Review Article

Exploring Mixed Reality in Architectural Design Education: A Systematic Review

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Abstract

This systematic literature review explores the integration and impact of Mixed Reality (MR) technologies in Architectural Design Studio Education (ADSE). Covering the period from 2019 to 2024, this review consolidates the current role of MR in design education by analysing existing studies. The study aims to evaluate both the positive and negative contributions of MR in ADSE and discuss its future potential in this field. The articles were selected and reviewed according to PRISMA (2020) guidelines (Page M.J.et al.,2021), and findings were analysed from databases including ScienceDirect, Web of Science, and Scopus. The review identified articles focusing on the application of MR in ADSE. The research findings indicate that MR technologies significantly enhance experiential learning by providing interactive and immersive environments that allow real-time visualization and manipulation of architectural designs. However, integrating MR into ADSE faces challenges such as high implementation costs and the need for specialized training for instructors. Nevertheless, if these challenges are addressed, MR can offer an alternative reality to ADSE with transformative potential. This paper provides a comprehensive guide for educators, curriculum developers, and students interested in leveraging MR technologies to foster innovative learning environments in ADSE.

Keywords: Architectural Design Studio Education, Architectural Education, Mixed Reality (MR), Quality Education (SDG 4).

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İnceleme Makalesi

Mimari Tasarım Eğitiminde Karma Gerçekliği Keşfetmek: Sistematik İnceleme

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Özet

Bu sistematik literatür taraması, Karma Gerçeklik (KG) teknolojilerinin Mimari Tasarım Stüdyosu Eğitimi (MTSE) içindeki entegrasyonunu ve etkilerini araştırmaktadır. 2019'dan 2024'e kadar olan dönemi kapsayan bu inceleme, mevcut çalışmalar aracılığıyla KG'nin tasarım eğitimindeki güncel rolünü derlemektedir. Çalışmanın amacı, KG'in MTSE'ndeki olumlu ve olumsuz katkılarını değerlendirmek ve bu alandaki gelecekteki potansiyelini tartışmaktır. Makaleler, PRISMA (2020) kılavuzlarına (Page M.J.et al.,2021) göre seçilmiş ve gözden geçirilmiş, bulgular ScienceDirect, Web of Science ve Scopus veri tabanlarından analiz edilmiştir. İnceleme, KG'in MTSE'ndeki uygulamalarına odaklanan makaleleri belirlemiştir. İncelenen araştırmalardan elde edilen bulgular, KG teknolojilerinin, mimari tasarımların gerçek zamanlı görselleştirilmesi ve manipülasyonuna olanak tanıyan etkileşimli ve sürükleyici ortamlar sağlayarak deneyimsel öğrenmeyi önemli ölçüde artırdığını göstermektedir. Ancak, KG'in MTSE 'ne entegrasyonu, yüksek uygulama maliyetleri ve eğitmenler için özel eğitim gereksinimleri gibi zorluklarla karşı karşıyadır. Bununla birlikte, bu zorluklar aşıldığında, KG MTSE'ne alternatif bir gerçeklik sunarak dönüştürücü bir potansiyel sağlayabilir. Bu makale, KG teknolojilerini kullanarak MTSE'nde yenilikçi öğrenme ortamları geliştirmek isteyen eğitimcilere, müfredat geliştiricilere ve öğrencilere kapsamlı bir rehber sunmaktadır.

Anahtar Kelimeler: Mimari Tasarım Stüdyosu Eğitimi, Mimarlık Eğitimi, Karma Gerçeklik (KG), Kaliteli Eğitim (SKA 4).

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INTRODUCTION

Recent progress in digital technology has greatly affected architectural education. Shifting from the conventional studio paradigm, renowned for its tranquil and uninterrupted ambiance that fosters imaginative inquiry (Weiner, 2005), towards incorporating digital resources, has reshaped the instruction, application, and depiction of architectural concepts.

Extended Reality (XR), comprising Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR), introduces revolutionary platforms that merge real and computer-generated environments to generate immersive, participatory interactions. These encounters enrich architectural design's educational and professional facets of architectural design (Gownder, 2016). Such innovations assist in comprehending spatial dynamics critical to architectural learning and facilitate synchronous cooperation and design alterations, which are essential competencies for modern architects. However, integrating XR technologies in higher education, specifically in the field of architecture, poses difficulties. The assimilation of these technologies requires thoroughly examining pedagogical goals, technological framework, and curriculum development. It is apparent that although the potential for XR in education is encouraging, significant transformation in instructional approaches is necessary to fully harness its advantages (Darwish et al., 2023).

Mixed reality (MR) technology tools within the extended reality (XR) technologies framework, such as Microsoft HoloLens, aid students in analysing architectural configurations in a three-dimensional manner within their genuine environmental context. This specific characteristic plays a crucial role in comprehending intricate spatial connections and the magnitude of architectural components, ultimately boosting spatial understanding and design proficiencies (Milgram & Kishino, 1994). Mixed reality (MR) enables real-time engagement with design components, allowing students to adjust and transform architectural prototypes digitally. This interactive involvement enhances comprehension of the repercussions of design choices and advocates for a more iterative and adaptable design methodology (Milman, 2018). Mixed reality (MR) facilitates cooperative design endeavours by empowering multiple students to simultaneously approach and engage with a collective virtual prototype, irrespective of their geographic position. This strategy fosters student cooperation enriches negotiation competencies, and seamlessly integrates diverse design components (Parveau & Adda, 2018).

The application of technology is crucial in determining the curricula and instructional approaches in the rapidly changing domain of architectural design education. This study investigates the integration, effects, and future possibilities of Mixed Reality (MR) technologies in architectural design education. A methodical literature review -from 2019 to 2024- was carried out for this examination. Conventional architectural education typically combines theoretical understanding with practical experience, often constrained by physical models and two-dimensional drawings. The introduction of digital technologies has introduced new dimensions in this field. The fusion of Virtual Reality (VR) and Augmented Reality (AR) to form Mixed Reality (MR) establishes an immersive environment where virtual and real components interact, demonstrating the potential to improve students' spatial comprehension and design skills, thus emerging as a crucial area of concentration. The article explores the integration of MR technologies in architectural design education and evaluates their influence on the educational process and scholarly outcomes. Through an analysis of the shift from conventional methodologies to advanced

digital interactions, the objective is to comprehend the changing landscape of architectural education and its alignment with contemporary professional standards.

The research has three main objectives: to evaluate the use of Mixed Reality (MR) technologies in architectural design studio education; to provide a general overview, investigate the positive and negative contributions and impacts of these technologies; to critique the current state of technology in design education; and finally, to discuss the transformative potential of Mixed Reality technologies for architectural design studios in the near future.

The importance of this article lies in its capacity to guide future research pathways and educational approaches. The study is designed to aid educators, curriculum developers, and policymakers in making well-informed decisions about incorporating Mixed Reality (MR) technologies into architectural education programs through a detailed examination of current applications and discoveries. The assessment proceeds with a systematic literature review method following PRISMA principles to integrate and assess relevant research. The method used for selecting and evaluating the research through systematic literature review is explained in the subsequent section, while other sections detail the findings and results. Discussions on future educational implications resulting from integrating MR into architectural design education are presented in the conclusion.

METHODS

The research employs a systematic review methodology distinguished by thorough and clear information analysis from various studies addressing a particular research query. It entails systematic exploration, meticulous selection, and critical assessment of related literature, preceded by a detailed synthesis of results. The principal research inquiries concentrate on how mixed reality (MR) technology is utilized in architectural design studio education, its impacts on learning encounters, and its prominence in the investigations of the architecture domain. A literature exploration spanning from 2019 to 2024 was carried out utilizing Science Direct, Scopus, and Web of Science databases, with keywords pertinent to the research queries. Chosen studies specifically investigated experiential learning in architectural design studios, notably utilizing MR technology. The research complies with PRISMA guidelines (2020) (Page et al., 2021), which are clear and comprehensive documentation guidelines. Its objective is to offer an evidence-based comprehension of the influence of digital technology, particularly MR, on experiential learning in architectural design education and practice.

Eligibility Criteria

The initial search was conducted by entering the query "mixed reality technology in architectural design studio education" into the selected databases. The search criteria were set as follows: research language: English; document type: review or research article; research fields: engineering, social sciences, arts, and humanities (Table 1).

Table 1. Systematic Literature Review Results in Science Direct, Scopus, WoS Databases.

Database	Query Formula/Terms	Document Type	Research Area	Results
Science Direct	Find articles with these terms: mixed reality technology in architectural design studio education	Review article, research article	Engineering, Social Sciences	102
Scopus	ALL (mixed AND reality AND technology AND in AND architectural AND design AND education) AND PUBYEAR > 2018 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SUBJAREA, "ENGI") OR LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "ARTS")) AND (LIMIT-TO (EXACTKEYWORD, "Architectural Design") OR LIMIT-TO (EXACTKEYWORD, "Mixed Reality"))	Article	Engineering, Social Sciences, Art and Humanities	216
Web of Science	Mixed reality technology in architectural design education (All Fields) and 2019 or 2020 or 2021 or 2022 or 2023 or 2024 (Final Publication Year) and Review Article **or** Article (Document Types)	Review article, article	-	15
TOTAL				333

Source: Science Direct, Scopus, WoS Databases.

RESULTS

The initial search resulted in 333 (three hundred thirty-three) reviews and research articles. The eligibility criteria outline the parameters for selecting studies examining the integration of mixed reality (MR) technology in architectural design studio education. These criteria emphasize investigations exploring the application and effects of MR within this educational context, focusing on articles published in English between 2019 and 2024. The selection process prioritizes papers addressing MR and architectural design studio education, especially those investigating the use of MR technologies for experiential learning in architectural design studios.

Selection Criteria

Research related to architectural education and MR technology has been included in this study.
Exclusion criteria were established, and in the initial phase, the retrieved studies were assessed by reviewing their abstracts or full texts. The exclusion criteria for this systematic literature review involved filtering out studies that did not focus on Mixed Reality (MR) technology, were unrelated to higher education or architecture, or were off-topic. Only papers directly addressing MR technology in architectural design studio education were included. Non-English studies and duplicate publications were also excluded to maintain methodological rigor and ensure the selection of relevant sources.

The review process followed a clearly defined procedure of identifying, screening, and including articles. This led to the exclusion of numerous papers based on specific criteria: duplicates (n = 4), work unrelated to MR (n = 60), content not related to higher education (n = 141), material not focused on architecture (n = 19), studies outside architectural design education (n = 96), and inaccessible sources (n = 1). This systematic approach identified twelve papers most relevant to the study's objectives. These selected papers were evaluated based on their aims and conclusions to explore the use of MR technology in architectural design studio education (Figure 1).

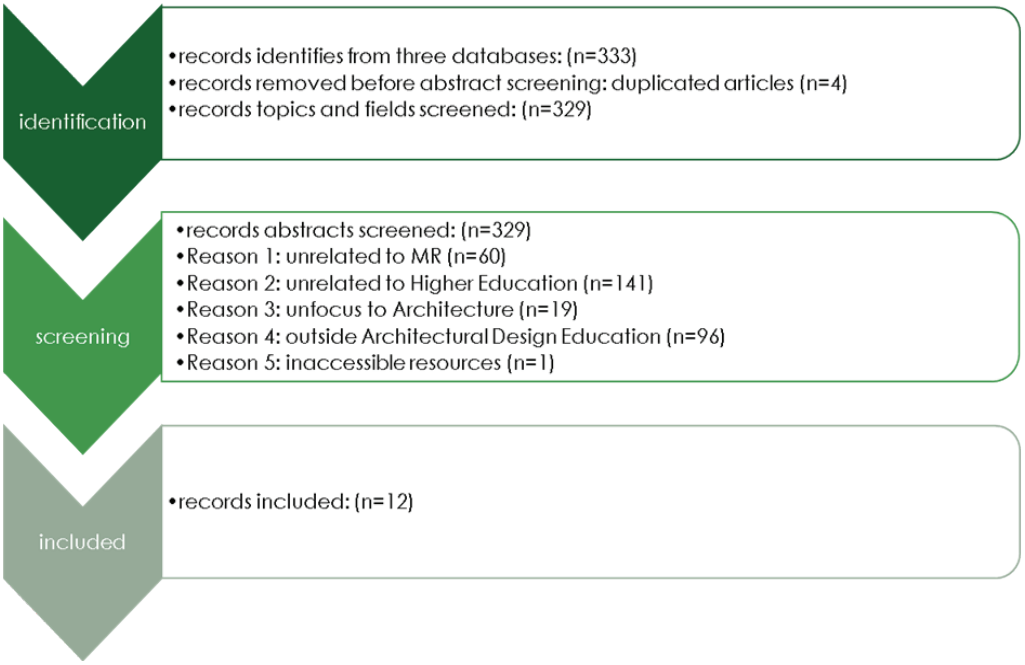

Figure 1: Modified Prisma Flow Diagram.

This systematic literature review examined 12 critical articles selected from 333 reputable databases such as Web of Science, ScienceDirect, and Scopus, focusing on integrating Mixed Reality (MR) technologies in architectural design education. Synthesis and assessment of the outcomes derived from examining these studies are presented here (Table 2).

Table 2. Most Related Papers as a Result of Systematic Literature Review.

no	Topic	Author(s)	Aim	Method	MR Relation	Conclusions
1	Architectural education challenges and opportunities in a post-pandemic digital age	Saleh et al. (2023)	To explore architectural education challenges and proposing digital strategies from pandemic opportunities.	analyzing literature on the pandemic's impact on architectural education to identify problems and opportunities for developing new models.	investigating how MR tools enhance architectural education through improving design, collaboration, and learning environments.	highlights the pandemic's effects on architectural education and as a result suggests a model emphasizing networking, exploration, and adaptability with MR.
2	Collaborative Educational Environments Incorporating MR Techs: A Systematic Mapping Study	Ali et al. (2019)	To discover trends, challenges, and gaps for further study on literature in education associated with MR.	systematic mapping of the development and pinpointing deficiencies in MR technologies in the educational field.	MR were examined for their application in collaborative learning settings	identifies an increasing curiosity in MR technologies in academia
3	Exploring the Potential of MR in Enhancing Student Learning Experience and Academic Performance	Almufarreh. (2023)	To investigate how MR enhances education and scholarly achievement.	a numerical method with a survey and data analysis was executed utilizing structural equation modeling (SEM).	MR technologies used to blend digital and physical environments for studying on immersive learning.	MR technologies enhance students' learning experiences, resulting in greater satisfaction and academic achievement.

4	XR for enhancing spatial ability in architecture design education	Darwish, et al. (2023)	To examine how early adoption of XR technologies influences spatial skills in architectural education.	Uses control and experimental groups to compare the effectiveness of XR integration against conventional teaching methods.	uses XR to measure if it promotes engaging learning, reduces cognitive load, and improves spatial understanding.	XR enhances spatial skills in architecture students, even with challenges in adapting to new technologies.
5	Framework for the Use of Extended Reality Modalities in AEC Education	Spitzer et al. (2022)	To provide a framework to assist AEC educators in selecting XR technologies, taking into account budget, scalability, space requirements, and educational outcomes.	uses a comprehensive review and analysis of XR modalities in AEC education, proposing a framework for selecting XR tools aligned with educational goals.	Utilizes MR, VR, and AR within the XR spectrum to evaluate their impact on visualization, engagement, and interactive learning in AEC education.	highlights the transformative impact of XR technologies on AEC education, advocating for their integration to enhance student engagement and outcomes.
6	HoloDesigner: A mixed reality tool for on-site design	Dan et al. (2021)	To illustrate how MR technology and the HoloDesigner tool improve on-site design through real-time visualization and manipulation of 3D models in real-world settings.	Involves using the HoloDesigner tool with Microsoft HoloLens for real-time MR integration, tested at a community park to assess design based on user experiences.	HoloDesigner employs MR to blend virtual 3D models with real environments, enabling designers to adjust designs on-site using spatial mapping and gesture control.	HoloDesigner improves on-site design by offering tools for instant visualization and adjustment of 3D models, thereby enhancing accuracy in architectural and urban planning decisions.
7	Impact of extended reality on architectural education	Kharvari and Kaiser (2022)	To evaluate XR technologies in architectural education, assess their impact on student performance, and offer recommendations for curriculum integration.	Reviews XR technologies in architectural education from 2015 to 2020 using a modified PICO strategy and databases SciDirect, WoS, and Scopus.	Uses the keyword "MR in architectural education" to review its role in enhancing student engagement and learning by merging physical and virtual worlds.	Finds that XR technologies benefit architectural education by improving the design process, enhancing learning outcomes, and effectively involving end-users.
8	Interactive Parametric Design and Robotic Fabrication within Mixed Reality Environment	Buyruk and Çağdaş (2022)	To test parametric design and robotic fabrication integration in mixed reality for real-time enhancement.	Develops a digital twin in mixed reality through parametric modeling and robotic fabrication, incorporating visual updates.	Uses Mixed Reality (MR) to enhance interactivity in parametric design and robotic fabrication, enabling real-time adjustments and multi-user collaboration.	Combining parametric design and robotic fabrication in mixed reality enhances design flexibility, efficiency, and human-robot collaboration.

9	Proposing a Novel Mixed-Reality Framework for Basic Design and Its Hybrid Evaluation Using Linkography and Interviews	Cindioglu et al. (2021)	To examine how MR affects design thinking skills in novice designers within BD education, improving their ability to generate and evaluate design options.	Uses linkography and interviews to analyze design decisions and explore how students benefit from MR technology.	Uses the DesignMR framework to enrich design education with Mixed Reality (MR), enhancing creativity and real-time feedback through the integration of physical and digital elements.	DesignMR boosts creativity, productivity, and idea exploration for novice designers, making MR valuable in BD education for exploring solutions and engaging in the design process.
10	The Contribution of Digital Tools to Architectural Design Studio: A Case Study	Ceylan et al. (2024)	to investigate how digital tools influenced architectural design studios during the pandemic-driven shift to online education.	Involves a case study with a questionnaire for architecture students to gather opinions on digital tools in the studio process.	MR is used in architectural education to enhance visualization and design features.	MR in architectural education enhances visualization, design, and creativity through real-time changes and collaborative feedback.
11	The Application of Extended Reality Technology in Architectural Design Education: A Review	Wang et al. (2023)	To analyze XR technology in architectural design education over the past five years, providing a framework for future use, and identifying limitations and research directions.	Employs content analysis and a literature review from Science Direct, Google Scholar, and Web of Science to evaluate XR technology in architectural education.	Uses MR and XR as a keyword to determine if it enhances architectural education by merging real and virtual elements, improving understanding, and providing real-time feedback and collaboration.	XR technologies enhance architectural education by fostering active learning, encouraging reflection and communication, and potentially replacing conventional teaching methods.
12	Design Assessment in Virtual and Mixed Reality Environments: Comparison of Novices and Experts	Wu et al. (2021)	Explores how VR and MR can link novice and experienced designers in construction, boosting rapid knowledge acquisition and skill development.	Uses VR and MR simulations to assess small house accessibility with students and experts, collecting data via think-aloud protocols, surveys, and recordings.	Uses VR and MR technologies to create immersive virtual learning experiences, enabling direct interaction with design tasks to boost expertise development.	VR and MR bridge the gap between novices and experts, allowing novices to undertake expert tasks through immersive learning experiences.

Source: Science Direct, Scopus, WoS Databases.

The reviewed articles consistently highlight the transformative impact of Mixed Reality (MR) on conventional architectural education methods. Technologies like Virtual Reality (VR) and Augmented Reality (AR) provide immersive, hands-on experiences that greatly improve learning outcomes, as demonstrated by studies such as Saleh et al. (2023). These technologies enhance conventional educational content and introduce novel teaching approaches, encouraging deeper engagement and interaction. This leads to a more dynamic learning environment where students can actively explore and understand complex design principles, marking a new phase in architectural education.

Several studies, including one by Darwish et al. (2023), highlight the effectiveness of Mixed Reality (MR) in enhancing key skills for architectural design, such as spatial awareness and visualization. MR's immersive nature provides a deeper understanding of spatial relationships, a crucial aspect of architectural training. By interacting with MR technologies, students can dynamically visualize and engage with structures, which improves their spatial cognition and problem-solving abilities.

The integration of MR has significantly boosted student engagement and satisfaction. Almufarreh's research (2023) demonstrates that MR enhances academic performance and enriches the learning experience. MR technologies make learning more interactive and engaging, capturing students' attention and improving their overall academic results and satisfaction. This transition to interactive learning is essential for keeping pace with digital educational advancements. Wu et al. (2021) state in their research that despite their limited experience, novice students exhibited similar behaviour patterns and achieved design review results comparable to those of seasoned professionals when using VR and MR mock-ups. This study adds to the existing knowledge by offering initial evidence that VR and MR can help bridge gaps in experience and suggests that these technologies could expedite the development of workplace expertise among college students. The insights gained may also guide the development of instructional and pedagogical strategies incorporating VR and MR technology into undergraduate construction and engineering programs.

According to Ceylan et al. (2024), digital technologies have recently exceeded conventional methods in the field of architecture, offering new formal and structural possibilities. The diversity of tools and practical interfaces encourages users at all levels and increases the shift toward digital solutions. Digital tools already play an active role in materializing pre-designed ideas in architectural education and are increasingly integrated into the design process for new experiments. Consequently, the study considered it valuable to explore the transformative effect of digital tools on architectural design education through students who have personally experienced these technologies. However, the value and contributions of conventional methods, such as hand sketching and physical model making, should not be overlooked. Further research is needed to examine their relationship with digital tools to enhance their contribution to architectural education, even in an era dominated by digital technologies.

Despite the benefits, integrating MR into architectural education presents challenges such as high costs, technology integration, and curriculum alignment, as noted by Dan et al. (2021). Implementing MR requires substantial investments in hardware, software, and educator training. Additionally, adapting MR into existing curricula involves reworking course structures and objectives.

Ali et al. (2019) identified research gaps, particularly in augmented virtuality and technical integration. Further research is required to evaluate MR's enduring impacts and establish more effective integration frameworks. Future studies should address these challenges and improve the scalability and accessibility of MR technologies in architectural education.

This review highlights MR's transformative potential in enhancing architectural education by improving experiential learning, increasing student engagement, and developing key skills. However, it also stresses the importance of further research to address the challenges and maximize MR's benefits in educational contexts.

CONCLUSION

This study has conducted an in-depth review of integrating Mixed Reality (MR) technologies into architectural design education, analysing 12 pivotal articles from an initial pool of 333. The review suggests that MR technologies, such as Virtual Reality (VR) and Augmented Reality (AR), can potentially transform architectural education. These technologies, with their capacity to enhance interaction, experiential learning, and essential design skills, offer a deeper engagement with architectural concepts, inspiring a new era of architectural education.

The review highlights that MR technologies enable students to immerse themselves in virtual environments, allowing for a more nuanced understanding of complex design principles. By facilitating real-time interaction with virtual architectural models, MR enhances spatial cognition and design capabilities, thus aligning educational practices with contemporary industry requirements.

The impact of MR on student engagement and performance underscores its value in modernizing educational methodologies. MR's interactive nature contributes to heightened student involvement and improved academic outcomes, signifying a significant shift from conventional, less dynamic learning approaches.

Despite these advantages, several challenges accompany the integration of MR into architectural education. These include the high costs of technology, the need for specialized educator training, and the adaptation of existing curricula to incorporate MR. However, with strategic planning and investment from educational institutions, these barriers can be overcome, ensuring successful and sustainable implementation of MR technologies in architectural education.

Future research should address the existing gaps by exploring the long-term impacts of MR technologies and developing cost-effective solutions. Research should focus on creating adaptable frameworks that facilitate MR integration across diverse educational settings, instilling confidence in MR's flexibility in education. Enhancements in MR technology, such as user-friendly interfaces and natural interaction simulations, will likely expand its accessibility and effectiveness in education.

Interdisciplinary applications of MR offer exciting opportunities for enriching architectural education. Integrating MR with engineering, urban planning, and interior design can give students broader learning experiences and practical insights. Collaboration with industry partners could also enhance the practical application of MR in real-world scenarios, fostering a more comprehensive educational experience.

"Scalability and inclusivity are essential for the widespread adoption of mixed reality (MR) in education." Future strategies should consider a range of resource levels, and learning needs to ensure that MR technologies are accessible to all students. Implementing adaptive learning systems within MR environments could further personalize educational content and support various learning styles.

Finally, establishing robust longitudinal studies and evaluation frameworks will be essential for assessing MR's impact on educational outcomes. These studies should include quantitative and qualitative measures to capture the full range of MR's effects on spatial reasoning, design skills, and student engagement.

Addressing these considerations can help architectural education harness the full potential of MR technologies, creating more engaging and effective learning environments. As MR technology evolves, it will continue to offer new opportunities for advancing educational practices and outcomes in the architectural field (Table 3).

Table 3. Conclusion Summary: Integrating Mixed Reality in Architectural Education.

Aspect	Details
Purpose	Review of integrating Mixed Reality (MR) technologies in architectural design education.
Benefits	Enhanced interaction, experiential learning, deeper engagement with architectural concepts.
Impact	Improved student engagement and performance, modernized methodologies, enhanced spatial cognition.
Challenges	High costs, specialized educator training needs, curriculum adaptation.
Future Research	Explore long-term impacts, develop cost-effective solutions, create adaptable MR integration frameworks.
Opportunities	Interdisciplinary integration with engineering, urban planning, interior design.
Scalability	Ensure accessibility for all students, considering diverse resources and learning needs.
Adaptive Learning	Personalize educational content, support various learning styles.
Evaluation	Establish robust longitudinal studies with quantitative and qualitative measures.
Potential	Advancing educational practices and outcomes in architectural education.

Conflict of Interest:

No conflict of interest was declared by the authors.

Author' Contributions

A.K. and B.A. reviewed the resources regarding the evolution of architectural design studio education. A.K. conducted analyses, while both authors performed the synthesis in preparing the manuscript. All authors have read and agreed to the published version of the manuscript.

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Ethics Committee Approval

Ethics committee approval was not required for this article.

Legal Public/Private Permissions

Legal Public/Private Permissions approval was not required for this article.

Data Availability Statement

The data sets generated and analysed during the current study will be publicly available upon publication.

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