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Smart Integration of XR Technologies in Architectural Education: Metaverse Opportunities and Challenges

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ABSTRACT

Extended Reality (XR) technologies—encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR)—are transforming architectural education by offering interactive, student-centered learning within immersive Metaverse environments. This study examines the level of adoption, benefits, and challenges of XR integration in Middle Eastern architecture programs, highlighting both qualitative and quantitative insights derived from comprehensive literature reviews and a questionnaire survey of 266 participants. Results indicate that although 35% of respondents are highly familiar with XR, broader curriculum-wide integration remains fragmented. XR-based design studios are the primary area of adoption, emphasizing immersive, hands-on training that facilitates spatial understanding and sustainable design insights. Nonetheless, institutional barriers—such as limited infrastructure, substantial cost outlays, and the need for faculty training—constrain wide scale implementation. Student-specific challenges include accessibility concerns, health implications of prolonged VR usage, and the scarcity of high-speed internet in some educational contexts. Despite these hurdles, XR fosters enhanced collaboration, global engagement, and real-time design prototyping, foreshadowing significant pedagogical shifts. The study recommends establishing dedicated XR labs, faculty development programs, and strong industry partnerships to support large-scale XR adoption. Future research should focus on in-depth frameworks and Participatory Action Research (PAR) to systematically integrate XR across architectural curricula. Adapting to these immersive platforms could reshape how architectural students conceive, create, and critique built environments.

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1. Introduction

For almost four decades, artificial intelligence (AI) has been harnessed in education to support a variety of teaching and learning tasks, including tracking student progress, diagnosing learning difficulties, and automating assessments (UNESCO, 2023; Wang et al., 2023). AI-based solutions mimic human cognitive processes, capitalizing on computational power to manage large and complex datasets (Reiners et al., 2021). More recently, these AI-driven advances have converged with immersive technologies—collectively referred to as Extended Reality (XR)—to transform the educational experience (Wang et al., 2024; Crolla et al., 2024).

Extended Reality is an umbrella term encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). Each domain manipulates digital environments to various extents, providing learners with immersive, interactive spaces (Milgram et al., 1995). XR blurs the boundaries between physical and digital realms by superimposing digital content onto real-world or purely virtual scenes (Guo et al., 2021). Within architecture education, XR offers novel avenues for exploring design concepts, visualizing building proportions at full scale, and simulating architectural interventions in real-time (Schumacher, 2022).

In tandem with these technologies, the Metaverse has emerged as a three-dimensional, persistent virtual universe populated by realistic avatars and interactive experiences (Guo et al., 2021). Metaverse platforms enable collaborative design processes, distance learning, and hybrid virtual-physical interactions that defy traditional time and location constraints. On a practical level, students can engage with digital content via desktops or headsets and mobile devices, smart TVs, and other embedded displays (Schumacher, 2022). In an architecture-focused Metaverse, even physical design studios may integrate panoramic screens or holographic projections, offering an immersive environment that enriches both individual and collective learning.

While adopting such immersive tools holds great promise for higher education, particularly in architecture, the opportunities are accompanied by challenges. Institutional hurdles—such as limited infrastructure, high equipment costs, and the need to train faculty in novel pedagogical approaches—can stall implementation (Guo et al., 2021). Equally significant are student-specific obstacles, ranging from accessibility and motion sickness to inadequate internet bandwidth, especially in certain regions of the Middle East (Ratten, 2023). Yet, the potential benefits are extensive: XR may shift learning from a teacher-centered model to a more experiential, student-led paradigm, fostering deeper engagement and improving academic outcomes (Wang et al., 2023).

Moreover, the COVID-19 pandemic highlighted the importance of digital transformation in education. Platforms previously perceived as optional quickly became essential for distance and hybrid learning (Ratten, 2023). This rapid shift underlined the adaptability of XR technologies in bridging physical distances, supporting synchronous and asynchronous collaboration, and offering simulations that can approximate real-world conditions. Beyond the pandemic, XR also enables dynamic exploration of complex architectural concepts, including sustainability and energy efficiency, without incurring the high costs and logistical burdens of physical field trips (Crolla et al., 2024).

In alignment with global educational transformations, architecture faculties are increasingly recognizing XR's capacity to revolutionize spatial understanding, design practice, and professional development (Wang et al., 2024). Some institutions are experimenting with fully virtual design studios—complete with digital building information modeling (BIM) integration—to offer hands-on, immersive experiences that mirror real-world architectural practice (Guo et al., 2021). Such holistic approaches can enable future architects to cultivate better decision-making skills, adaptability, and creative problem-solving capabilities in once unfeasible ways.

Against this backdrop, the current research investigates XR adoption in Middle Eastern architecture education, focusing on adoption trends, perceived benefits, and barriers. The study uses qualitative and quantitative approaches—specifically, a literature review and a questionnaire administered to 266 participants—to gauge familiarity, implementation scope, and systemic constraints within academic programs. The findings address whether XR has triggered a fundamental transformation in architectural pedagogy and propose recommendations for an integrative framework that can guide its future application.

Moreover, understanding how immersive technologies function in architecture classrooms is critical for anticipating emerging educational paradigms. By exploring XR's capacity for real-time feedback, cross-disciplinary collaboration, and practical design exploration, this study contributes a systematic perspective on how to deploy these tools effectively. Emphasizing “smart integration” underscores that XR is not merely an add-on technology; rather, it must be embedded strategically within curricula to facilitate measurable learning benefits (Reiners et al., 2021).

This work seeks to determine whether Extended Reality technologies have engendered substantial paradigm shifts in architectural teaching and learning methods. It evaluates the challenges and opportunities accompanying Metaverse-based instruction and provides recommendations for shaping a future-ready, immersive architecture curriculum.

Two primary methodological strands guide the research as graphically presented in Figure 1. First, a qualitative approach examines existing literature on immersive technology’s impact on architecture education, providing a broad conceptual framework. Second, a quantitative analysis—via questionnaire—offers empirical data regarding XR adoption and familiarity among Middle Eastern architecture students, faculty, and professionals.

According to the questionnaire data, 35% of participants are very familiar with XR technologies, reflecting a noteworthy but not universal acceptance. Despite increasing enthusiasm, XR integration in existing curricula remains sporadic, revealing the need for targeted faculty training, infrastructural investments, and policy-level support.

Following this introduction, the paper reviews XR concepts and categorizes potential applications in architectural education, drawing on relevant studies. Subsequent sections detail the research design and questionnaire results, discussing major findings related to adoption rates, perceived benefits, and obstacles. Finally, strategies for scaling up XR adoption are presented, along with a conclusion that encapsulates the study’s implications for future pedagogical advancements.

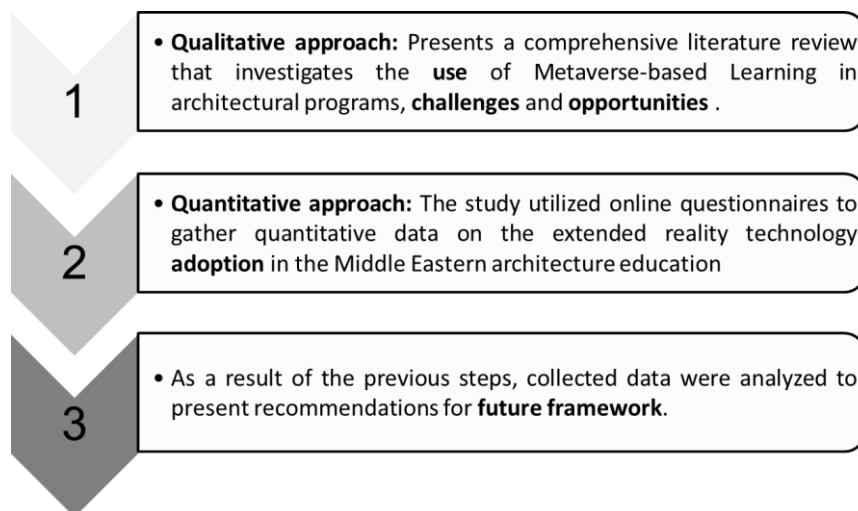


Figure 1. A graphical figure representing the theoretical framework and methodology.

In light of the transformative capacity of XR, the primary research objectives and questions are detailed below:

1. Which XR tools and applications are currently being integrated into architecture curricula across the region?
2. What are the benefits and challenges of using these technologies in classrooms?
3. What is the level of familiarity and experience that architecture educators in the Middle East possess regarding XR?
4. What strategies are required to enhance the utilization of XR technologies in Middle Eastern architecture programs?

Answering these questions illuminates how immersive learning platforms can recalibrate the traditional, single-mode teaching approaches (Wang et al., 2023). Additionally, insights on the broader technological shifts following the COVID-19 pandemic (Ratten, 2023) are leveraged to underscore the urgency and potential of Metaverse-based education. As technology continues to reshape the educational landscape, this study argues for a “smart integration” that leverages the strengths of XR while acknowledging infrastructural, health, and pedagogical considerations (Guo et al., 2021).

By assembling interdisciplinary insights, the study paves the way for a future in which architectural students not only conceptualize buildings but also dynamically inhabit and interact with them in virtual form—unlocking innovative solutions to real-world spatial challenges. Through careful analysis of existing barriers and targeted recommendations, the findings aim to inform educational policy, institutional planning, and the next generation of technologically adept architects.

2. Extended Reality (XR) for Immersive Experiences

The origins of extended reality can be traced back to the 1800s, when "stereoscopes," or binocular-like devices, induced viewers to believe they were watching pictures in three dimensions. Over a century later, the same XR technology would serve as the foundation for an even more immersive experience dubbed "Sensorama," which provided viewers with a visual, auditory, and even olfactory tour of a Brooklyn motorcycle ride (Marr, 2021). The field of Information and Communication Technologies (ICT) and Human-Computer Interaction (HCI) is changing as a result of the introduction of new design paradigms that alter how we interact with digital data (Partarakis, et al., 2024). Computer graphics and wearable technology generate both virtual and actual settings. The various components of XR are presented in Figures 2 and 3.

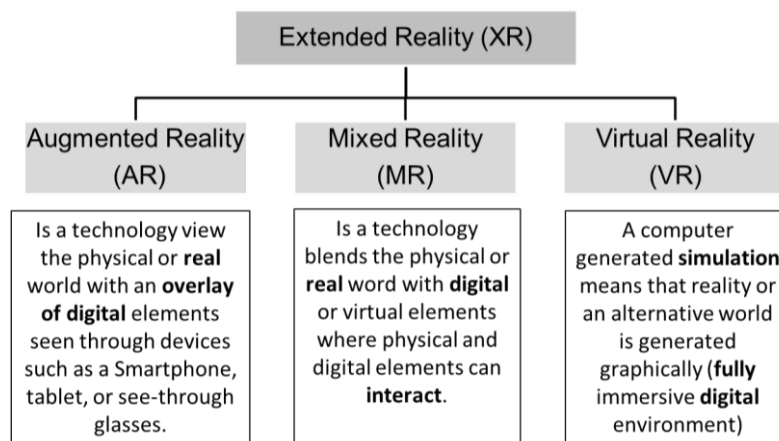


Figure 2. Venn diagram representing XR and its components (Researcher, 2024).

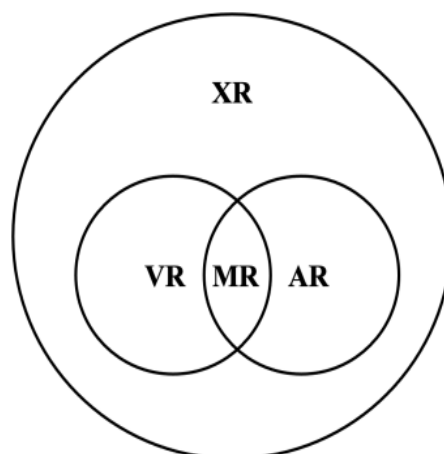


Figure 3. Description of various components in XR (Sharma, 2021).

2.1 Virtual Reality (VR)

Guo et al., (2021) define virtual reality as "The complete replacement of the real environment with a digitally produced one". It immerses viewers in a fully virtual environment created using computer technology (Sharma, 2021) and relies on Head-Mounted Displays (HMDs) to deliver a virtual world that totally substitutes the actual world (Calvet et al., 2019; Wang et al., 2023). Its "3I" attributes

include immersion, interactivity, and imagination. VR has been used in education and has demonstrated considerable promise for stimulating instructional change and creativity in fields like as preschool education, physics experimental teaching, geography experimentation, medical training, and art and design (Guo et al., 2021). Virtual reality technology allows for importing building models at 1:1 size onto displays through their glasses while wearing a head-mounted display (Wang et al., 2023).

2.2 Augmented Reality (AR)

Augmented reality (AR) is a hybrid of virtual and physical surroundings. AR is a technology that integrates virtual information into the actual world to create an interactive experience (Guo et al., 2021). It enriches the user's physical presence by overlaying visuals, movies, or other content over the surrounding area (Sharma, 2021; Wang et al., 2023). Virtual features are superimposed on a real-world environment as seen through a smartphone, tablet, or see-through glasses (Calvet et al. 2019). AR in science lectures can help students grasp complicated subjects by providing three-dimensional representations of previously unseen and difficult-to-visualize situations (Guo et al., 2021).

2.3 Mixed Reality (MR)

Mixed reality (MR) is a technological concept that enables the coexistence and real-time interaction of virtual information and the physical world. This creates a novel visual experience that incorporates both real-world aspects and virtual items (Wang et al., 2023). MR uses infrared scanning technology on a head-mounted display to integrate virtual content into the real world (Sharma, 2021). This enables educators and experts from a range of fields to instruct students in professional skills in a genuine context (Guo et al., 2021). Virtual Reality (VR) and Augmented Reality (AR) are now the most widely used applications, while Mixed Reality (MR) is gradually creating new ones (Wang et al., 2023).

The 3Rs (VR, AR, and MR) vary in terms of their interaction capabilities as graphically presented in Figure 4. VR offers one-way interaction, AR offers one-way and two-way engagement, and MR allows for two-way interaction between users and virtual and actual worlds (Wang et al., 2023).

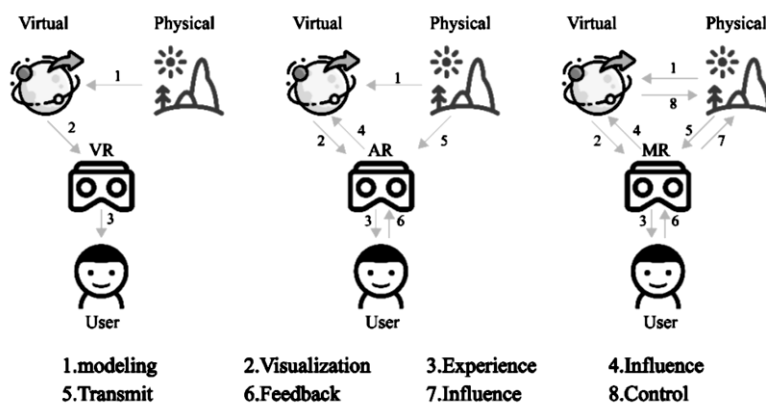


Figure 4. Technology interaction capability for the 3Rs (Wang et al., 2023).

3. Potential applications of XR in Architectural Education

The rising usage of computerized and advanced technologies has fundamentally changed architectural and infrastructure design techniques, resulting in a closer relationship between both the physical and digital environments (Schumacher, 2022). XR technology is revolutionizing the architecture education methodology by shifting it from a "teacher-centred" approach to a "student-centred" one. This paradigm shift signifies the emergence of an active teaching style to replace the traditional passive teaching technique (Wang et al., 2023).

3.1 Holographic Lectures for remote Instruction and Mentoring

- **Virtual Classrooms:** Architecture students are no longer bound to traditional classrooms or video conferencing. Instructors appear as 3D holograms (Nermine et al, 2023).
- **Personalized Feedback:** Instructors can offer personalized feedback and guidance to students by annotating their virtual design projects and engaging in real-time discussions within the Metaverse.
- **Global Collaboration:** Interact with larger-than-life holograms of renowned architects and industry experts, engaging in dynamic discussions and immersive demonstrations that redefine the learning experience (Abhari et al., 2021).

3.2 Integrated XR into Design Studios and Workshops

Smart integration of XR into design studios and workshops has different applications, as presented in Figure 5.

- Students visualize and interact with complex 3D models by immersing themselves in virtual or augmented environments, they can gain a deeper understanding of scale, proportion, and spatial relationships (Nermine et al, 2023; Wang et al., 2023).
- These immersive experiences help students identify design flaws, test alternative solutions, and refine their concepts more effectively than traditional 2D representations (Abhari et al., 2021).

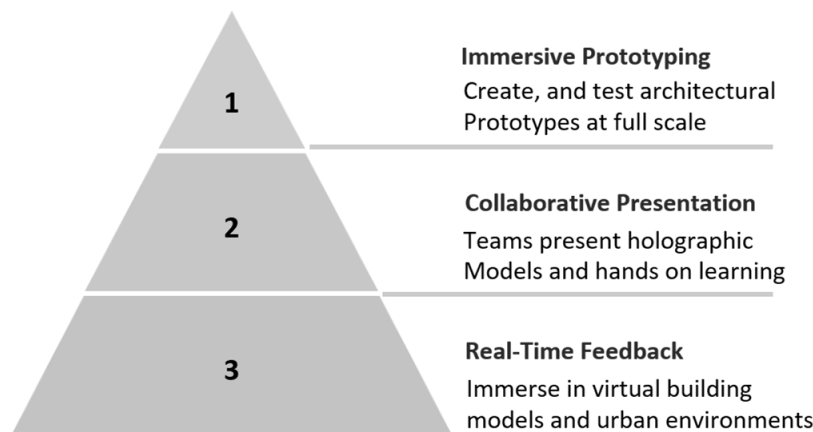


Figure 5. Integrated XR into Design Studios and Workshops.

3.3 Site Visits and Real-World Environments for Architectural Projects

- XR technologies allow architecture students to simulate real-world environments and test their designs in immersive, true-to-life settings by overlaying 3D models onto the actual site or generating a virtual replica (Crolla et al., 2024).
- Students can better understand how their concepts will integrate with the surrounding landscape, climate, and infrastructure. Nevertheless, the current state of VR technology is insufficient for providing realistic tactile simulation of materials, necessitating more advancements (Wang et al., 2023; Crolla, 2024).

3.4 Virtual Simulation for Building Systems

- Architecture students in the Metaverse harness the power of Building Information Modeling (BIM) to digitally design, simulate, and collaborate on complex building projects (Keying, 2024).
- BIM software allows them to create comprehensive 3D models, integrating structural, mechanical, and electrical systems into a cohesive virtual prototype (Abhari, et al., 2021).
- Architects may utilize extended reality (XR) technology to construct immersive design environments. This enables clients, stakeholders, and designers to engage with and experience the proposed design in a realistic and captivating manner. Consequently, this can result in more informed decision-making and enhanced design outputs (Crolla et al., 2024).

3.5 Sustainable Development & Energy-Efficient

- Leverage renewable energy sources like solar, wind, and geothermal power to create virtual buildings with a low carbon footprint (AlQallaf et al., 2022).
- Design virtual buildings using sustainable materials, recycled, and biodegradable materials that have minimal environmental impact (Abhari et al., 2021).
- Optimize energy consumption for energy efficiency through smart design, advanced thermal regulation, and intelligent lighting and climate control systems. Through the utilization of XR technologies, architects have the ability to generate designs that are more sustainable, efficient, and focused on the needs of the user (Crolla et al., 2024).

4. Challenges and Limitations of Implementing XR in Education

XR technology provides numerous opportunities in architecture design. Designers can have access to extensive data and viewpoints via virtual experiences, architectural ecosystem visualization, BIM integration, and exact environmental simulations, potentially directing the architecture field toward sustainability. Despite existing cases demonstrating the great potential of XR technology, additional research, and practical implementations are necessary for understanding its application in education in architecture and dealing with related design problems (Keying, 2024). The widespread implementation of XR in architecture education encounters substantial barriers. The challenges encompass a disparity in abilities between students and instructors, the difficulty of creating appropriate simulation and experimental settings to meet specific educational requirements, and the intricacies of incorporating new technologies into conventional curriculum (Crolla et al., 2024).

4.1 Institutional Challenges

XR has the potential to act as a transforming tool in education. Furthermore, it emphasizes the significance of tackling financial, technological, and infrastructural obstacles in order to enable effective implementation (Skola et al., 2024).

- **Compatibility Challenges:** Achieving seamless interoperability between various Metaverse platforms and existing educational systems remains a technical and logistical hurdle (Nermine et al., 2023).
- **Technical Expertise:** Effectively training educators to integrate Metaverse-based learning into their teaching practices and overcoming resistance to new technologies can be complex (Skola et al., 2024).
- **Institutional Adoption:** Integrating Metaverse-based approaches into established architectural curricula can face resistance and the need for effective pedagogical strategies (Crolla et al., 2024).
- **Cost Considerations:** Equipping design studios and classrooms with Metaverse hardware and software can be a significant investment for educational institutions (Skola et al., 2024; Crolla et al., 2024).

4.2 Students Challenges

- **Equitable Accessibility:** Ensuring virtual learning spaces are accessible to all students, including those with disabilities, is crucial but can pose technical and design challenges (Wang et al., 2023).
- **Health and Safety Concerns:** Long-term usage of virtual reality (VR) headsets can cause concerns including motion sickness, strain on the eyes, and physical pain, which require careful handling and mitigation processes (Ziker et al., 2021).
- **Infrastructure Barriers:** Reliable high-speed internet, robust computing power, and suitable spaces for XR experiences are often lacking in many educational settings.
- **Extensive training:** Absence of structured technical instruction and the need for skill in rapidly generating virtual environments (Wang et al., 2023) The necessity for extensive training programs to provide instructors and students with the essential expertise to incorporate XR into their work processes (Crolla et al., 2024).

- **Ethical Considerations:** Addressing concerns around data privacy, online safety, and the potential for digital divides in Metaverse-based education (Partarakis et al., 2024).

5. Material and Methods

To attain the research goal, qualitative and quantitative methodologies were applied. Research publications on XR applications in architectural education were reviewed and the following procedures were taken:

- Literature review to investigate the use of Metaverse-based Learning in architectural programs, challenges and opportunities.
- Data collecting through online questionnaires to gather quantitative data on the extended reality technology adoption in the Middle Eastern architecture education.
- As a result of the previous steps, collected data were analysed to present recommendations for future framework.

5.1 Study Context

The use of extended reality (XR) technology in architectural education in the Middle East is still relatively nascent, but gaining momentum. While some pioneering institutions have integrated immersive tools into their curricula, the overall integration remains limited and uneven across the diverse higher education landscape.

5.2 Purpose of the Questionnaire

1. Gauge Familiarity with XR: The questionnaire aims to assess the level of familiarity and experience that architecture educators in the Middle East have with extended reality (XR) technologies.
2. Understand Current Adoption: It will explore the extent to which XR tools and applications are currently being integrated into architecture curricula across the region.
3. Identify Barriers and Needs: The survey will also uncover the key challenges and resource requirements for broader adoption of XR in architecture education.
4. Inform Future Strategies: The insights gathered will help shape strategies to enhance the utilization of XR technologies in Middle Eastern architecture programs.

5.3 Participants' Demographics

- The questionnaire was designed using Google Forms, a 5-point scale was used for the Likert-scale.
- 266 respondents were received; participants' demographic distribution is presented in Figure 6, and descriptive statistics of the data were processed.
- This mix of perspectives provides a holistic understanding of extended reality technology adoption in the Middle Eastern architecture education landscape.

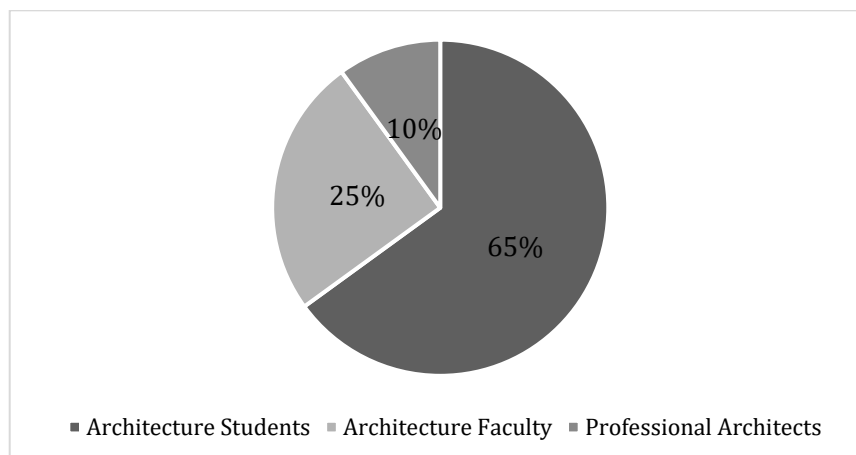


Figure 6. Participants' demographic distribution.

6. Results

6.1 Familiarity with Extended Reality Technology

The survey results show that the majority of architecture students, faculty, and professionals in the Middle East have at least some familiarity with extended reality (XR) technologies as presented in Table 1, with 35% reporting being very familiar and 45% somewhat familiar. However, 20% indicate they are not familiar with XR, highlighting the need for increased awareness and educational efforts in this field.

Table 1: Familiarity with Extended Reality Technology.

Level of Familiarity	Level of Familiarity
Very Familiar	35%
Somewhat Familiar	45%
Not Familiar	20%

6.2 Level of XR Integration in Architecture Course work

- The survey results as presented in Figure 7 indicate that extended reality (XR) technologies are most widely adopted in architecture design studios, where approximately 35% of courses utilize these immersive tools.
- XR integration is also significant in BIM (Building Information Modeling) courses, with nearly 22% of programs incorporating these technologies.
- However, the adoption rate remains relatively low in other core architecture subjects, such as architectural history (8%) and construction management (15%), highlighting the need for a more holistic integration of XR across the curriculum.

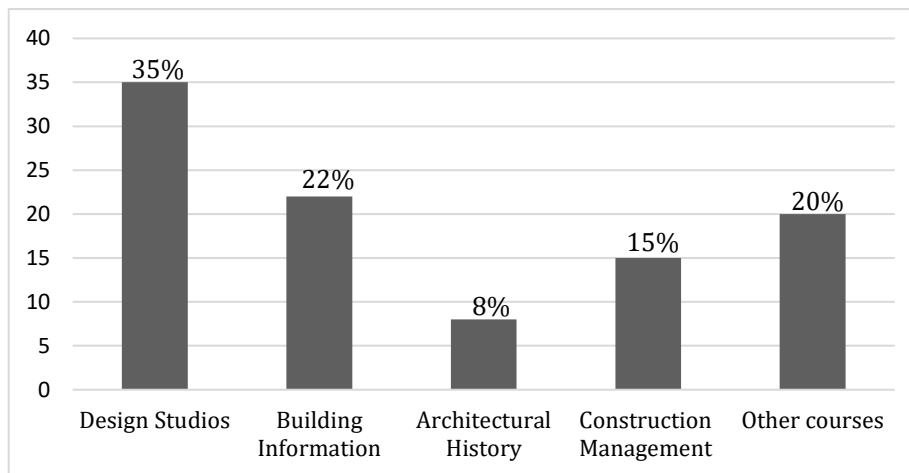


Figure 7. Level of XR Integration in Architecture Course work (Adoption rate).

7. Conclusion

An examination of past research reveals that as the Metaverse evolves, architectural education will endure substantial changes. Seamless virtual collaboration, AI-powered design tools, and limitless creative expression will change the way students learn, create, and experience the built environment. These technologies create a virtual (three-dimensional) environment in which students can practice and develop abilities in situations that would be difficult or impossible to cope with in reality. (Partarakis et al., 2024).

There is a wide range of software and gadgets accessible, and it is vital to assess and compare them to find the best one. Furthermore, XR systems have serious accessibility issues that must be addressed with both hardware and software. Many experiences need entire 360° movement and motion controller input, yet lack accessibility features to enable a larger range of users (Ziker et al., 2021). According to Partarakis, cross-disciplinary approaches have the ability to improve the design process

by guaranteeing that interfaces are psychologically, morally, and technologically sophisticated (Partarakis et al., 2024). In contrast, virtual educational settings cannot express the cognitive and emotional sensations of participation, gestures, co-presence, body language, and social contact. According to Khukalenko, the usefulness of VR may vary by field, and teachers' viewpoints in specific subject areas may produce intriguing findings.

Moreover, there are some challenges and limitations of Implementing XR in Education for students' health after utilizing XR technology for a lengthy period of time. As Ziker pointed out, the encompassing nature of VR headgear may create inconvenience or dangers for any students since they lose total control and visibility over their body. It might be challenging to keep students focused when utilizing technology. As a result, students who are working on a worksheet or workbook may benefit from AR while staying on schedule with their studies (Ziker et al., 2021).

Due to ongoing technological advancements, such as enhanced hardware performance, reduced costs, and progressively developed software solutions, XR technologies are gradually becoming more prevalent and easily accessible (Crolla et al., 2024). Architectural curricula will deeply integrate Metaverse technologies, enabling students to design, prototype, and simulate their ideas in fully immersive, real-time virtual spaces. This boundless creativity paves the way for a new era of innovative, sustainable, and dynamic virtual architecture.

Strategies for Smart Integration of XR in Education

The future roadmap for incorporating XR in architecture education was presented in Figure 8.

- ***Dedicated XR Spaces:*** Establish dedicated XR labs and studios within architectural institutions, equipped with the latest hardware and software, to facilitate hands-on exploration and experimentation by students and faculty.
- ***Faculty Training:*** Invest in comprehensive training sessions to equip faculty with the skills and confidence to seamlessly incorporate XR into their teaching methods and course activities.
- ***Curriculum Adaptation:*** Carefully map out how XR can be integrated into existing course structures and learning objectives, ensuring a cohesive and meaningful integration across the architectural education program.
- ***Industry Partnerships:*** Foster collaborations with architecture firms and technology companies to stay up-to-date on industry trends, access the latest XR tools, and provide students with real-world, immersive design experiences.

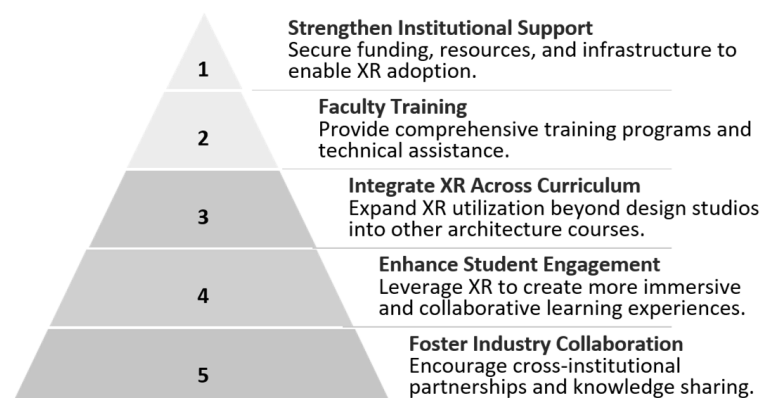


Figure 8. Future Roadmap for Incorporating XR in Architecture Education.

The use of XR in education need the support and resources of an interdisciplinary community of dedicated experts from education, government, and business who will work together to overcome the present challenges to adoption. Although the study offers compelling insights, it is crucial to recognize its limits. The study's sample size was restricted to 266 participants from Middle Eastern

countries which may affect the generalizability of the findings. Establish framework for integrating XR technologies into architectural curricula for studio courses by using Participatory Action Research (PAR) methodology.

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Conflicts of Interest

The Authors declare that there is no conflict of interest.

Data availability statement

The data that support the findings of this study are available from the author upon reasonable request.

Institutional Review Board Statement

Not applicable.

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