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XR Experience in Architectural Design Studio Education: A Systematic Literature Review

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Abstract: Pursuing innovative methods in architectural education continually evolves in response to the profession's dynamic and changing demands. Today, Extended Reality (XR) technologies are emerging as powerful tools with the potential to transform design studio education fundamentally. Focusing on "Extended Reality (XR)" rather than individual terms like VR, AR, and MR is due to XR's encompassing nature. Using all realities collectively allows for a comprehensive evaluation of their synergies. Each reality has distinctive capabilities, and their combined use may offer a richer educational experience than focusing on them individually.

This study examines the use and impact of XR technologies in architectural design studio education (ADSE), exploring how conventional components can evolve with XR from 2019 to 2024. It highlights XR's influence on design studio education and experiential learning, guiding students, educators, and researchers at the intersection of XR and ADSE.

The authors conducted a systematic literature review following the PRISMA (2020) checklist (Page M.J.et al.,2021). Searches in three primary databases resulted in 183 articles. After identifying and removing duplicates, 178 abstracts were reviewed, and full texts were examined. Ultimately, three articles related to "XR Experiences in ADSE" were subjected to detailed analysis.

The research found limited studies with the "the impact of the XR in architectural education" keyword. Following the systematic review, three articles remained. These articles were assessed to investigate the use of XR technologies in design studio education. The reviewed articles generally indicated positive outcomes from using XR technologies in one or more components of design studio education.

Keywords: Architectural design education, XR technologies, XR integration in architectural education, Extended reality, Quality education.

1. Introduction

Architectural design studio education is the linchpin of pedagogical evolution within the architectural domain. Rooted in the historical evolution from conventional mentorship to its contemporary status, this educational model epitomizes a complex interplay of components. Its adaptability to emerging technological paradigms, particularly "Extended Reality" (XR) technologies, presents a significant trajectory deserving detailed investigation. This systematic literature review seeks to delve into the integration and implications of XR technologies within architectural design studio education, offering comprehensive insights into its multifaceted impact.

In architectural pedagogy, the term "studio" embodies a dual essence: it signifies a physical space for learning activities and a pedagogical methodology reminiscent of an artist's studio (Crowther, 2013) (1). This multifaceted notion delineates the studio as a crucible where future architects engage in experimental exploration, fostering collaborative problem-solving skills (Akyıldız, 2020) (2). Unlike conventional classroom settings, studios nurture analytical synthesis and evaluative modes of thought essential for architectural creation (Dutton, 1987) (3). Over time, this educational framework has evolved in response to technological advancements, particularly the advent of computer-aided design (CAD), marking a transformative phase in pedagogical strategies. The evolution of studios is underscored by adaptable infrastructure and the integration of personal computing devices, reshaping conventional educational landscapes. The convergence of architecture and computer science has precipitated groundbreaking alternatives to physical reality, notably Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), collectively termed Extended Reality (XR) (Reffat, 2007) (4).

Despite these technological strides, there exists a need for more exhaustive research examining the nuanced integration and repercussions of XR within architectural design studio education. This systematic literature review aims to fill this gap by illuminating the utilization of XR technologies within these educational contexts. Focusing on the timeframe from 2019 to 2024, coinciding with pivotal technological advancements, this study aims to provide nuanced insights into XR's integration and impact on architectural design studio education.

Employing a meticulous three-stage systematic review encompassing 183 abstracts sourced from Science Direct, Scopus, and Web of Science databases, this study rigorously scrutinizes the influence of extended reality technology on design studio education. By exemplifying exemplary applications of digital technology within design studios, it endeavors to shed light on associated benefits and challenges and contribute substantively to the evolving discourse on XR's role in architectural education.

2. Methodology

Systematic Review Methodology is used in this study. As defined by Petticrew and Roberts (2006) (5), systematic review methodology is a meticulous and transparent approach to analyzing information from multiple studies that address a specific research question. It involves a systematic search, careful selection, and critical evaluation of relevant literature, followed by a comprehensive synthesis of the findings. A systematic review produces a reliable and unbiased summary of the available evidence by reducing bias and adhering to a predetermined methodology. This methodology enables informed decision-making and identifies potential areas for further research.

To thoroughly investigate the utilization and effects of XR technologies in Architectural Design Studio Education, the research questions "How are Extended Reality Experiences Utilized in Architectural Design Studio Education?" and "What Effects Do They Have on Experiences?" were formulated. These questions clarify the study's objectives and guide the research process. A systematic literature search was conducted using PRISMA (2020) guidelines to address these questions. Searching on Science Direct, Scopus, and Web of Science databases -based on their extensive coverage, reliability, advanced search capabilities, citation tracking, interdisciplinary insights, and analytical tools -focus on studies published between 2019 and 2024, when digital technology gained significant momentum and increased use. Keywords relevant to the research question were used to identify relevant literature.

Studies within this timeframe that specifically explored experiential learning in architectural design studios, particularly utilizing extended reality (XR) technologies, were selected for inclusion. The most frequently used digital technologies in these studies were identified, and those focusing on XR technologies, which offer various tools and environments, were prioritized.

This study's reporting adheres to the PRISMA (2020) (Page M.J.et al.,2021) guidelines, ensuring transparency and comprehensive reporting of the systematic review process. By following this methodology, the study aims to provide an evidence-based understanding of the impact of digital technology on experiential learning in architectural design and culture.

2.1 Eligibility Criteria

The evolution of design studio education is an intricate interplay of diverse influences, refraining from unilateral outcomes. This study investigates the imminent trajectory of architectural design studio education, scrutinizing the intricate components inherent in exploring XR technology's role within this domain. Emphasizing the consequential impact of these investigations, the research seeks to provide a comprehensive understanding of XR's implications on architectural design studio education and culture. By synthesizing this information, the study aims to furnish invaluable insights to stakeholders in the field, contributing significantly to the scholarly discourse and the progression of the discipline. This systematic exploration, encompassing literature from Science Direct, Scopus, and Web of Science, maintains rigorous criteria for inclusion and exclusion (Table 1).

2.1.1 Inclusion Criteria

This systematic literature review considers architecture or design education studies, focusing on architectural design studio education, culture, and the integration of XR (Extended Reality) technology. The included investigations delve into the application, effects, or integration of XR Technologies within architectural design studio education. The selected researches explore the influence of XR experiences on various facets of architectural design studio culture, including tools, methodologies, interactions, and outcomes. Articles published in English

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

Database	Query Terms	Type	Research Area	Category	Results
Science Direct	the impact of XR on architectural education (2019-2025 and Eng.)	review art., research art.	Eng., Comp.Sci., Decis.Sci., Soc. Sci., Env. Sci., Psychol.	Eng., Env. Science, Psychol.	79
Scopus	the impact of XR on architectural education (2019-2025 and Eng.)	article	Soc. Sci., Arts, Psyc., Multidiscip.	Eng., Comp. Sci., Soc. Sci., Arts Humanit., Psychol., Multidiscip., Env. Sci.	85
Web of Science	the impact of XR on architectural education, XR technologies and architectural design education (2019-2025 and Eng.)	review article, article	Arch.	Eng., Civ. Eng., Constr. Eng., Build. Technol., Env. Sci., Arch., Edu. Educ. Res., Eng. Env., Env. Stud., Archaeol., Eng. Multidiscip., Comp. Sci. Interdiscip. App., Psychol., Multidiscip., Imaging Sci. Photogr. Tech., Remote Sens.	19
				TOTAL	183

between 2019 and 2024 will be considered. Inclusion criteria were applied by focusing on XR and architectural design studio education on most related papers. Studies conducted during this specified period that specifically examined the use of experiential learning in architectural design studios, focusing on utilizing extended reality (XR) technologies, were selected for inclusion. The digital technologies most commonly employed in these studies were identified, and those that concentrated on XR technologies, which provide a range of tools and environments, were given precedence.

2.1.2 Exclusion Criteria

Literature not centered on XR technologies, studies unrelated to higher education, works not directly associated with architecture, and off-topic or divergent studies will be excluded from this review. Specific papers selected for inclusion must align with the review's focus on XR technologies in architectural design studio education. Non-English language studies and duplicate publications will be excluded. These criteria ensure a systematic literature review, emphasizing the selection of pertinent and rigorous sources essential for an extensive exploration of XR experiences in architectural design studio education.

The systematic literature review followed a well-defined procedure involving the distinct identification, screening, and inclusion stages. This methodological rigor facilitated the elimination of numerous articles based on specific criteria: duplicates (n=5), scholarly works deviating from the domain of extended reality (n=98), content unrelated to the of higher education (n=98), material not focused on the discipline of architecture (n=47), studies conducted outside the field (n=26), and particular research papers that did not align with the primary objectives of the review (n=2) (Fig. 1).

Duplicated papers: 5, Literature that is unrelated to XR technologies:2, Literature that is unrelated to higher education:98, Literature that is unrelated to architecture:47, Off-field studies: 26, Specific papers which are irrelevant to the aim of the review:2.

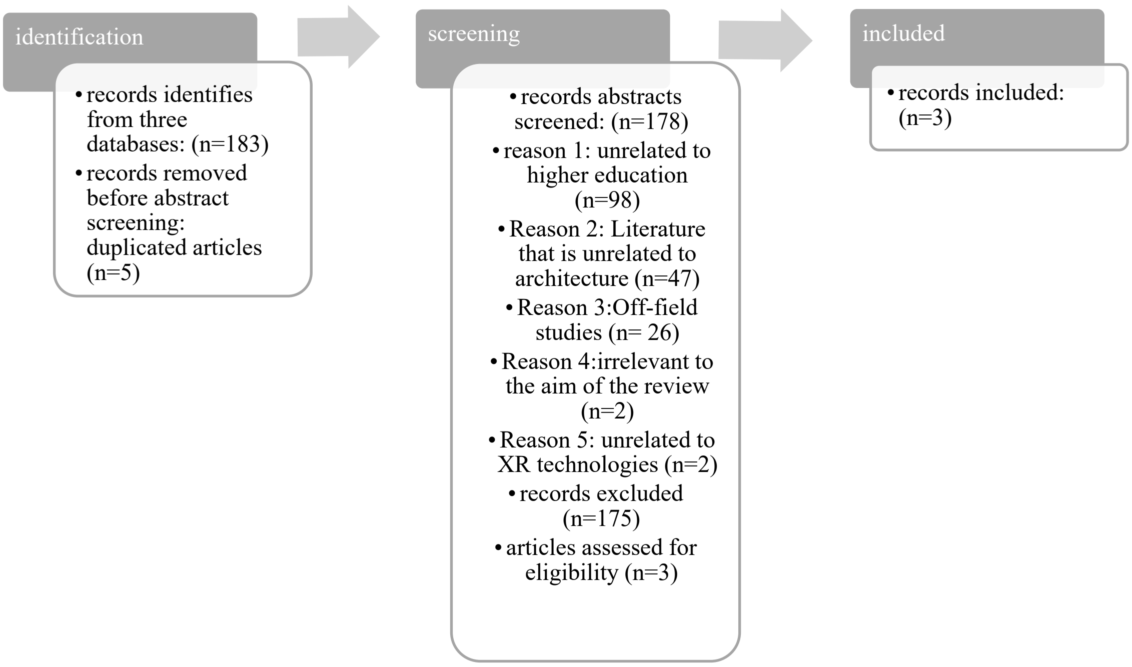

Figure 1: *Adapted Prisma Flow Diagram*

The systematic literature review process identified three papers that are most related to this study's aim. To evaluate papers and their reviews and determine the utilization of XR technology in architectural design studio education, three main titles were created to assess: method, aim, and conclusion (Table 2).

Paper 1: Darwish, M., Kamel, S., & Assem, A. (2023). Extended reality is used to enhance spatial ability in architecture design education. Ain Shams Engineering Journal, 14(6), 102104. https://doi.org/10.1016/j.asej.2022.102104. (6)

Paper 2: Kharvari, F., & Kaiser, L. (2022). Impact of extended reality on architectural education and the design process. Automation in Construction, 141, 104393. https://doi.org/10.1016/j.autcon.2022.104393. (12)

Paper 3: Spitzer, B. O., Ma, J. H., Erdogmus, E., Kreimer, B., Ryherd, E., & Diefes-Dux, H. (2022). Framework for the use of extended reality modalities in AEC Education. Buildings, 12, 2169. (28)

Review papers and review of these three papers are examined with the criteria as focus, XR experience, XR tools, and conclusion and projection comments to investigate whether enhancing the components of conventional design studio education using XR technologies is possible and beneficial.

2.2 Paper 1: Extended Reality for Enhancing Spatial Ability in Architectural Design Education, Darwish et al., 2023 (6)

In Paper 1, experimental research carried out in this paper aims to conduct an empirical study in architectural education to assess the impact of XR technology on students' spatial ability. The study's findings reveal enhancement among those who utilized XR technology, unlike a control group that did not exhibit any alterations in their spatial competence scores. Furthermore, the paper comprehensively examines existing literature about using XR technologies in architectural design education, encompassing these previous applications' objectives, methodologies, conclusions, and limitations.

Table 2: *Included papers' main frame.*

Paper	Method	Aim	Conclusion
1.**Darwish** et al.**, 2023**	Review + Research	to explore the benefits and drawbacks of incorporating this technology in the initial stages of architectural design and assess its influence on student performance.	XR significantly improved students' spatial abilities and enriched architectural education by reducing cognitive burden.
2. **Kharvari** and Kaiser**, 2022**	Systematic Review	to examine the effects of XR technologies on architectural education and investigate how XR technologies influence the design process.	XR tech helps architectural ed by enhancing learning and design.
3. **Spitzer** et al., **2022**	Literature Review & Framework	to create proposed framework for AEC educators to integrate XR technologies into teaching methods	XR tech can enhance AEC education. A model suggests XR modalities to aid instructors. XR can boost perseverance and interest. The framework needs continuous updates due to rapid XR development.

In the experimental research phase of this paper, the authors undertake a case study to investigate the influence of XR technology on spatial ability within the educational process of architectural design. To provide the VR experience, the authors utilized the VR-Oculus2 HMD and the Gravity Sketch Application, while for the AR experience, they utilized the iPad and the Augment Application. Second-year architecture students selected randomly from Ain Shams University were chosen to partake in an experiment to evaluate the impact of extended reality (XR) on spatial abilities. Participants engaged in augmented reality experiences as part of their design studio activities, utilizing either an iPad Pro or a smartphone. Spatial ability tests were administered before and after the XR-assisted sessions, with the overall scores as the dependent variable. To enhance the presentations and facilitate life-size virtual walkthroughs, the study utilized Immersive Virtual Environments (IVE). However, a notable limitation was identified in the XR system's incapability to simultaneously accommodate multiple users, thus affecting the collaborative nature of student interaction during the study.

In the review phase of this paper, the authors present a collection of previous papers that employed XR applications, offering insights into the aims, methodologies, findings, and significant limitations of each study under review. According to analysis, literature reviews examining virtual reality (VR), augmented reality (AR) technology, and mixed reality (MR) technology applications as XR technologies in the design process converge on the consensus that these technologies improve the understanding of dimensions, proportions, and design. Moreover, participants commonly perceive the utilization of VR and AR as a motivating, enjoyable, and thrilling experience. The authors assess five relevant studies that employ applications for integrating extended reality in architectural design education.

This study examined the paper and assessed the reviews of the papers in question from an alternative standpoint to assess the implementation of XR technology within the context of architectural design studio education. This evaluation was conducted within the framework of the study's focus point, which included considerations of XR experience, XR tools, and, ultimately, the conclusion.

As a result of evaluation, studies focus on improving spatial ability, immersive learning & teaching, pedagogy, representation & criticism, informal approaches, and environmental developments; XR technologies used as VR, AR, MR, or VR & AR technologies; for VR technology Oculus Quest2, HTC Vive devices used as HMD and Gravity Sketch App, Unity Engine, GIS used as applications & software, for AR technology iPad & smartphones used as devices and Augment used as application; for MR technology HMD used as a device and scanning tool used as application. The conclusions of these studies can be categorized as positive and negative. The positive impacts of using XR technologies are enhancing the educational process for architectural design, creating a desire to learn, and leading to improved design education pedagogy. The negative impacts of using XR technologies are technical challenges as the system cannot handle multiple users simultaneously, which limits interaction; the IVE was only used for the critique sessions, not for the design process itself; students saw the AR tool as a challenging tool for integration in architectural education as a tool for representation, lacked the time necessary to understand the program entirely (Table 3).

Table 3: *Paper 1 (Darwish et al., 2023: "Extended Reality for Enhancing Spatial Ability in Architecture Design Education") and review summaries.*

Study	The Focus of the Study	XR Experience	XR Tools	Conclusion & Projection Comments
Rev. Darwish et al.**, 2023**	XR -technologies application on architectural experiences	various	various devices & apps	various: mentioned below
Res & Exp. Darwish et al., **2023**	improving the spatial ability of students	VR & AR for element design (as a part of design problem)	VR- Oculus Quest2 (HMD)&Gravity AR–iPad&Augment	+: enhancing the educational process -: technical challenges
Nisha, **2019**	pedagogy	VR for city spatial development maps	VR HDM and GIS	+: enhancing design pedagogy
Zhang and Chen**, 2019**	immersive learning and teaching	VR environment to interact with designs	VR – HTC Vive, Unity, and VR package	+: creating a keen to learn -: limited multi-user support
Sopher et al., **2019**	representation & critics	AR/IVE for presentation & critics (life-size experience)	AR- Immersive Virtual Reality Env.	+: increased productivity in design activities -: used for the critique sessions
Fonseca et al**., 2016**	informal approaches	using AR for representation	Not mentioned	+: students were enthusiastic about technology -: AR integration challenges
Lu and **Ishida, 2020**	environment development	MR to create VR furnishing on scanned real world	MR- Scanning tool and HMD	+: system receives favorable feedback

2.3 Paper 2: Impact of Extended Reality on Architectural Education and Design Process, Kharvari and Kaiser, 2022 (12)

In Paper 2, the study comprehensively examines the influence of extended reality (XR) technologies on architectural education and the design process outcomes. It classifies the findings into four distinct course types and posits that XR technologies positively affect various design stages and facilitate architectural learning. Utilized PRISMA (2020) checklist guidelines and a modified PICO strategy for systematic review and research question formulation. Included user studies on AR/VR in architectural education, excluding conceptual studies without participants.

The study emphasizes that VR, AR, and MR are transforming industries, including education. VR is defined as an immersive computer simulation, AR overlays digital information, and MR blends physical and virtual interactions. XR technologies have shown potential in various educational fields, but their integration into architectural education needs more consensus. This study aims to systematically review XR technologies' impact on architectural education and the design process.

The data extraction for the reviews included defining the authors of the articles and publication years, the design of the studies, the fields of application, the software and devices utilized, the specified results, and the number of participants. The articles were classified into four categories: "Construction and Building Science," "Design Education," "Lecture Courses," and "Other Courses and Applications."

The findings of the authors' investigation reveal that implementing XR technologies in architectural education leads to enhancements in both learning outcomes and student performance. Moreover, using VR, AR, and MR in this context positively influences the design process. XR technologies present students with an experience centered around their needs, resulting in substantial advancements in learning. To be more precise, immersive VR enhances spatial perception compared to non-immersive environments.
In the ideation stage, VR improves critical thinking and problem-solving. AR enhances the ability to mentally rotate objects, thus aiding in comprehending spatial relationships. MR, on the other hand, facilitates the evaluation and reflection stages of the design process. The employment of XR technologies fosters a more effective retention of architectural precedents. Additionally, VR stimulates contemplation on design, leading to an enhancement in the overall design process. Lastly, XR technologies are crucial in assessing created spaces' experiential and evaluative aspects. More research is needed to quantify the impact of XR tech on creativity and idea generation (Table 4).

Table 4: *Paper 2 (Kharvari, F., & Kaiser, L. (2022). Impact of extended reality on architectural education and the design process) and review summaries.*

	The Focus of the Study	**XR Experience**	**XR Tools**	**Conclusion & Projections Comments**
Kharvari and Kaiser**, 2022**	XR - technologies (VR, AR, MR) application on architectural experiences	various	various devices & apps	+: affordability, efficiency, enhanced learning in architectural education with XR tech. -: creativity, idea generation, psychological studies required XR effects
Kharvari and Hohl, **2019**	space/site visit/built-environment experience	serious gaming using VR applications for 3D architectural visualization	VR-HTC Vive & Unreal Engine	Not mentioned
Ozgen et al., **2019**	learning problem solving	VR for basic design education	VR- Oculus RiftDK2, Google Blocks	VR boosts problem-solving in interior architecture
Hopfenblatt and **Balakrishnan, 2018**	teaching problem solving	VR as an instruction tool for foundation studios in learning, adapting, and prototyping	VR- ZSpace, HTC Vive, Nine Cube VR	+: useful for design creation, simplified teaching without 3D software
Llorca et al.**, 2018**	teaching importance of sound in urban spaces	urban acoustics education	VR- Oculus Rift, music	+: enhanced satisfaction, and space awareness via VR, opportunity to feel-in-place

Huang et al., **2018**	learning/exploring about an urban space	integrating agent-based modeling with VR for learning	VR- HTC Vive	+: enhanced design process
Abu Alatta and Freeman, 2**017**	Learning early design process	enhancing spatial perception within the design process with IVE	VR-General, Oc.Rift, Unity3D	+: improving performance, creativity, and overall design quality
Fonseca et al., **2017**	Motivation	tech adaptation of the student with 3D visualization	Not mentioned	+: advanced visualization improved motivation
Valls et al., **2017**	Exploring/creating/experiencing	improving student motivation	AR- Unreal Engine 4	+: gamification or serious game strategies in VRE creates motivation
Paes et al., **2017**	Experiencing/exploring	IVE for understanding of architectural 3d models	VR & IVR- 3D model, VR techs	+: IVR provides better spatial perception conventional
Sun et al.**, 2017**	Experiencing architecture in VR /AR	VR technologies for online architectural education	Not mentioned	+: VR technologies are better than conventional
Fonseca et al., **2016**	Experiencing via VR-AR-DS hybrid	informal interactions in 3d education	AR/VR/DS/HM	+: boosted motivation, enhanced graphics & spatial skills for academic success
Valls et al., **2016**	Learning via VR	Videogame technology for learning	VR- Unreal Engine 4	+: create a speculation to improve method and tools
Ayer et al., **2016**	Experiencing design via VR, AR and conventional	AR gaming for sustainable design education	VR/AR – Game ecoCampus	+: reduced time frustration, diverse design thinking breaks fixation
S ́anchez Riera et al., **2015**	Evaluating presentations on site by using AR	Geo-located teaching using AR	AR- 3d models	+: low degree of immersion provided by these devices
Yoon and **Chandrasekera, 2015**	Teaching drawings by using AR	AR in design communication	Not mentioned	+: teaching orthographic projection with AR, enhancing spatial skills

2.4 Paper 3: Framework for the Use of Extended Reality Modalities in AEC Education, Spitzer et al., 2022 (28)

The article presents a theoretical structure for Architecture, Engineering, and Construction (AEC) instructors to proficiently incorporate Extended Reality (XR) technologies into their educational plans, amplifying the process of acquiring knowledge and fostering active participation. This proposed framework is substantiated by its implementation in a summer camp at the esteemed Georgia Institute of Technology.

AEC professions hold great significance within society, as they are regarded as highly esteemed and esteemed. Architectural Engineering and Construction Management are remarkably esteemed due to their substantial financial benefits and profound societal influence. In the realm of AEC education, XR technologies are progressively being employed to augment the processes of recruitment, retention, and student involvement. This is occurring despite the obstacles encountered in adopting such technologies and the absence of instructional guidance provided to educators.

A thorough examination of the existing literature was undertaken to comprehensively understand XR technologies and their various applications within AEC education. The authors employed the Model of Domain Learning (MDL) as a theoretical framework to connect AEC's educational objectives with XR's modalities. Subsequently, a framework for decision-making was constructed to assist AEC educators in selecting appropriate XR technologies based on their academic goals and priorities. To ensure the validity and effectiveness of this framework, it was implemented and tested during a summer camp held at the esteemed Georgia Institute of Technology's School of Building Construction. The study conducted by the authors yielded several outcomes. First and foremost, XR technologies were defined, and their advantages and disadvantages for AEC education were clarified. Second, a decision-making framework for selecting XR modalities in AEC education at a summer camp was validated. Third, it is demonstrated that XR tech can enhance student engagement, self-confidence, and learning outcomes through immersive experiences. Lastly, immersive XR modalities such as IVR and MR are particularly effective in generating interest.

In conclusion, XR technologies have the potential to significantly enhance AEC education by improving comprehension, involvement, and professional visualization. The decision-making framework assists educators in determining appropriate XR modalities for different educational objectives. Using XR to generate interest may result in heightened motivation and continued engagement in AEC curricula. Given the rapid progress of XR technologies, it is imperative to update the decision-making framework continually.

The reviewed studies generally include architectural engineering education, and there could not be any related to design education, so Paper 3's reviews are not in the framework of this study (Table 5).

Table 5: *Paper 3 (Spitzer, B. O., Ma, J. H., Erdogmus, E., Kreimer, B., Ryherd, E., & Diefes-Dux, H. (2022). Framework for the use of extended reality modalities in AEC Education. Buildings,) review summary.*

Study	The Focus of the Study	XR Experience	XR Tools	Conclusion & Projections Comments
Spitzer et al.**, 2022**	XR -technologies (VR, AR, MR) application on architectural experiences	various	various devices & apps	+: XR increases student interest and so engagement -: XR for improved learning is more complicated to achieve and measure. control groups are needed 0: XR interventions should only partially substitute the conventional teaching methods. 0: if interventions are more likely to increase engagement, self-efficiency, and learning of students.

3. Results
The synthesis of three distinct papers on Extended Reality (XR) applications in architectural education reveals multifaceted insights into its impact and utilization within design studio contexts. The results of the systematic literature review can be summarized as:
- XR technologies can be used for various pedagogical components in architectural design studios.
- XR technologies (VR, AR, MR) have been utilized individually or in combination, but no study involving all three was found.
- The use of XR technologies (VR, AR, MR) in a complementary system is limited and has mainly been applied in partial stages of the design process.
- XR technologies are limited and experimental within architectural design studio education.
- No study was found comparing experiences with XR technologies to all components of conventional design studios.
- In experiences with partial architectural design studio education using XR technologies, disadvantages related to device and hardware health effects can occur.
- Overall, experiences with partial architectural design studio education using XR technologies have resulted in positive student learning outcomes and effective teaching by instructors.
- The studies conducted within the framework of 'XR Experience in Architectural Design Studio Education' are primarily experimental, have partially addressed education components, and are limited in terms of published works.

Collective Focus and XR Experience

The papers collectively emphasize the beneficial impact of XR technologies on architectural education. While Paper 1 concentrates on enhancing spatial ability through VR and AR experiences, Paper 2 delves into the broader influence of XR (VR, AR, MR) on various design stages. Paper 3 offers a theoretical framework for integrating XR modalities (IVR, MR) into architectural education, targeting improved learning experiences and engagement (Table 6).

Table 6: *Evaluation of reviewed papers' pursuit results.*

Paper	Pursuit	Findings
1 **Darwish** et al.**, 2023**	enhancing spatial ability via XR experience	implementing XR technology in early architectural design education significantly enhances students' spatial ability levels
2 **Kharvari** and Kaiser**, 2022**	understanding Influence of XR on various design stages	XR technologies enhance learning outcomes and student performance
3 **Spitzer** et al., **2022**	creating theoretical framework for integrating XR modalities into architectural education	proposes a decision-making framework for AEC educators to select suitable XR technologies for various educational outcomes

XR Tools and Educational Outcomes

The tools utilized across the papers—from Oculus Quest2 and HTC Vive to iPad, smartphones, and applications like Gravity Sketch, Unity Engine, GIS, and Augment—showcased significant potential in enhancing architectural pedagogy. These tools positively influenced spatial perception, critical thinking, problem-solving, and student engagement, thereby improving learning outcomes in architectural design education.

Positive Impacts and Limitations

Overall, the studies highlight the positive impacts of XR technologies in enriching architectural education. Students perceived XR experiences as motivating, enjoyable, and conducive to enhanced learning. However, technical limitations, such as the inability of XR systems to accommodate multiple users simultaneously, hindered collaborative interactions, suggesting a need for improved multi-user capabilities for a more seamless educational experience.

4. Discussion

Despite the positive impacts, notable gaps remain. The studies mainly focus on architectural engineering education, lacking emphasis on design education. None integrated all three XR technologies (VR, AR, MR), missing a holistic approach. Addressing technical challenges and conducting comparative assessments between XR and conventional methods could provide deeper insights into XR's efficacy. Additionally, more attention is needed on the health effects of device and hardware usage in the context of XR technology.

The reviewed papers shed light on the evolving architectural design education, particularly emphasizing the transformative impact of XR technologies. Although these studies show promising results, certain critical areas require further exploration and consideration (Table 7).

Table 7: *The Summary of the impact of the XR on ADSE Systematic Review Findings*

	Findings
Educational Impact	- Enhancing students' spatial abilities (Darwish et al., 2023) - Improving critical thinking and problem-solving skills in the design process (Kharvari and Kaiser, 2022) - Increasing student engagement and participation (Spitzer et al., 2022)
Positive Outcomes	- Enhancing the effectiveness of education and improving student performance - Increasing students' learning motivation - Enriching experiential learning
Challenges	- Technical limitations, especially the inability to support multi-user environments - Health issues related to device and hardware usage - Challenges in integrating XR technologies into all educational components
Research Gaps	- Lack of studies that use all components of XR technologies (VR, AR, MR) together - Lack of studies focused on design education - Lack of comparative assessments between XR technologies and conventional educational methods
Future Directions	- Holistic integration of XR technologies in education - Improving technical capabilities and multi-user interactions - In-depth examination of health effects

Specialized Focus and Educational Context
It is important to note that the studies reviewed focused on architectural engineering education rather than design education. Future research must expand the scope to include design-centric educational contexts, as this would provide valuable insights tailored to design studio pedagogy.

Holistic Integration and Comparative Assessments
None of the reviewed papers incorporated all three XR technologies (VR, AR, MR) in a unified educational context. Taking a more holistic approach and exploring the combined impact of these technologies could yield comprehensive insights into their synergistic effects. Moreover, conducting comparative assessments between XR and conventional educational methods would enhance our comprehension of the effectiveness of XR in architectural education.

Technical Advancements and Seamless Integration
Efforts should be made to advance XR systems' technical capabilities to facilitate seamless multi-user interactions. Enhancing XR technology to support collaborative learning environments can significantly enhance its effectiveness in design studio education.

In conclusion, while XR technologies are promising to enhance architectural design education, further research is needed to address specialized design contexts, achieve holistic integration of XR technologies, and make technological advancements. The evolution of XR holds immense potential in revolutionizing pedagogical approaches and fostering enhanced learning experiences within architectural design studios.

The authors conducted a systematic literature review using the PRISMA (2020) checklist and guidelines, searching three primary databases. The research found limited studies on this topic with the keywords "XR technologies" and "architectural design education." Three articles remained after the systematic review. Extended Reality (XR) experiences in the architectural design studio education context; this study investigated whether enhancing the components of conventional design studio education using XR technologies is possible and beneficial, how XR technologies have influenced design studio education, and if it provides valuable insights that enhance experiential learning and highlight the advantages and challenges of this innovative approach.

This study guides students, educators, and researchers in navigating the dynamic intersection of XR technologies and architectural design studio education. In the papers and their reviewed studies, it is observed that experiences were generally conducted on one or more components of design studio education; typically, one of the XR used and using XR technologies resulted in positive outcomes.

In conclusion, XR's experiences in architectural design studio education are promising. As experiments, experiences, and research progress continue, there is a high potential to develop these outcomes further, thus suggesting a solid potential for an alternative approach to conventional design studio education.

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