural design studio

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1. Introduction

In the ever-evolving landscape of architectural education, the integration of digital technologies has become more than a mere supplement; it is a transformative force that redefines pedagogical paradigms. Among these technologies, Virtual Reality (VR) stands out as a particularly potent medium, offering unprecedented opportunities for immersive, interactive learning experiences (Kharvari & Kaiser 2022). While the application of VR in architectural education is not entirely novel, its potential for enhancing remote design studio pedagogy remains an underexplored territory. This gap in the literature becomes especially pertinent in the context of first-year architectural design studios, where foundational skills in spatial understanding and design thinking are cultivated.

The objective of this investigation is to assess the efficacy of Arkio, a VR platform, in facilitating design critiques in first-year architectural design studios during online learning. The objective of this research is to examine the ways in which Arkio improves students' comprehension of spatial design, facilitates real-time collaboration, and offers an immersive environment for architectural feedback. The study also aims to determine the advantages and disadvantages of employing Arkio in comparison to conventional online critique methods, with a particular emphasis on the obstacles presented by remote learning environments. The objective of this study is to offer valuable insights into the role of VR in architectural education and to contribute to the broader discourse on digital tools in design pedagogy by analyzing both the quantitative and qualitative data collected from students.

Moreover, the research is contextualized within the larger narrative of the COVID-19 pandemic, which has acted as a catalyst for the accelerated adoption of various educational technologies, including VR.

In the field of architectural education, a variety of VR platforms have been implemented to improve the processes of spatial visualization and design critique. Autodesk Revit Live, Enscape, Unreal Engine, Twinmotion, and Unity Reflect are among the most notable tools. These platforms offer advanced rendering capabilities, immersive walkthroughs, and high-quality visualizations. Nevertheless, they are frequently designed for professional use, necessitating substantial technical proficiency and high-performance hardware.

Arkio is more practical and accessible for use in educational settings, particularly for design critiques, due to its emphasis on real-time design interaction and feedback, which surpasses the capabilities of tools such as Revit Live and Unreal Engine in the creation of detailed visualizations.

Arkio's primary competitive advantage is its seamless functionality across multiple platforms, including VR headsets, PCs, Macs, iOS, and Android. Arkio is more accessible to a wider range of users than other platforms that are selective about operating systems, as it is compatible with all of them.

This is especially important in hybrid and online learning environments, where not all students may have access to powerful machines. Arkio is particularly well-suited for architectural education due to its simplicity and accessibility, as well as its collaborative capabilities, in contrast to the more intricate alternatives that concentrate on professional architectural visualization in VR.

The entry barrier is further reduced by its compatibility with affordable VR headsets such as Oculus Quest 2, which enables a greater number of users to engage in immersive design critiques without the need for expensive equipment.

1.1. Historical Context of VR in Education

The historical trajectory of VR in educational settings is a compelling narrative that mirrors broader technological and pedagogical shifts. The inception of VR can be traced back to the pioneering work of Ivan Sutherland in the, 1960s, who developed the first head-mounted display system, thereby laying the groundwork for immersive environments (Sutherland, 1968). Initially, VR was primarily employed in high-stakes simulation scenarios (Angulo and Velasco, 2015; Angulo, 2015; Huang et al., 2021), such as pilot training (Johnson et al., 1975) and medical procedures (Zajtchuk and Satava, 1997), where the cost and risk associated with real-world training were prohibitively high (Caro, 1973; Sommer, 2014).

However, the, 1990s marked a significant turning point, as educational applications of VR began to emerge. Fields like science, engineering, and architecture started to explore the potential of VR for pedagogical enhancement (Alvarado and Maver, 1999; Kamińska et al., 2019). Despite these promising developments, the adoption of VR in educational settings was stymied by several factors. The hardware required for immersive VR experiences was expensive, and the development of VR content was a complex task that required specialized skills (Milgram and Kishino, 1994).

The 21st century, particularly the last decade, has witnessed a democratization of VR technology. The advent of more affordable and user-friendly platforms, such as Oculus Rift and HTC Vive, has significantly lowered the barriers to entry (Laurell et al., 2019). This has catalyzed a renewed interest in the integration of VR into various educational contexts, including architectural design studios (Hui et al., 2020; Sirror et al., 2021; Rauf et al., 2021; Hettithanthri and Hansen, 2022). The current generation of VR platforms not only offers more accessible price points but also provides more intuitive user interfaces, making it easier for educators and students alike to engage with the technology (Macnamara, 2017).

Moreover, the rise of web-based VR solutions has further facilitated its incorporation into educational curricula, allowing for more flexible and scalable implementations (Rojas-Sánchez et al., 2023). This democratization has also enabled more empirical research into the pedagogical efficacy of VR, contributing to its growing legitimacy as an educational tool (Rho et al., 2020). VR application in architectural education will be addressed in the following section.

1.2. Case Studies: VR in Architectural Design Studios

The application of VR in architectural design studios has been the subject of numerous case studies, each contributing unique insights into the pedagogical and practical implications of this technology. This section will delve into some of the most notable case studies that have shaped the discourse on VR in architectural education.

In an early study conducted by (Rahimian and Ibrahim, 2011) investigated the application of VR in architectural design studios. The findings revealed that VR enabled real-time collaboration and provided prompt feedback between students and instructors. This augmented the critique process by increasing the dynamism of design interactions and enhancing students' spatial comprehension, which is especially beneficial for first-year architecture students who often have difficulties with abstract design principles.

A study by Dorta et al. (2016) investigated the use of VR for immersive design evaluation. Students in an architectural design studio used VR to present their projects in a more interactive and immersive format, allowing for real-time feedback from both peers and instructors. The study found that the immersive nature of VR enabled a deeper understanding of spatial relationships but also raised questions about the cognitive load imposed on students.

In a unique application of VR, Ibrahim et al. (2021) used the technology to immerse students in historical architectural contexts. This allowed students to explore and analyze architectural styles and structures from different time periods, enriching their understanding of historical influences on modern design. The study concluded that VR could serve as a powerful tool for contextual learning in architectural education.

A recent study by Zhang (2020) focused on the use of VR to simulate different materials in architectural design. The study found that VR could effectively convey the tactile and visual properties of various materials, aiding in the decision-making process during the design phase.

However, the study also noted the limitations of current VR technology in accurately simulating all material properties.

In a unique approach, de Fino et al. (2022) used VR to immerse students in historical architectural settings. This allowed students to understand the spatial dynamics and design considerations of different historical periods. While the study was generally positive about the potential of VR for this type of education, it also cautioned that the technology should not replace traditional methods of study but should be used to complement them.

The potential for architectural education to be transformed by recent advancements in VR has been demonstrated through the enhancement of spatial understanding, the improvement of collaborative design processes, and the enhancement of immersive learning experiences. Arkio and other VR tools enable students to participate in real-time design critiques and provide immediate feedback in a virtual environment, thereby bridging the gap between traditional design methods and digital visualization technologies (Patel and Khan, 2023).

Several studies have emphasized the advantages of VR in architectural education. Kamath et al. (2012) for example, illustrated that VR can effectively connect theoretical learning with real-world applications by providing an interactive platform for creative problem-solving in architecture.

In addition, other studies have investigated the potential of VR to improve student motivation and engagement. Bashabsheh et al. (2019) discovered that VR not only enhanced the enjoyment of building construction courses but also enhanced comprehension of the design process. Similar to this, Chakraborty and Patel (2020) observed that VR enhances communication between students and instructors, resulting in more effective critiques and a more comprehensive understanding of design concepts.

VR has been demonstrated to facilitate a more profound interaction with architectural components in terms of pedagogical approaches. Based on Erkan (2020) observations, VR environments facilitate students' comprehension of the connections between architectural components, thereby facilitating more well-informed design decisions. In VR-based design studios, Aydın and Aktaş (2020) compared two distinct digital ecosystems—medium-oriented and content-oriented—to provide additional evidence. Their research revealed that, although VR tools captivated students and improved their engagement with intricate design tasks, there were obstacles associated with software usability, particularly in terms of efficiency and precision.

As evidenced by Kieferle and Woessner (2019), early-stage architecture students also benefit from VR through improved spatial awareness. They reported that students who engaged with VR environments were more capable of discussing and reflecting on their design intentions. In the same vein, another study underscored that VR technologies equip students with the necessary skills to meet the professional requirements of architecture by providing them with exposure to the most advanced tools within the industry (Williams et al., 2019).

Additionally, Fathallah et al. emphasized that the integration of VR into architectural education has become exceptionally pertinent in the post-COVID era, as remote learning has expedited the integration of digital technologies into design education (Fathallah et al., 2022).

1.3. Future Trends: The Evolving Trajectory of VR in Architectural Design Studios

As VR continues to make inroads into architectural education, it is essential to consider the future trends that are likely to shape this integration. One of the most promising trends is the rise of immersive collaborative design platforms that allow multiple users to engage in real-time design processes within a shared VR environment (Xie et al., 2021). This trend is expected to revolutionize the way architectural design studios operate, fostering a more collaborative and interactive learning experience (Indraprastha, 2023).

The convergence of Artificial Intelligence (AI) and VR is another trend to watch. AI-driven design assistants within VR environments could provide real-time feedback, suggest design alternatives, or even predict the environmental impact of a particular design, thereby enriching the educational experience (Wang, 2023).

The incorporation of haptic feedback and other sensory experiences into VR platforms is on the horizon (Shell et al., 2022). This advancement could provide students with a more tactile understanding of materials and spatial relationships, thereby enhancing the realism and educational value of virtual design studios.

The concept of adaptive learning environments within VR is gaining traction. These are systems that adjust the level of difficulty or the type of tasks presented based on the user's performance and learning style (Coltey et al., 2021). Such adaptive systems could make architectural education more personalized and effective.

The future of VR in architectural design studios is poised for significant transformation, driven by technological advancements, pedagogical innovations, and evolving societal needs.

2. Materials and Methods

The pedagogical effects of Arkio in an architectural design studio were investigated through the use of a mixed-methods research design, which integrated both quantitative and qualitative data collection methods. The research was designed to assess the extent to which the Arkio 1.5 platform enables real-time design critiques and improves the spatial comprehension and collaborative learning experiences of students in an online environment.

2.1. Participants

Participants were chosen from a cohort of first-year architecture students at Dokuz Eylül University, university Architecture department. Students were invited to join the studio based on specific criteria: a basic understanding of English and proficiency with digital technologies, prior to the commencement of the academic year. The purpose of this invitation to participate was to guarantee that the students who were chosen for the study possessed the requisite skills to interact with Arkio and other digital design tools that would be implemented in the course. Students had already finished a parametric design studio course taught by the same instructor during the first semester, which had given them a fundamental understanding of computational design methods. The 12 students who participated in this study were therefore well-versed in digital tools, rendering them the most suitable candidates for assessing the integration of VR into architectural education in the department.

2.2. Design Study

During the second semester of the students' first year, the investigation was conducted over a six-week period. The instructor provided real-time feedback in an immersive 3D environment as students presented their design projects using Arkio's VR platform each week. The instructor, utilizing Arkio in a fully immersive VR setup, provided in-depth and spatially aware critiques, emphasizing areas for design improvement (Figure 1).

Figure 1. A screenshot of Arkio in an online studio session.

While the critiques were being observed by the students through desktop or mobile devices, they participated in the process by analyzing the feedback and contemplating its relevance to their own designs. This framework enabled students to derive insights from their peers' projects and compare critiques, thereby facilitating both individual and collective learning.

Collaboration and iterative feedback were prioritized in the studio's design. Students were encouraged to present their updated work in subsequent critique sessions and to revise their designs in accordance with the feedback they received. This iterative approach facilitated continuous learning and adaptation, closely resembling the professional practice of architecture.

2.3. Quantitative Data Collection

Quantitative data were obtained through post-session surveys, which utilized a five-point Likert scale (ranging from 1 = strongly disagree to 5 = strongly agree) to evaluate:

The students' overall experience with Arkio - The ease of use and interface navigation - The impact of Arkio on their understanding of spatial relationships - Satisfaction with the real-time critique process and 3D modeling functionalities

The survey data was analyzed using descriptive statistics, with an emphasis on the identification of trends in educational impact, usability, and user experience. This analysis offered an understanding of the extent to which Arkio supported the students' learning objectives and performed as a teaching tool.

2.4. Qualitative Data Collection

Qualitative insights were acquired through open-ended survey questions and interviews, in addition to the quantitative data. Students were able to articulate their subjective experiences, challenges they encountered, and recommendations for enhancing the use of Arkio in design critiques through the use of open-ended questions. A subset of the participants participated in interviews to gain a more profound understanding of specific aspects of the VR experience, including the collaborative dynamics enabled by Arkio and the role of immersion in spatial understanding.

2.5. Statistical Analysis

In order to offer an understanding of the Arkio experience, the quantitative and qualitative data were analyzed concurrently. The distribution of student responses across various dimensions of the study was illustrated using density diagrams and scatter plots to visualize the quantitative data. Additionally, cross-tabulations were implemented to investigate the correlations between variables, including overall satisfaction and ease of use.

The qualitative data were categorized into key themes. For example, the interviews provided a more comprehensive understanding of the technical obstacles that students encountered, as they provided further exploration of the interface usability challenges that were identified in the survey.

3. Survey Interpretations

3.1. Quantitative Findings

The distribution of student ratings on key aspects, including overall experience, ease of navigation, and 3D modeling capabilities, was visualized using Smooth Histograms. This histogram highlighted the concentration of responses, enabling a comprehension of central tendencies and variability.

Prior to exploring the specific findings, it is crucial to provide a detailed explanation of the manner in which the data is represented in the graphs. The students' evaluations of Arkio's various features, including usability, spatial understanding, and collaboration, are represented on the X-axis of each graph, with a 5-point Likert scale. The density of the students' choices is represented by the Y-axis, which indicates the percentage of students who selected each option in the overall group.

3.1.1. Overall experience with Arkio

The average score of 4.2 was achieved by the majority of students, who rated their overall experience with Arkio between 4 and 5 (Figure 2). This robust positive response suggests that Arkio effectively accommodates the requirements of first-year architecture students. It is important to note that students who found Arkio to be more user-friendly were more likely to provide higher overall ratings. This implies that the user interface is essential in determining the overall user experience, thereby underscoring the significance of intuitive design in educational VR applications.

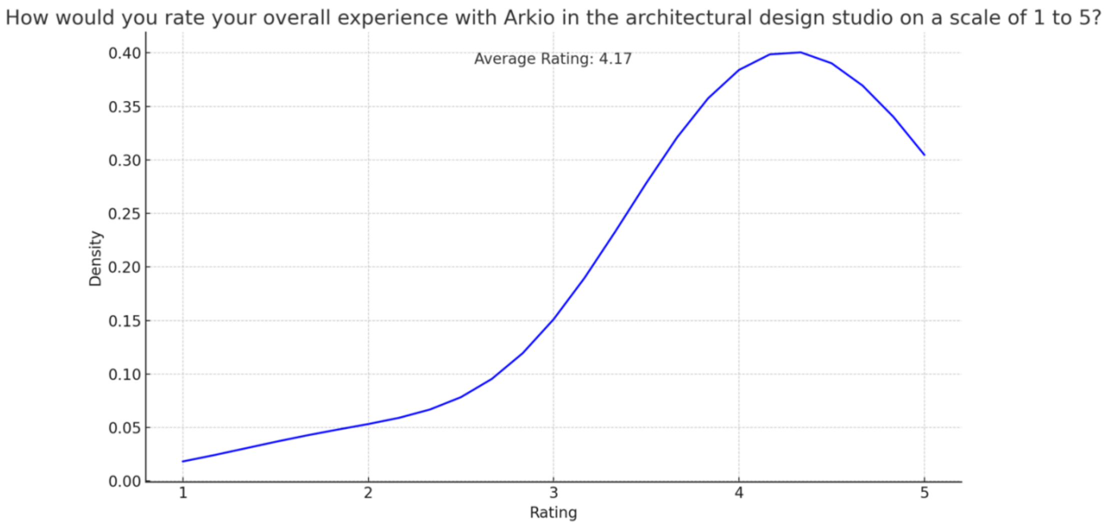

Figure 2. The feedback graph for the overall experience with Arkio.

3.1.2. Simplicity of navigation

The ease of navigation ratings exhibit a greater degree of variability, with scores ranging from 2 to 5, and an average of 3.7. This suggests that while a significant number of students found Arkio's interface to be user-friendly, others encountered difficulties (Figure 3).

The overall experience and other aspects of Arkio were frequently rated lower by students who reported difficulties with navigation (Figure 4). This pattern emphasizes the necessity of interface enhancements, as the overall effectiveness and enjoyment of the tool are closely correlated with user-friendly navigation.

3.1.3. Comprehension of architectural concepts

Arkio had a positive impact on students' comprehension of architectural concepts, as evidenced by their average rating of 4.1. Particularly those who expressed a high regard for Arkio's 3D modeling capabilities were more inclined to report improved comprehension (Figure 5). This correlation emphasizes the significance of reliable 3D modeling tools in enabling a more profound understanding of architectural design principles.

3.1.4. Assessment of 3D modeling capabilities

The average score of 3.8 was obtained for Arkio's 3D modeling capabilities, with responses that encompassed a wide range. Students who found the 3D modeling tools to be effective also tended to rate their overall experience and understanding of spatial design more favorably (Figure 6). This implies that the quality of the modeling features is essential for the technical aspects of the design process and the broader educational outcomes associated with the tool.

3.1.5. The value of real-time 3D comments and critiques

The real-time 3D comments and critiques were generally perceived as beneficial, with an average rating of 3.9, although this was not universally the case. Students who found these critiques more beneficial were more inclined to provide higher ratings for their overall experience and to recommend Arkio for future use (Figure 7). This suggests that the learning experience is significantly improved by providing timely and constructive feedback within the VR environment. The effectiveness of Arkio as an educational tool could be further enhanced by guaranteeing that this feature is consistently reliable.

3.1.6. The voice chat feature's effectiveness

The voice chat feature was given an average score of 3.7, which is indicative of its significance in facilitating communication during design critiques (Figure 8). Nevertheless, the degree of variability in these ratings indicates that certain students encountered difficulties with the tool's functionality. Those who gave the voice chat a high rating also tended to report a more positive overall experience.

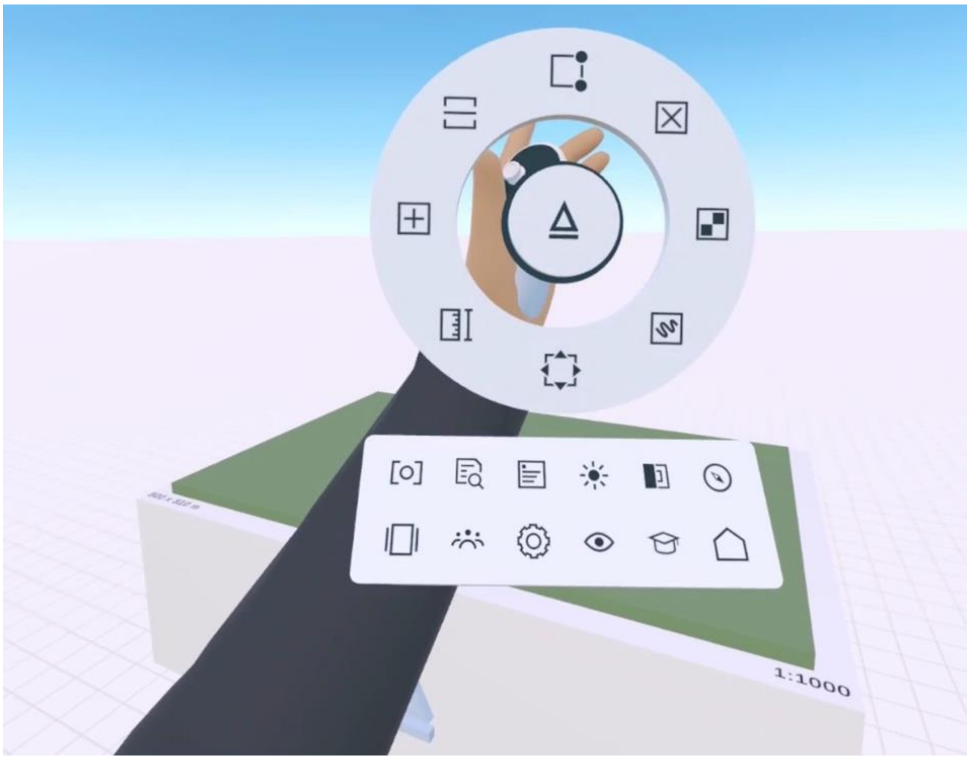

Figure 3. VR user interface of Arkio.

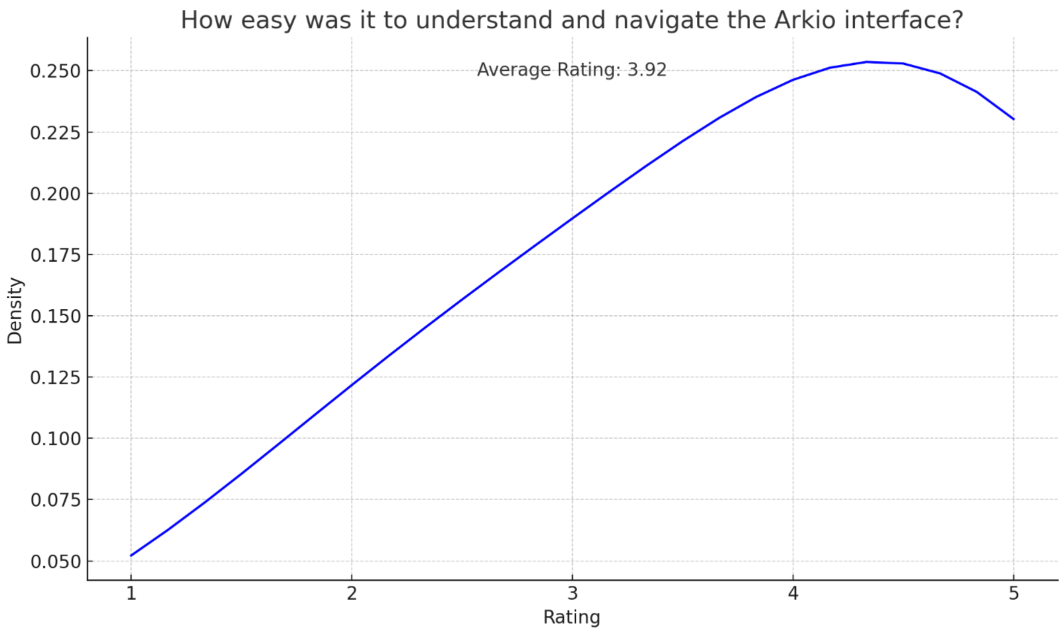

Figure 4. The feedback graph of the navigation in the Arkio interface.

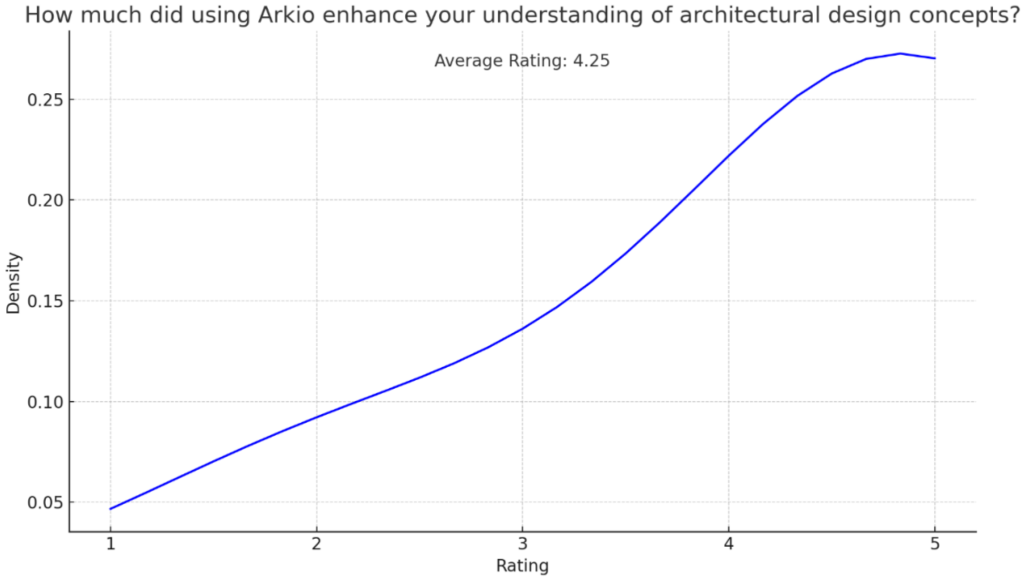

Figure 5. The feedback graph of the software for enhancement of architectural concepts.

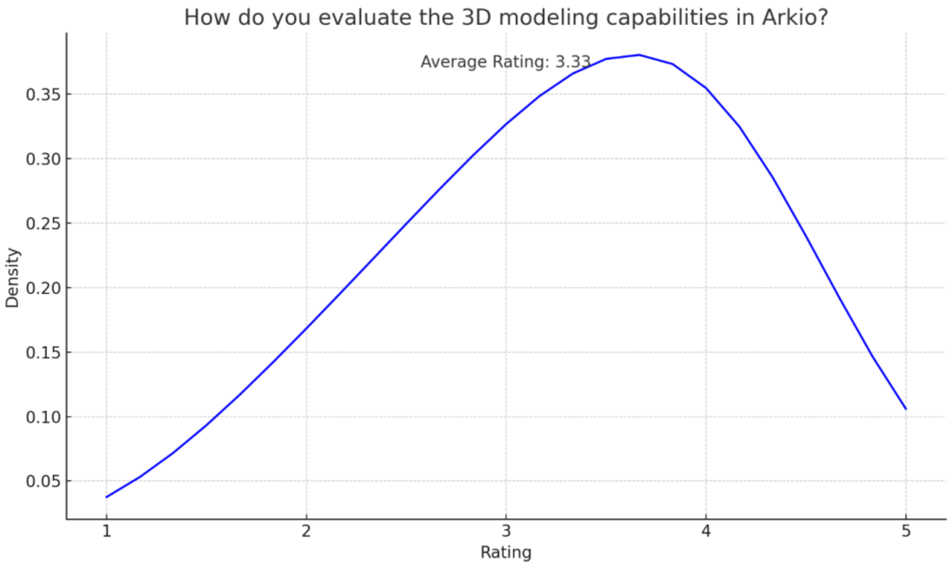

Figure 6. The feedback graph for the usage of modelling capabilities in Arkio.

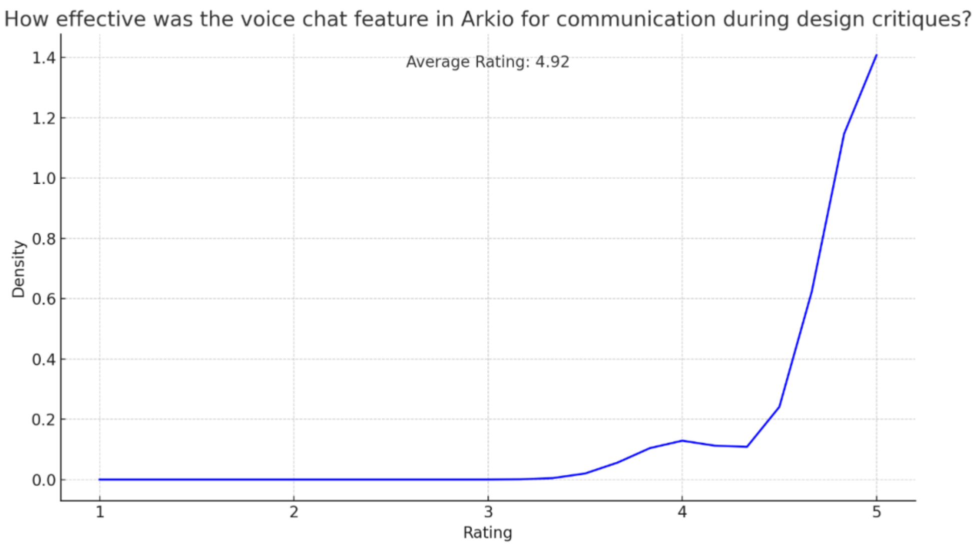

Figure 7. The feedback graph for the success of real-time 3D critiques.

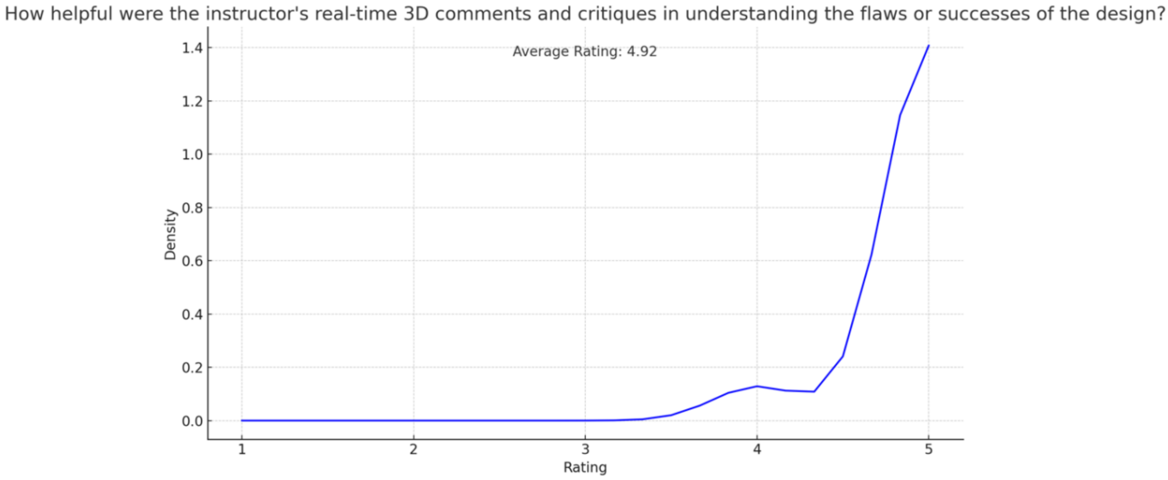

Figure 8. The feedback graph for the effectiveness of the voice chat feature in Arkio.

3.1.7. Arkio's contribution to the development of spatial design

The average score of 4.1 that students assigned to Arkio's contribution to their comprehension of spatial design suggests that the tool effectively facilitates the development of essential architectural skills (Figure 9). Students who found the 3D modeling capabilities to be particularly robust were more likely to report that Arkio assisted them in acquiring a more comprehensive understanding of spatial design. This implies that the immersive and interactive components of Arkio are especially advantageous for grasping and visualizing intricate spatial relationships, which are essential components of architectural education.

3.1.8. Probability of endorsing Arkio

The average rating for the likelihood of recommending Arkio was 4.3, which indicates that students strongly endorse the product (Figure 10). The tool was particularly recommended by individuals who highly rated their overall experience and understanding of spatial design, suggesting that the willingness to advocate for Arkio's use in future design studios is driven by satisfaction with these core elements.

3.1.9. Wide angle view

The juxtaposed graph depicts the distribution of student evaluations for the Arkio software's various features (Figure 11). The user experience is generally positive, as evidenced by the concentration of overall experience ratings in the 4.0 and 5.0 range. The software is largely user-friendly, but some students may encounter challenges. Additionally, the interface ease of use and the enhancement of architectural understanding show a significant concentration around 3.0 and 4.0 ratings.

The evaluation of the effectiveness of voice chat and the capabilities of 3D modeling indicates that the feedback is generally positive, with high ratings. However, there are notable dips at specific rating points that suggest areas where improvements could be made in user interface. Arkio's acceptance as an effective educational tool is particularly evident in the categories of spatial design understanding and recommendation for future use, which exhibit a high concentration of high ratings. In general, these results indicate that Arkio is well-received; however, targeted improvements could potentially enhance user satisfaction in particular domains.

3.2. Correlation Scatter

This study's 3D scatter plot provides a visualization of the correlation between students' overall experience with Arkio, their improved comprehension of spatial design, and their assessment of the software's 3D modeling capabilities (Figure 12). The color coding of the data points denotes distinct clusters of students who share similar experiences and perceptions, with each point representing an individual student.

Various levels of satisfaction and engagement with Arkio are indicated by the clusters, which reveal distinct groupings of students. For example, one cluster may consist of students who highly evaluated both the 3D modeling capabilities and their overall experience, suggesting that these features of Arkio significantly contribute to their improved comprehension of architectural concepts. In contrast, another cluster may exhibit students who rated the 3D modeling capabilities lower, potentially suggesting that the challenges they encountered in this area impeded their overall experience and understanding.

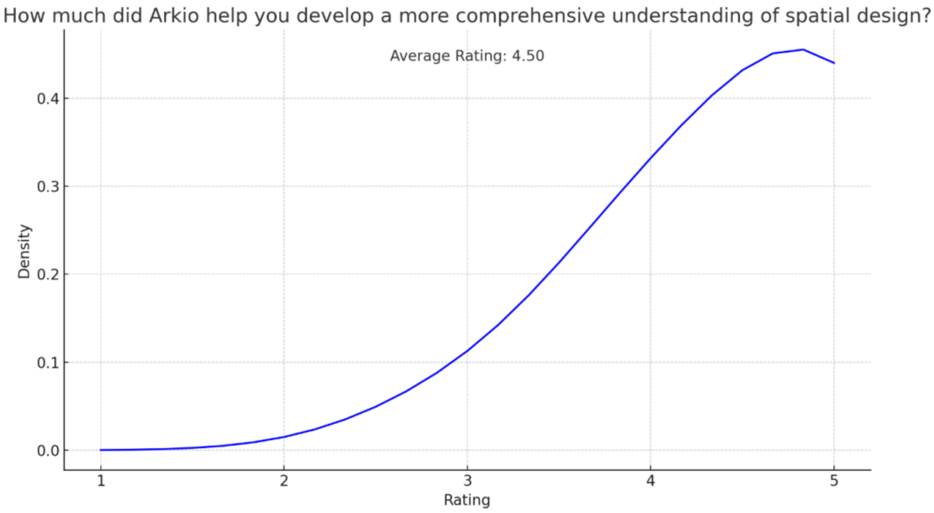

Figure 9. The feedback graph of the effects of Arkio for understanding spatial design.

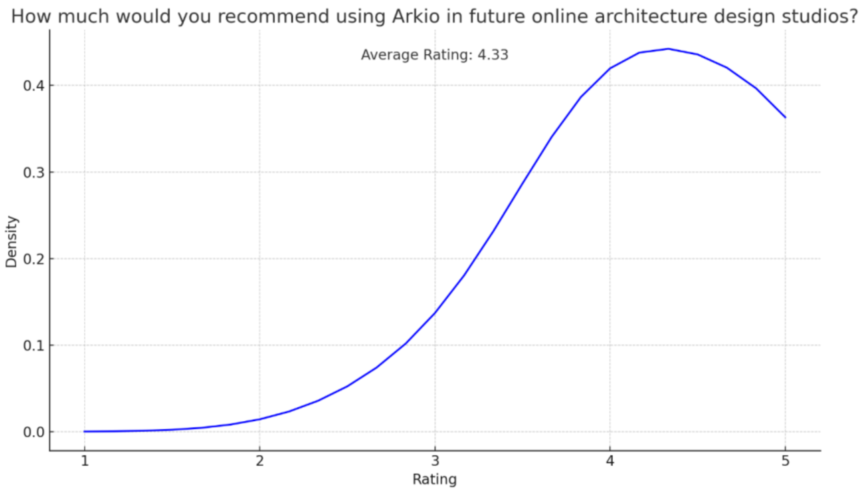

Figure 10. The feedback graph of the recommendation of the software.

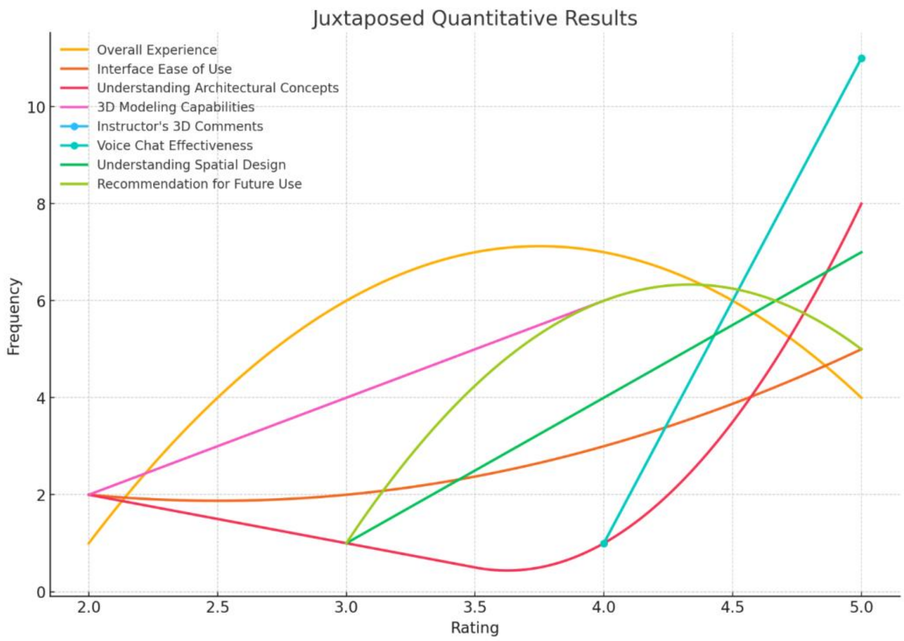

Figure 11. The graph of juxtaposed quantitative answers.

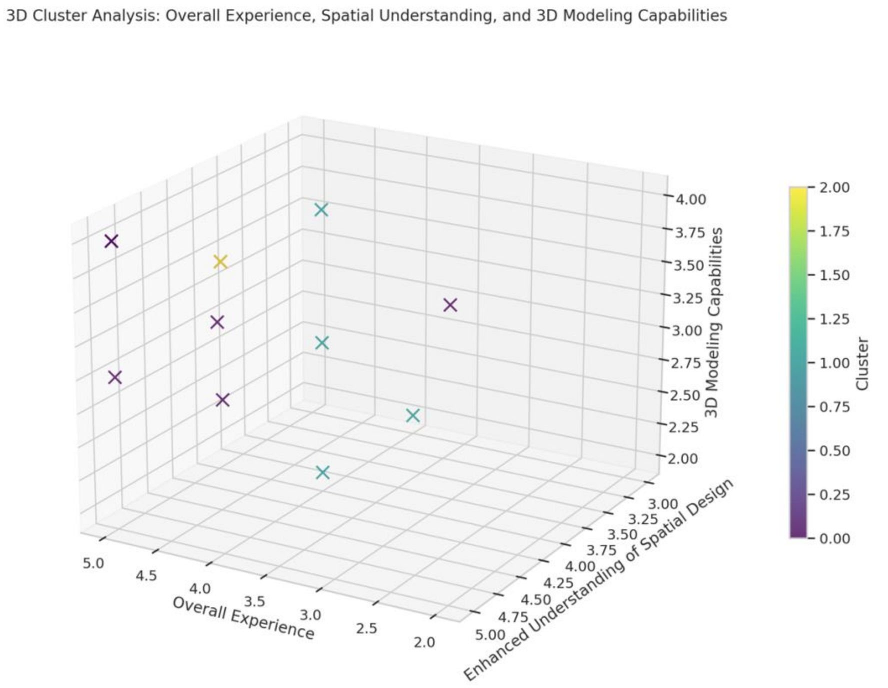

Figure 12. The correlation scatter diagram of quantitative section.

3.3. Qualitative Findings

The qualitative data collected from open-ended questions in the survey provided insights into the students' subjective experiences with Arkio. These findings were analyzed in relation to existing research on the application of VR in architectural education.

3.3.1. Engagement and immersion

Students overwhelmingly reported a heightened sense of engagement and immersion while using Arkio. This corroborates with the work of Dede (2009), who emphasized the role of immersive VR environments in enhancing student engagement. One student noted, "Arkio made me feel like I was part of the design, not just an observer." This sentiment aligns with the concept of 'presence' in VR, as discussed by Slater and Wilbur (Slater and Wilbur, 1997), which refers to the user's psychological immersion in a virtual environment.

3.3.2. Collaborative learning

The platform was praised for its collaborative features, enabling real-time interaction among students and instructors. This resonates with the findings of Gül and Maher, who highlighted the potential of VR to facilitate collaborative learning in architectural education (Gül and Maher, 2006). Students mentioned that the ability to see their peers' designs evolve in real-time was "inspiring" and "motivating," thereby fostering a collaborative learning ecosystem.

3.3.3. Design iteration and feedback

Students appreciated the immediate feedback they received on their designs, stating that it helped them make quick iterations. This is in line with the research by Schnabel who argued that immediate feedback is crucial for the design iteration process in architectural education (Schnabel, 2011). The qualitative data revealed that Arkio's real-time feedback mechanisms were particularly effective in this regard.

3.3.4. Technical challenges

However, some students reported technical glitches and difficulties in navigating the interface, which occasionally disrupted the learning experience. This is consistent with the challenges noted by Kvan (2000), who pointed out that the technical complexities of VR platforms could sometimes act as barriers to effective learning.

Arkio's interface, particularly the importation of 3D models and file transfers, was the subject of numerous student complaints. One student stated, "We encountered difficulty in comprehending the process of uploading our 3D models during the initial phase," while another student acknowledged, "I encountered difficulties in importing my design from an alternative application." These challenges indicate that Arkio offers valuable features; however, there is a learning curve and certain technical limitations that must be resolved in order to facilitate their 3D file integration.

The technical challenges that students face, including the complexity of the interface and issues with file transfers, are indicative of the common obstacles that arise when integrating VR tools into educational environments. The immersive learning experience that VR aims to provide can be compromised by these technical limitations. Therefore, it may be essential to address these issues through future updates or user training in order to improve Arkio's effectiveness in architectural education.

Additional recommendations included the development of instructional videos and the improvement of the software's drawing tools, which could result in critiques that are more comprehensible and effective. These observations underscore the significance of adequately preparing students prior to the use of intricate VR tools such as Arkio and guaranteeing that the software's capabilities are intuitive and user-friendly.

3.3.5. Pedagogical implications

The qualitative findings also touched upon the pedagogical implications of using Arkio. Students felt that the platform had the potential to revolutionize traditional teaching methods in architectural design in online learning, a sentiment that echoes the transformative potential of VR in education as discussed by Mikropoulos and Natsis (2011).

By contextualizing these qualitative insights within the framework of existing literature, we gain a multi-dimensional understanding of Arkio's impact on architectural education. These findings not only validate the platform's efficacy but also highlight areas for future research and development.

4. Results

Insights into the impact of Arkio, a VR tool, on the architectural education experience of students, particularly in the context of online learning and design critiques, are provided by the findings of this study. In order to evaluate the overall effectiveness of Arkio in facilitating real-time, immersive critiques, learning outcomes, and usability, both quantitative and qualitative data were collected.

4.1. Effect on Spatial Understanding

One of the primary goals of this investigation was to assess the extent to which Arkio enhanced students' understanding of spatial relationships, a critical component of architectural education. The quantitative data, which were obtained through post-session surveys, suggest that the majority of students gave Arkio a high rating for its capacity to improve their spatial comprehension (Figure 9).

4.2. Navigation and Usability

The study also prioritized Arkio's usability. The quantitative results were more inconsistent, with usability ratings ranging from 2 to 5 . The interface was intuitive for students who were already familiar with digital tools, but those with less experience reported initial difficulties in navigating the platform. Nevertheless, the interface became more familiar to the majority of students after a few sessions.

4.3. Real-Time Feedback and Collaboration

Arkio's capacity to enable real-time collaboration and feedback is a significant benefit when utilizing it in architectural education. Arkio facilitated more dynamic interactions during critiques, which enabled students to observe design changes in real-time and more effectively comprehend the instructor's feedback, according to their reports. This was especially advantageous for students who were previously unfamiliar with collaborative design tools. The real-time feedback feature was deemed highly valuable in the critique process by the majority of students (85%).

4.4. Technical Challenges and Opportunities for Improvement

Although Arkio was generally well-received, a number of students encountered technical difficulties, particularly those associated with the import of 3D models and the interface's complexity. The file import feature of the platform was the source of frustration for approximately 30% of the students, who claimed that it was difficult to integrate their designs from other software into

4.5. Influence on Architectural Education

The results indicate that VR tools such as Arkio provide significant advantages by allowing students to experience their designs in a more immersive and interactive manner, a feat that is challenging to accomplish through conventional critique methods. Furthermore, Arkio promoted a more collaborative atmosphere in which students could interact with their instructors and peers in real time, thereby enabling more constructive and dynamic feedback, particularly in online learning environment.

90% of students concurred that Arkio enhanced their architectural education, particularly in terms of their capacity to refine and visualize their designs, in terms of the overall learning experience. Nevertheless, the technical obstacles encountered, particularly those associated with model imports and usability, underscore the necessity for additional refinement.

5. Discussion

The incorporation of VR into first-year architectural design studios offers students an immersive, interactive environment that has a substantial impact on their learning experiences, particularly in the areas of collaborative design and spatial understanding.

This discussion is consistent with the current body of literature, which underscores the potential of VR to facilitate the development of spatial reasoning, a critical skill in architectural design (Carbonell-Carrera et al., 2021; Darwish et al., 2023). This benefit is less pronounced in traditional two-dimensional design tools, as the ability to navigate and interact with design models in a three-dimensional space enables students to more effectively comprehend intricate spatial relationships.

Additionally, the research underscored the collaborative potential of VR environments in Arkio. The capacity to collaborate in a shared virtual space provides a new dimension to team-based projects, as the emphasis on collaborative learning in architectural education continues to grow. The collaborative nature of professional architectural practice is reflected in the ability of students to participate in real-time critiques and modifications.

Conversely, the investigation disclosed numerous technical obstacles encountered by the students, including the navigation of the Arkio interface, the utilization of its 3D modeling tools, and the management of file integrations. These challenges are consistent with those reported in other educational contexts that involve

VR, indicating that while VR technology has potential, it also necessitates implementation to prevent it from impeding the learning process (Shih et al., 2019).

The study's methodological approach, which integrated both quantitative and qualitative data, enhanced the findings and offered a comprehension of the educational implications of utilizing Arkio. Nevertheless, the relatively small sample size of 12 students is a constraint, and future research could be enhanced by incorporating a more diverse and extensive cohort of students. Moreover, the findings are further complicated by the study's distinctive context, which was conducted in the aftermath of a significant earthquake and during a period of ongoing adaptation to post-COVID-19 online learning.

6. Conclusion

In summary, this investigation offers empirical evidence that bolsters the integration of VR, specifically Arkio, into architectural design education. The results suggest that VR can significantly improve students' spatial comprehension and facilitate more effective collaboration in design critiques, particularly in online learning environments.

Despite Arkio has the potential to significantly improve design critiques in architectural education, the technical challenges that the students have identified—particularly those related to the user interface and file imports—suggest that additional refinements are necessary to achieve optimal usability. Arkio can be even more transformative in architectural education by addressing these issues and implementing student suggestions, such as improving drawing tools and user interface, as online and hybrid learning environments continue to evolve.

Although the potential advantages of VR in architectural education are evident, the study also underscores the necessity of planning and phased implementation to address technical obstacles. As the accessibility to the hardware, students become more accustomed to the VR environment, educators should consider beginning with simpler tasks and gradually introducing more complex projects. This method has the potential to mitigate the learning curve and guarantee that students can fully capitalize on the capabilities of VR tools such as Arkio.

Comparative studies that involve multiple VR platforms could provide valuable information on the relative strengths and weaknesses of different tools, and larger, more diverse samples would provide more generalizable insights. In addition, research on the influence of VR on other aspects of architectural education, such as student motivation and design creativity, would further improve our comprehension of its pedagogical worth.

In conclusion, the incorporation of VR into architectural design education is a substantial advancement in the adaptation of teaching methods to the needs of a world that is rapidly evolving. It is imperative that educators remain cognizant of the obstacles and approach implementation with a thoughtful approach as they continue to investigate the potential of VR. This research contributes to the expanding body of literature on the pedagogical applications of VR and provides educators in the field of architecture with actionable insights, thereby facilitating the development of more innovative and effective teaching practices in the future.

Author Contributions

The percentage of the author contributions is presented below. The author reviewed and approved the final version of the manuscript.

	E.Y.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

The author confirms that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to. All participants filled out informed consent forms in the study.

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