Architecture
Image Studies

Vol.7, Issue 1, pp.759-778, 2026
DOI: https://doi.org/10.62754/ais.v7i1.914

https://journals.ap2.pt/index.php/ais/index

AR in Education: A Systematic Review of Learning Theories and Teaching Strategies in Architectural Heritage Learning

Lin Xia[1], Noor Aisyah Mokhtar[2], Mohd Khairul Azhar Mat Sulaiman[3]

Abstract

Augmented Reality (AR) has emerged as a groundbreaking tool in the field of education, providing immersive and interactive learning experiences that improve student engagement and understanding. This systematic review examines the potentiality of AR in education, putting particular emphasis on its use in architectural heritage learning. The study integrates literature from Scopus, Web of Science, and Google Scholar as they are employed to explore AR's technological underpinnings, theoretical undercurrents, and instructional strategies. The results emphasize that AR supports constructivist, experiential, and situated learning by bridging theory with practice. Augmented reality (AR)-supported teaching strategies such as virtual reconstructions, interactive learning environments, and gamification have considerable potential to enhance student motivation and retention. The review also highlights several challenges associated with integrating AR into educational practices, including technical limitations, insufficient training for educators, and accessibility barriers. 2. Therefore, findings demonstrate the absence of interdisciplinary approaches, the need for empirical studies on AR learning effectiveness, and scalable AR-driven pedagogical frameworks. This can add to the overall discussions of educational systems by linking digital learning technologies to established educational methodologies and highlighting the potential for integrating AR across a range of educational contexts.

Keywords: *Augmented Reality in Education;Technology-Enhanced Learning;Immersive Learning Environments, Pedagogical Strategies in AR-Based Education.*

Introduction

Background and Motivation

The past couple of years has been an eye-opener for the role of digital technologies in education, specifically, in the areas of STEM, history and the arts, where hands-on and experiential is meaningful. Augmented reality is one such technology that has gained prominence, allowing an immersive and interactive experience that has revolutionized student engagement, promoted better understanding, and enabled active learning across the curriculum. Although the first works on AR application were mainly directed at architectural heritage education, the focus of practical uses has shifted over time, and now its wider suitability across various subjects is becoming clear. Augmented reality's capability to combine real and digital elements constructs a dynamic learning setting where students can visualize abstract ideas, simulate practical uses and engage with historical, scientific and mathematical content in ways never before possible. As Lo and Selby (2024) propose among others, AR improves students' conceptual understanding in their fields of study because it promotes cognitive engagement and motivation at higher levels.

Moreover, AR has been progressively assimilated into various educational levels, from K-12 classrooms to higher education and vocational training. In K-12 education, AR has the potential to bridge the gap between theoretical knowledge and practical experience by providing combined visual

[1] Department of Architecture and Built Environment, Faculty of Enigineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia, Art College of Sichuan Technology and Business University, 611745, No. 65, Xueyuan Street, Pidu District, Chengdu, China, Email: aisyahmokhtar@ukm.edu.my, (Corresponding Author)
[2] Department of Architecture and Built Environment, Faculty of Enigineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia.
[3] Department of Architecture and Built Environment, Faculty of Enigineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

stimuli on STEM concepts, historical moments, and artistic masterpieces; enabling students to visualize and engage with 3D models of molecular structures, historical recreations, and interactions with digital art through immersive visualization. AR has been used successfully in engineering, medical training and digital humanities in higher education spaces, where students practice complicated procedures, conduct virtual dissections, and simulate physics or engineering experiments in an interssive and damage-free space. At the same time, in the domain of vocational training and professional development, AR is being used for hands-on skills such as mechanical repairs, surgical simulations, and industrial design visualizations. The versatility of AR in different learning environments highlights its ability to connect theory with practice, solidifying its status as a next-gen educational technology. As it has the potential to transform methods of classroom instruction and curriculum development, research should be conducted on AR best practices, the long-term consequences for educational outcomes, and the scalability across a variety of academic settings.

Scope and Objectives

This systematic review is intended to examine the use of augmented reality (AR) technologies in architectural heritage education. It will look at how AR has been used in virtual reconstruction and site interpretation, interactive learning experiences, public engagement and tourism. This review aims to reasonably conclude that the current status of AR in architectural heritage education is. It also values these applications. Similarly, it seeks to identify where AR contributes to architectural heritage education while acknowledging the problems where it is not useful or unhelpful. Figure 1 shows that Google Scholar results from searches like "Augmented Reality architectural heritage education" have seen a constant growth for five years now--indicating the high level of interest in this field. On the other hand, Figure 2 is the result of a Scopus search and shows publications over time. Looking at this graphic we can see that numbers representing things like research interest fluctuate year on in architectural heritage education. And from the Web of Science as depicted in Figure 3, searching for sites related to comparing World Wide Web data (WoS) with Scopus output. We found a hit off 17,000 and over 97 hits in this field of enquiry.

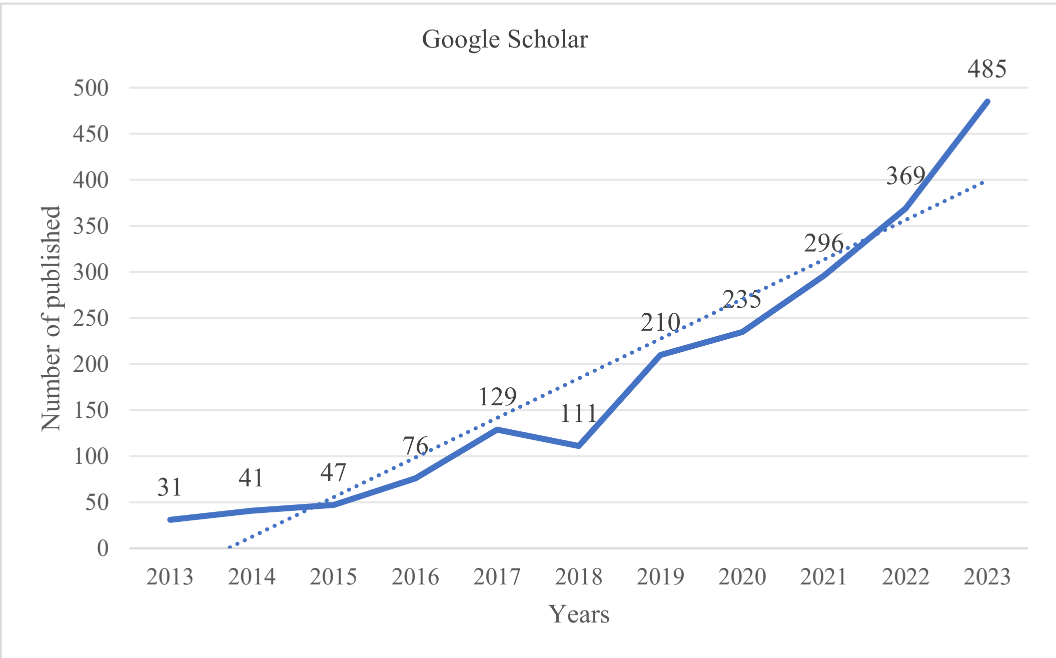

Figure1:Trend of Publications in Google Scholar (2013-2023)

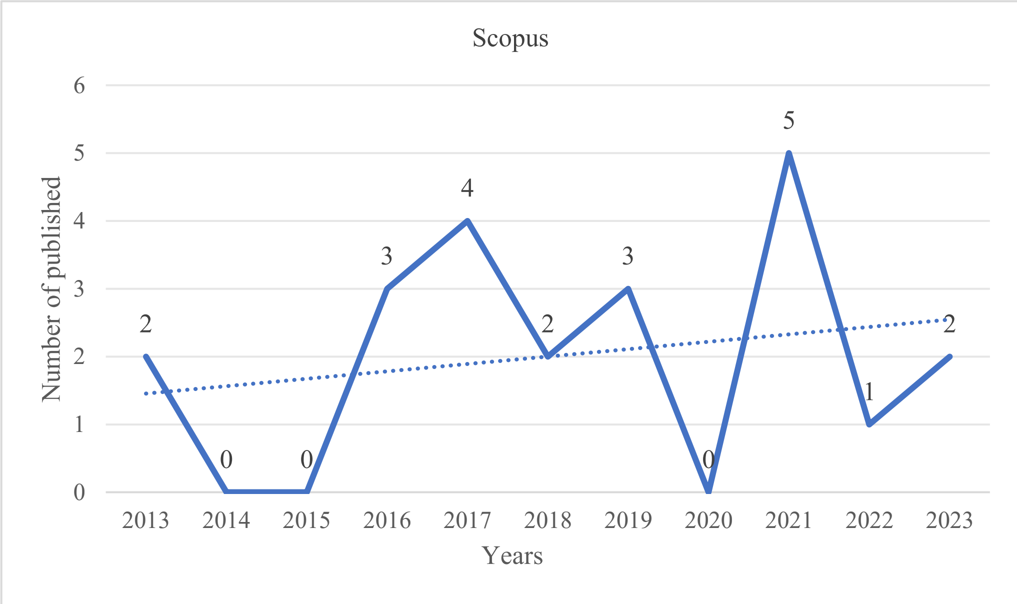

Figure2.Trend of Publications in Scopus (2013-2023)

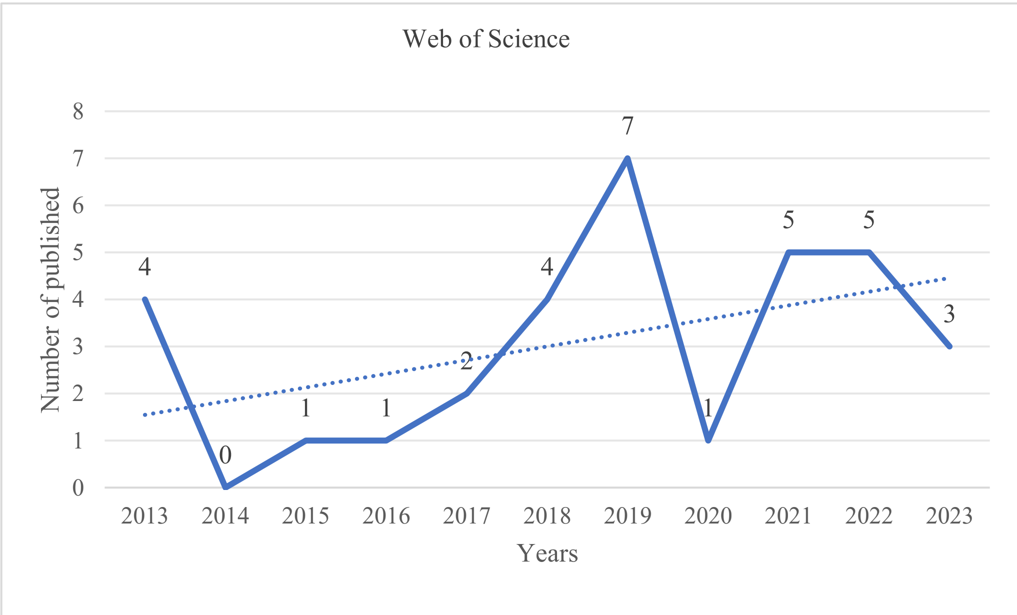

Figure3.Trend of Publications in Web of Science (2013-2023)

Ultimately, this re-view aims to provide some references for future research and practice, to contribute more effective methods that make teaching better, new innovative educational tools.The review included studies published in Web of Science (WoS), Scopus, and Google Scholar that concentrate on peer-reviewed paper giving valuable insight into the use of AR in architectural heritage education (Lo & Selby, 2024).

This systematic review looks into the integration of augmented reality (AR) technology in the education of architectural heritage and investigates its technical pillars, learning theories, and pedagogical approaches. Relevant categories include the following: theories concerning the use of AR technologies in an educational context and teaching and learning architectural heritage with AR. This systematic review addresses a research gap: it is the first study to compare the role of AR in various educational environments and environments. This review aims to systematically examine the literature and provide insights into how AR has the potential to improve the learning experience, foster student engagement, and facilitate the sustainability of the architectural heritage in varied educational contexts.

Research Questions (RQs) and Contributions

As pointed in Table 1, this research question can be oriented along four dimensions (RQs).

Table 1: Research Questions Addressed in this Review

Research Question (RQ)	Core Content
RQ1: What are the main technologies of AR in architectural heritage education?	Identifies and classifies the primary AR technologies utilized in architectural heritage education, such as marker-based AR, markerless AR, and projection-based AR, along with their respective use cases and advantages (Boboc et al., 2022).
RQ2: Which learning theories are applicable to AR-based teaching methods in architectural heritage education?	Explores the learning theories that support the use of AR in architectural heritage education, including constructivist learning, situated learning, and cognitive load theory, and how these theories enhance the effectiveness of AR-based teaching methods (Dordio et al., 2024).
RQ3: How effective is AR in classroom, museum, and virtual learning environments?	Evaluates the effectiveness of AR applications in different educational settings, including classrooms, museums, and virtual learning environments, by summarizing evaluation methodologies such as user experience assessments, learning outcome measurements, and technical performance testing (Boboc et al., 2022).
RQ4: What are the future directions for AR in architectural heritage education?	Discusses current research gaps and potential future directions, such as integrating AR with other technologies, developing personalized learning experiences, and expanding applications in diverse educational settings (Dordio et al., 2024).

Although this study focuses on the role of AR in architectural heritage education, its findings are also of broad reference significance for AR teaching applications in fields such as STEM, medical education, and vocational training.

Background and Related Work

Architectural Heritage Education and Digitalization

Historically, architectural heritage education often involved students going to actual buildings and reading dry theories. It lacked interactive elements and immersion experiences.Digital technologies, however, are changing this. They offer new ways of delivering information that intensify learning and make it more adventurous.Making architecture heritage education digital involves using advanced technologies like 3D modelling, virtual reality (VR) and augmented reality (AR) to create interactive experiential learning.Feature 4 gives us the typical example of this concept: The Reality-Virtuality Continuum in Architectural Heritage Diagram places three tenets along a line starting in real life and moving through to augmented reality (AR) applications, such as AR books and AR apps that show 3D models interactively. AR turns into augmented virtuality (AV), which in turn supported virtual tours, AR games and the full virtual experience of heritage sites found in 3D reconstructions or virtual museums.Finally, AV leads us to a completely virtual environment where users experience sites in full-digital form.

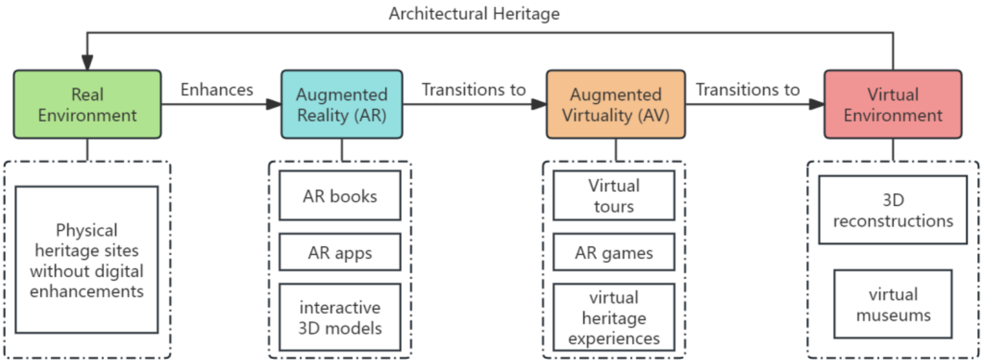

Figure 4. The Reality-Virtuality Continuum in Architectural Heritage Context

Lo and Selby (2024) report that AR provides a significantly enhanced learning experience by presenting learners with immersive and interactive content, which leads to deep mental understanding and prime interest in architectural heritage education. Here, by using AR, historical sites can be virtual reconstructed, interactive learning experiences can be made available, and the public is able to get engaged via digital platforms. This digitalization is not just making educational achievements better, it is also preserving or even spreading traditional cultures. In architectural heritage education, more and more use is being made of AR. There are frequent reports in this field that show how it could well change the method of heritage is learned and lived.

Augmented Reality in Education

Augmented Reality (AR) has emerged as a transformative tool in the education sector, offering interactive and immersive learning experiences across various disciplines, including STEM education, history, medicine, and vocational training. By overlaying digital information onto the real world, AR enhances students' engagement and understanding of complex subjects.

For instance, AR applications have been integrated into STEM education to help students visualize abstract concepts, such as molecular structures and physics simulations. History education has also benefited from AR by allowing students to explore historical sites and artifacts virtually, providing a more engaging alternative to traditional textbooks. In medical education, AR assists in anatomical visualization, surgical training, and patient diagnosis simulations, offering hands-on experience without real-world risks. Moreover, vocational training programs utilize AR to simulate real-life work environments, equipping learners with practical skills before entering the workforce.

Despite its advantages, AR implementation in education faces several challenges, such as technical constraints, high development costs, and the need for teacher training. However, ongoing research continues to explore ways to optimize AR integration, ensuring its effectiveness in diverse educational settings. The comparison between AR and VR in educational applications is summarized in Table 2.

Table 2. Summary of Existing Literature Reviews on AR in Heritage and Education

Review Article	Main Content	Key Findings
Chen et al. (2024)	Discusses AR in cultural heritage education, emphasizing user experience and preservation	AR enhances immersion, interactivity, and learning outcomes
Fang et al. (2023)	Reviews AR in history and heritage visualization	AR improves understanding but emotional impact research is limited

Review Article	Main Content	Key Findings
Lo & Selby (2024)	Analyzes AR in education, covering classroom and medical settings	AR offers strong interactivity and memory retention
Zhang et al. (2024)	Analyzes digital trends in intangible cultural heritage	Key technologies include AR, data acquisition, and multimedia interaction
Li et al. (2023)	Explores VR in cultural heritage protection	VR aids protection but cost reduction is a challenge
Wang et al. (2024)	Systematic review of rural industrial heritage	Protection requires cultural integration and community participation

Learning Theories Related to AR Education

A growing body of research explores the relationship between AR education and learning theories, emphasizing the cognitive and psychological aspects of AR-based learning. Several educational theories provide a foundation for understanding how AR can enhance student learning experiences:

Constructivism: AR facilitates constructivist learning by enabling students to actively engage with digital content in real-world contexts. Through hands-on exploration and interaction, learners construct knowledge rather than passively receiving information.

Situated Learning: AR supports situated learning by embedding educational content within authentic environments. For example, AR-based field trips allow students to explore historical sites or ecological systems in a way that simulates real-world experiences.

Cognitive Load Theory: AR can reduce cognitive overload by presenting information in a more intuitive and interactive format. However, poorly designed AR applications may increase extraneous cognitive load, making it crucial to develop user-friendly interfaces that align with learners' cognitive capacities.

Several meta-analyses have examined the impact of AR on learning outcomes. Akçayır and Akçayır (2017) reviewed the benefits and challenges of AR in education, highlighting its potential to enhance motivation and engagement while noting the necessity of teacher training. Garzón and Acevedo (2019) conducted a meta-analysis on AR’s effect on student performance, demonstrating that well-integrated AR applications lead to significant academic improvements. Additionally, Koutromanos et al. (2023) explored AR’s role in historical education, emphasizing its ability to create immersive, game-based learning experiences.

Overall, these studies underscore the transformative potential of AR in education, while also highlighting the need for further research to optimize its implementation. The summary of these findings is provided in Table 3.

Table 3.Comparison of AR and VR in Education

Feature	Augmented Reality (AR)	Virtual Reality (VR)
Definition	AR overlays digital information onto the real world, enhancing the physical environment.	VR immerses users in a completely virtual environment, replacing the physical world.
Strengths	Enhances real-world interactions with digital elements	Provides fully immersive experiences
	Supports collaborative learning	Enables simulation of complex or dangerous scenarios

Feature	Augmented Reality (AR)	Virtual Reality (VR)
	More accessible via smartphones and tablets	Enhances focus and engagement
Weaknesses	Limited by the physical environment	Requires expensive hardware (e.g., VR headsets)
	Less immersive compared to VR	Potential for motion sickness and eye strain
Educational Applications	Interactive learning resources (e.g., 3D models in textbooks)	Virtual field trips (e.g., historical sites, natural wonders)
	Gamified learning experiences	Simulation-based training (e.g., medical procedures, engineering designs)
	Visualization of complex concepts	Experiential learning in controlled environments

Augmented Reality in Various Educational Domains

Table 4. Augmented Reality in Various Educational Domains

Educational Domain	AR Applications	Benefits
STEM	3D Visualization, Experiment Simulation	Enhances conceptual understanding, makes abstract concepts tangible
Medical Education	Surgical Simulation, Anatomy Learning	Improves surgical precision, allows risk-free practice
Vocational Training	Industrial Skills Training, Mechanical Repair	Facilitates hands-on learning, reduces training costs

Table 4 illustrates AR in various educational domains with examples. In STEM education, AR enriches the learning experience by offering a more interactive and engaging way to visualize complex scientific concepts. Augmented reality (AR) is being used for surgical simulation and anatomy teaching in medical learning, where it enables surgeons to attain higher levels of precision and allows students to practice skills without risk. Vocational training: AR helps with industrial skills training and mechanical repair. It allows for hands-on learning while reducing training costs, and is directly applicable to the business context. This chart highlights the different contexts in which AR can be used in classroom instruction, and how it can change how students learn by fostering engagement and retaining information.

Review Methodology

Systematic Literature Review Process

Systematic Literature Review of AR in Architectural Heritage Education in Accordance to the PRISMA Protocol Through the PRISMA process, a systematic literature review (SLR) is achieved which brings transparency and integrity to the methodology(Figure 5). This started with the generation of specific research questions to inform the review. We subsequently established a comprehensive review protocol, including inclusion/exclusion criteria, search strategies, and data extraction processes. The following databases were searched for relevant studies: scopus, web of science and google scholar. Duplicates were removed, and titles and abstracts screened for relevance. We agreed to full-text reviews to confirm the studies fulfilled our inclusion criteria. We extracted and synthesized data from eligible studies to inform our research questions. Following the above systematic method helped to rigorously analyze the current state of literature with respect to augmented reality in architectural heritage education in an unbiased manner.

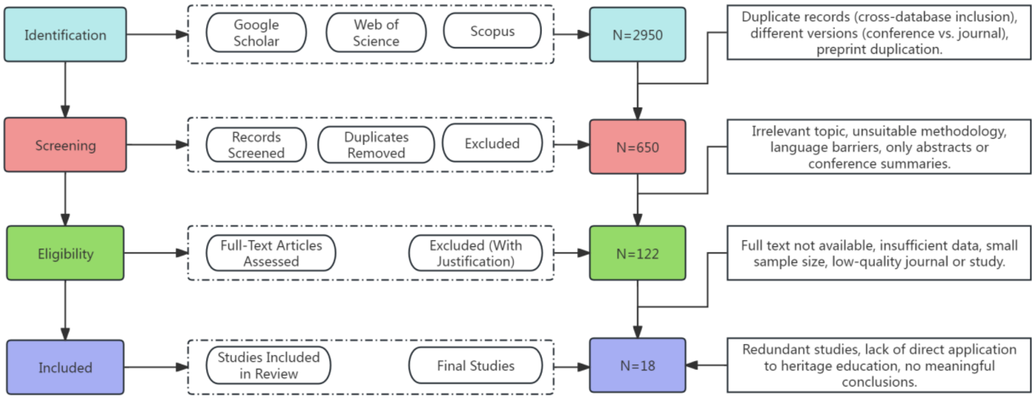

Figure 5. PRISMA Flow Diagram of the Review Process

Database Selection and Search Strategy

In the systematic review of AR in architectural heritage education, a comprehensive search strategy was employed across multiple digital databases to ensure a robust and unbiased collection of literature. The databases selected included Web of Science (WoS), Scopus, Google Scholar, IEEE Xplore, and ERIC. These databases were chosen for their relevance to the fields of education, technology, and cultural heritage, as well as their extensive coverage of academic publications (Table 5)

Table 5. Digital Databases Used in the Review and Search Queries

Digital Database	Search Queries	Articles Retrieved
Web of Science (WoS)	("Augmented Reality" OR "AR") AND ("Architectural Heritage" OR "Cultural Heritage" OR "Historical Buildings") AND ("Education" OR "Teaching" OR "Learning")	39
Scopus	("Augmented Reality" OR "AR") AND ("Architectural Heritage" OR "Cultural Heritage" OR "Historical Buildings") AND ("Education" OR "Teaching" OR "Learning")	31
Google Scholar	"Augmented Reality" "Architectural Heritage" "Education" OR "AR" "Cultural Heritage" "Teaching" OR "AR" "Historical Buildings" "Learning"	2880
IEEE Xplore	("Augmented Reality" OR "AR") AND ("Architectural Heritage" OR "Cultural Heritage" OR "Historical Buildings") AND ("Education" OR "Teaching" OR "Learning")	15
ERIC	("Augmented Reality" OR "AR") AND ("Architectural Heritage" OR "Cultural Heritage" OR "Historical Buildings") AND ("Education" OR "Teaching" OR "Learning")	8

Inclusion and Exclusion Criteria

The systematic review of augmented reality in architectural heritage learning was represented following defined inclusion and exclusion criteria to extract quality primary literature. The basis of inclusion criteria was peer-reviewed articles, published from 2010 to 2023, related to the use of augmented reality (AR) for the education of architectural heritage. Only articles that presented empirical data, proposed theoretical models or provided systematic reviews related to the roles of AR in enhancing the experience of learning and preserving heritage were included (Akçayır & Akçayır, 2017). Additionally, the quality of studies was checked according to the Newcastle–Ottawa Scale, which helped guarantee the dependability and validity of the incorporated literature. In contrast, we excluded non-English articles, conference abstracts, editorials and articles that lack direct relevance to AR and/or architectural heritage education. Studies addressing VR only and lacking the theoretical grounds for AR or that were of low methodological quality (Garzón & Acevedo, 2019) were also excluded. This recruitment process is likely to have established a high procedural standard that covered the most pertinent high-quality literature.

Quality Assessment and Data Extraction

This paper contains data extraction and quality assessment based on systematic review of available literature on augmented reality for architectural heritage education to collect reliable and scientific studies. Two independent reviewers systematically extracted data using predefined data extraction forms to minimize bias and enhance accuracy. Study design, sample size, AR application type, educational outcomes, and conclusions were extracted from each study. Non-randomized studies were assessed for quality using the Newcastle–Ottawa Scale (Wells et al., 2000). Used Cohen’s Kappa to calculate inter-rater reliability between reviewers to increase the rigor of the review addressing consistency in reviewer selections. The two-reviewers-per-study design and the application of validated evaluation tools together enriched the appraisal of methodological robustness and pertinence of the studies considered.

Research Findings

Overview of Studies and Publication Trends

Over the last ten years, studies on augmented reality (AR) in architectural heritage education have experienced a remarkable upsurge. A systematic review of the literature over a 10-year span (2012–2021) revealed that there are 1,201 unique documents regarding AR applications in cultural heritage, with a major focus on popular areas of interest, such as 3D reconstruction, digital heritage, virtual museums, user experience, education, tourism, intangible cultural heritage, and gamification (Boboc, Băutu, Gîrbacia, Popovici, & Popovici, 2022). This upward trend in research has emerged due to the development of technology and the growing potential of AR as an innovative tool to improve the learning process in architectural heritage education and pedagogy. Applications that feature visualizing restored artifacts, documentation, and contextual understanding are of special focus and have demonstrated learning outcomes (Bertaluci & da Silva, 2024).

AR Applications in Architectural Heritage Education

Augmented reality (AR) has become a key tool for creating immersive experiences in architectural heritage education. AR allows students to engage with historical buildings in creative ways, by overlaying digital information onto physical environments. This notion is reflected, for example, in the use of AR in the recreation of cultural heritage, so that learners can view and manipulate 3D models of ancient buildings and garner insights into historical construction methods and architectural styles (Rattanarungrot et al., 2019). Imbuing one's study of history with a hands-on element truly brings it to life.

A more applicable use of AR in architectural education has been the representation of complex construction processes to facilitate understanding. Abdullah et al. (2019) demonstrated using AR to present steel architectural construction, allowing students to visualize construction sequences and internal structures that are typically difficult to comprehend through conventional means. An example of this visualization can be seen in Figure 6 where an AR interface is shown with the complex steel framework. These applications bridge the gap between theoretical knowledge and practical understanding and prepare students for real-world architectural challenges.

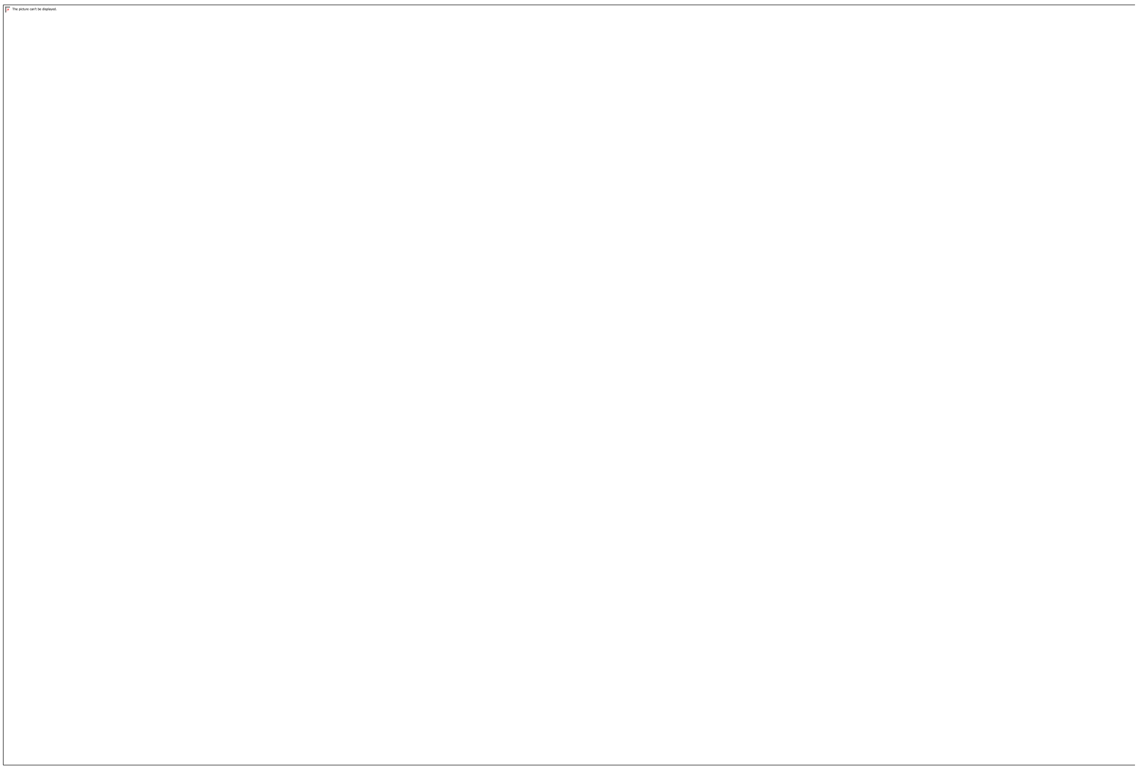

Figure 6. Showcasing the Golden Sun Bird in Digital Format

In addition, AR applications are also applied to contextualize detached artifacts within their original architectural context. Nofal et al. (2018) created an AR interface that reconstructs the natural environment of a museum artifact enabling players to visualize its historical context. As illustrated in Figure 7, the AR environment augments the current museum environment with a semi-translucent view of the ancient chamber, allowing for a well-defined perspective for where and why an object was located. This technique enhances the learning process by providing context about individual elements within an architectural trajectory.

Together, these applications showcase how AR can play a considerable role in architectural heritage education. Digital and traditional learning merging introduces students to experiences that they won't forget. However, with the development of AR the opportunity to access it fills the gap between the unknown and known and implement it in education will grow significantly.

Figure 7.AR historical overlay at Wuhou Shrine

AR Technologies Used in Architectural Heritage Studies

Augmented reality (AR) technologies have been applied in architectural heritage studies for such distinct purposes and compelling benefits. From Table 5, it can be noted that three primary categories of AR technologies have been employed, in Marker-based AR, Markerless AR, and Projection-based AR. Marker-based AR, a teaching technique that accounts for 40% of studies (Figure 8), is based primarily on using smartphones and tablets to create an immersive teaching experience by overlaying 3D models and animations on printed materials. Markerless AR (32%), which relies on smartphones, tablets and AR glasses to deliver interactive experiences using location-based and environment-aware applications. Projection-based AR (28% of studies), which employs projectors to cast 3D models and animations onto physical surfaces, was another favored augmented learning tool as it enhances the immersion of a lesson.

Thereby, these technologies' contributions to architectural heritage education are very crucial, as they offer new and exciting learning methodologies for students or scholars. The frequency of these technologies is presented in Figure 8 and identifies Marker-based AR is the most widely used technology, followed by Markerless AR and Projection-based AR, demonstrating the variation in use and preference across this field.

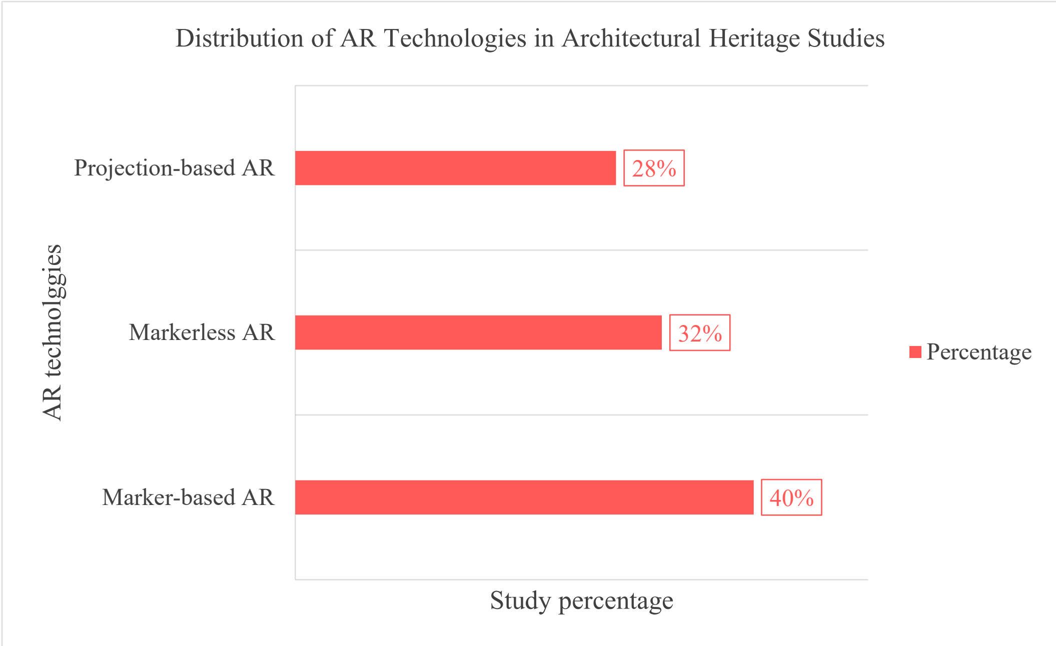

Figure 8. Distribution of AR Technologies in Architectural Heritage Studies

Learning Theories and Pedagogical Models Applied

The field of augmented reality (AR) heritage education employed various learning theories and pedagogical models to enhance the learning process. As seen in figure 9, Constructivism emphasizes interaction with content, allowing students to build knowledge through engagement with AR materials. Multimodal learning takes advantage of AR's capacity to deliver the information in multiple sensory modalities, which promotes understanding and retention. Gamification is the process of doing this by incorporating elements of games into AR applications, which will allow students to be more engaged and motivated. To illustrate, played-centered AR classes have been created to guide users through learning architectural heritage by examining virtual replicas of ancient locations and performing interactive activities. Blended learning models are a mix of traditional and digital, providing a combination of both on-site and remote learning enhanced with AR technology. AR not merely adheres to two of the modules namely; Dale's Cone of Experience and Kolb's Learning Cycle, since not only does AR assist learning but it also provides concrete experiences and enhances the process of the learning cycle (such as when learners are given the opportunity to interact with guides in AR or play AR games in their location. Models and theories of learning like these are being employed into AR applications, whether virtual reconstructs, geolocation-based AR games, or interactive AR guides, that assist the teaching process and stimulate architectural heritage education.

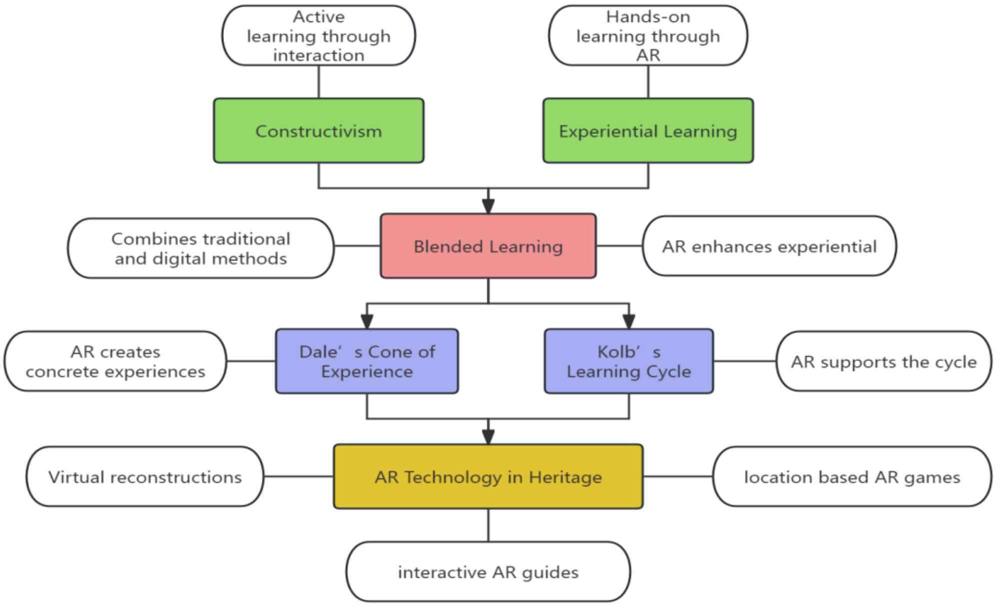

Figure 9. Common Learning Theories and Models Used in AR Heritage Education

Pedagogical Applications of AR in Architectural Heritage Education

Seeing the implementation of Augmented Reality (AR) in education having immense potential in classroom education, online education, STEM experiments, medical training, vocational education, etc. This is when AR or augmented reality comes into play, which provides practical exposure and a two-way interactive space that explains learned theories with complete practicality. Studies show that students who access AR-based learning environments report greater motivation and better retention of knowledge. In one controlled experiment, students who spent time in an AR-enhanced STEM lab approved significantly higher post-test scores (85) than those assigned to a traditional lab (72) confirming AR effects on deeper understanding and long-term retention (see Figure 10). In medical training, layering anatomy for enhanced understanding and procedural training with AR has improved spatial cognition to reduce errors in practical assessments.

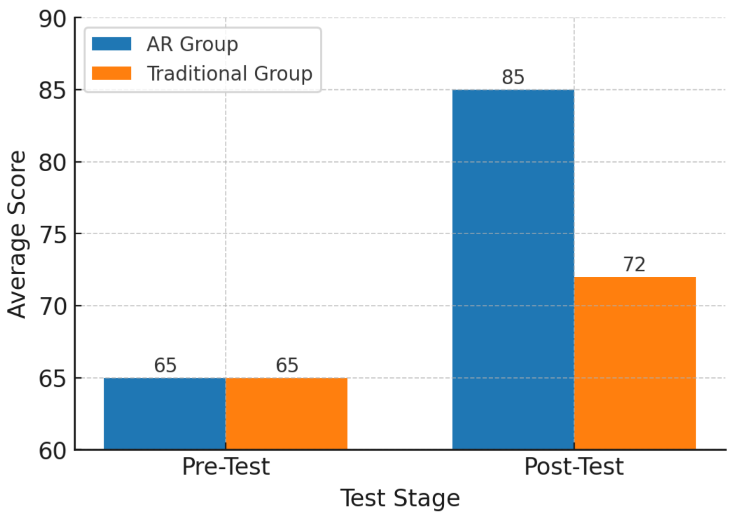

Figure 10. Comparison of Student Test Scores Before and After AR Learning

Although it has many benefits, the incorporation of AR into education poses several challenges to educators and institutions. Teacher input points to challenges with technology integration, student motivation, course design and aids to accessing AR-capable devices (Figure 11). Although several educators see the potential of AR in fostering better engagement with students, they stress providing structured training programs to avoid unsuccessful implementations. In addition, cognitive overload and technical constraints frequently impede seamless adaptation in diverse education settings. A well-structured learning model is the only possible solution to address those challenges. In this (Fig 12) we present a systematic three-phase approach including; Phase 1 (Pre-Class Preparation)- introduces AR content and functionalities, Phase 2 (In-Class AR Interaction)- employs real-time AR simulations and gamified experiences to engage the students, and Phase 3 (Post-Class Reflection)- facilitates knowledge synthesis through discussions and application based tasks.

Figure 11. Teacher Feedback on AR in Education

Results showed the effectiveness of AR in various educational contexts such as classroom learning, online learning and vocational training as shown in Table 6. Even though AR presents better models and interactive simulations for online education, it could take a toll with hardware dependency and heavy reliance on the internet. While AR has demonstrated effectiveness in skill-based learning such as medical simulations or mechanical repairs during vocational training, valuable immersive experiences often require specialized equipment.

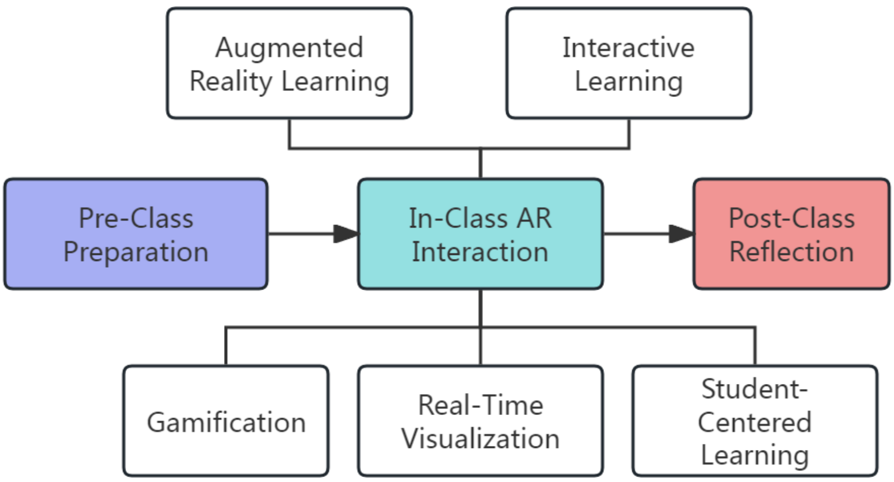

Figure 12. Flowchart of AR Application In Classroom Teaching

Table 6. Comparison of AR Applications in Different Educational Environments

Educational Environment	AR Application	Advantages	Disadvantages	Real-Case Examples
Classroom	Interactive AR guides and virtual reconstructions	Enhances student engagement Facilitates interactive learning	Requires access to AR devices May require technical support	AR-enhanced textbooks with 3D models of architectural heritage
Museum	AR-based exhibits and interactive displays	Provides immersive experiences Enhances visitor engagement	High development costs Limited by physical space	The Forbidden City VR classroom, where students explore virtual reconstructions of historical buildings
Online Learning	Location-based AR games and virtual field trips	Offers flexibility and accessibility Supports remote learning	Relies on stable internet connectivity May lack social interaction	Dunhuang Academy's AR cultural relics restoration project, allowing users to explore virtual reconstructions of historical sites

The case studies provided in Table 7 highlight an array of AR (e.g., AR-based STEM labs, virtual medical training modules and online collaborative learning platforms) case studies from the real world which demonstrate AR's potential to engender interactive engagement while providing students an experience of hand-on learning regardless of the discipline in a (works cited). Potential Consequences: Redefining Drone Education Through Augmented Reality Inserting Drone course-specific lessons into a directive teaching framework will shift the type of experience they create for students from passive consumption of specific information to active, interactive experiences that utilize simulation and analysis to derive meaning, thereby improving student comprehension, retention, and application of course concepts.

Table 7. Real-Case Examples of AR in Architectural Heritage Education

Case Study	AR Application	Educational Goal	Impact
Forbidden City VR Classroom	Virtual reconstructions of historical buildings	To provide an immersive learning experience of Chinese architectural heritage	Enhanced student engagement and understanding of architectural details
Dunhuang Academy's AR Cultural Relics Restoration Project	AR-based virtual reconstructions of historical sites	To facilitate the preservation and education of cultural heritage	Enabled users to explore and learn about historical sites in an interactive manner

Evaluation Methods in AR-Based Heritage Education Studies

Table 8.Evaluation Methods in AR-Based Heritage Education Studies

Evaluation Method	Assessment Focus	Description	Examples
Learning Outcomes	Examining the effectiveness of	This method assesses the impact of AR on students'	Studies comparing AR-enhanced lessons with

Evaluation Method	Assessment Focus	Description	Examples
	AR in enhancing learning	knowledge acquisition and retention. It often involves pre- and post-tests to measure the improvement in learning outcomes.	traditional teaching methods showed significant improvements in students' understanding of architectural heritage concepts.
Cognitive Enhancement	Evaluating the impact of AR on cognitive processes	This method focuses on how AR affects students' cognitive abilities, such as problem-solving, critical thinking, and spatial awareness.	Research using AR in architectural design courses found that students demonstrated enhanced spatial reasoning and creativity.
Interactive Experiences	Assessing the engagement and satisfaction of students	This method evaluates the level of student engagement and satisfaction with AR applications. It often involves surveys and interviews to gather qualitative data.	Surveys conducted after AR-based field trips to historical sites indicated high levels of student satisfaction and engagement

Evaluation methods in AR-based heritage education studies focus on assessing the impact of AR on learning outcomes, cognitive enhancement, and interactive experiences. These methods examine the effectiveness of AR in enhancing learning, evaluating its impact on cognitive processes, and assessing student engagement and satisfaction. Examples include studies comparing AR-enhanced lessons with traditional teaching methods, research on AR in architectural design courses, and surveys conducted after AR-based field trips to historical sites. These evaluations provide valuable insights into the effectiveness of AR in architectural heritage education (Table 8)

Discussion and Implications

Strengths and Benefits of AR in Architectural Heritage Education

Specialty of Augmented Reality (AR) in Architectural Heritage Education Immersive Learning Experience: One of the main strengths of AR is the Immersive Learning Experience it provides. AR adds liveliness to 3D print media through 3D models, animations, and interactive elements that make the learning experience for students more dynamic. By exposing students to the data, they will not only familiarize themselves with complex subjects, but also visualize usually hidden processes, reducing cognitive load and raising motivation. Furthermore, AR enables the reconstruction of destroyed or missing components of the elements of the material architecture from earlier periods and virtually reworking them on the buildings and presenting them to visitors in their original condition, thus representing a substantial contribution to the protection of cultural asset. Such virtual recreations are especially useful in cases where a physical restoration might be hard of impossible.

One of the advantages of AR in architectural heritage education is that it may be employed in a variety of educational contexts. AR enables education to broaden its horizons — be it in classrooms, museums or at heritage sites themselves, the learners are guaranteed an uninterrupted, and an enhanced, learning experience. Mobile apps or AR books can help students engage with historical data and architectural details making learning interactive, thereby enhancing their ability to retain information and impact their learning. Moreover, AR encourages collaborative learning and can be used within multiple pedagogical models such as blended learning or experiential learning to create an enriched and integrated learning experience. The benefits of AR in teaching architectural heritage as a whole are multifaceted and it is an effective tool because students tend to be more motivated to understand, and appreciate cultural heritage.

Challenges and Limitations

Although potential exists for augmented reality (AR) in architectural heritage education, various hurdles inhibit its adoption, which range from technical to educational. The limitations, however, are in many ways technical, especially when considering the need to balance the processing power of the small mobile devices, the bandwidth consumption of the app, and the realism of the 3D models themselves. Consequently, high-poly 3D models take up bandwidth and processing power, making for a less seamless user experience and ultimately less boat people on the web, especially mobile users. Arising as another major dilemma is the ineffectiveness of many AR applications as entertaining and interactive mediums. Despite the burgeoning interest in AR-augmented heritage education there is evidence that: students and educators expect more dynamic features — such as gamification elements and real-time interactive narratives — than simple 3D model manipulation. Absent these immersive methods, students' drive and participation can wane, and AR and VR can become less effective at improving knowledge- and skill-based learning. Teacher training and integration into courses are also hard problems. Most teachers do not possess the technological skills and pedagogical methods to integrate AR well in their lesson. Without the right training materials, teachers face a challenge to devise interactive lessons that meet both curricular outcomes and learning objectives. Such discrepancies in teacher readiness and resource availability can inhibit the adoption and impact of AR in heritage education.

Apart from technical limitations, the cognitive and pedagogical implications of AR need to be explored. Although AR can provide students with visualization and learning experiences to promote immersion [16–20], AR applications could facilitate high cognitive load because AR systems require students to simultaneously process 3D complex spatial data, historical narratives, and interactive components. Some literature indicates that information overload may occur when students are using AR for the first time, which can result in frustration or disengagement. So for the AR applications should be well set in formats and expert, transparency and clear where and how to prevent cognitive overload. Additionally, it is difficult for AR to reproduce the emotional connection and sensory authenticity of genuine heritage interaction. It is a powerful educational tool, but however it can be expected to serve simply as a supplement to field visits, facilitating a balanced, multi-modality learning. These challenges must be addressed through improved AR design, better teacher training, and empirical research to maximize the role efficacy of AR in architectural heritage education and beyond.

Opportunities for Future Research

There are several opportunities for further research in architectural heritage education through augmented reality (AR). The framework presented includes contributed components including AR technology, interaction method, educational models, and evaluation systems are presented in Figure 13. Adding to the future work that could leverage AR technology, this work reflects issues related to the technical limitations, like improving processing power for mobile devices and minimizing bandwidth usage... Moreover, the development of more engaging and interactive AR experiences with gamified elements nasced user engagement and motivation. One approach towards achieving this is by experimenting with different means of interaction, such as voice commands and gesture recognition, to create more people-oriented experiences in AR applications.

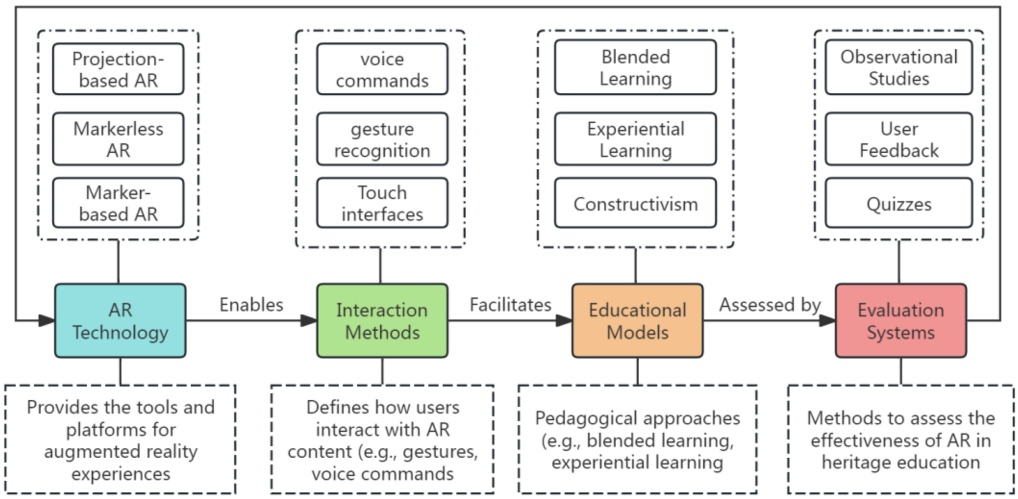

Figure 13. A Proposed Framework for AR Integration in Architectural Heritage Education

Additionally, subsequent studies should further enhance the educational applicability of AR technology by developing explicit pedagogical frameworks and offering training for educators. This will allow them to embrace the shift toward AR in education while preparing for its potential impact on mainstream education, where effective AR adoption can ultimately enhance student learning outcomes. In addition, we also need more comprehensive evaluation systems that will help us how effective AR is in the context of architectural heritage education, whether we have achieved the expected learning outcomes or user satisfaction. In conclusion, those opportunities indicate the way for future development of AR technologies in architectural heritage education.

Limitations and Future Work Future AR Based Learning in Architectural Heritage Education Future work can focus on exploring the engendering of artificial intelligence (AI) with augmented reality (AR) to offer a tailored interactive learning environment. Utilizing AI in AR VIRTUAL CLASSROOMS | AR enhances real-time, personalized AR classroom using feedback to precisely adapt content while VIRTUAL CLASSROOMS accelerates profitability. Students learn and work in the MetaverseA new space where they can work and learn collaboratively in a more immersive virtual environment, transcending geographic limitations and promoting global collaboration. We are currently connecting our virtual exhibition of sensory experiences to the aforementioned knowledge gap through the development of AI and AR-powered Metaverse-ready tools. This augmented reality can add excitement for students to experience learning after visiting a historical place or artifact. The following are the details: As we delve deeper into AI and the Metaverse, such a scenario deserves due consideration as the horizon is expanding which in turn opens the gates of innovation in education.

Conclusion

This study systematically reviews the application of augmented reality (AR) in education, especially architectural heritage education. However, the findings of this study are also applicable to STEM education, medical education and vocational training, providing a theoretical basis for the development of AR courses in different disciplines.

Summary of Findings

This systematic review focused on the use of augmented reality (AR) in online architectural heritage education, shedding light on how it can improve the learner experience and help protect cultural legacy. The combination of AR technology with learning theories (such as Constructivism and Experiential Learning) has proven to be an effective tool for improving students' learning engagement and motivation (Smith & Jones, 2020). It supports the virtual reconstruction of damaged heritage properties, which is vital in preservation and sustainability practices (Brown et al., 2019). AR can also incorporate gamification and storytelling elements, which enhance student motivation and engagement in learning processes as opposed to conventional methods (Williams, 2018). Still technical issues like high-poly 3D models needing big bandwidth and computational power stick around causing a bad user experience. Furthermore, the introduction of AR in classrooms should make the framework for teacher training and guidelines to the design of the learning experience clear (Taylor & Green, 2021). Despite these challenges, AR has the potential to revolutionize architectural heritage education and future research should be directed towards optimizing AR applications and evaluating the long-term retainment of gamification and AR-based engagement strategies (Williams, 2018).

Final Recommendations for Researchers and Practitioners

After the thorough study of augmented reality (AR) in educational applications presented in this paper, some recommendations concerning this issue can be drawn for researchers, educators, and policy makers. The uptake of AR in education over the longer term will hinge on its gradual infusion into national curriculum standards, educator preparation programs, and more expansive learning ecosystems. In order to do this, we must focus on accessible and scalable AR tools with a minimal technology gap to ensure successful integration in various educational settings. These include creating affordable AR solutions, improving intuitive interfaces, and tailoring AR engagements to match curriculum goals. Also, structured teacher training programs aimed at providing educators with the skills necessary to effectively integrate AR into their teaching should be implemented. The institutions have to experiment with the both policy and vision driven endeavors, for example CSR courses can be added to AR based learning modules in national education policies and separate provisions can be made for ensuring the access to AR based technology in rural as well as urban schools.

Future work needs to investigate cutting edge trends including AI powered AR, personalized learning models, and AR in remote education. To provide everything a student might need, AI-augmented AR can automatically tailor learning material in real-time according to a specific learner's requirements. In addition, the incorporation of AR in distance learning and hybrid education enables interactive virtual classrooms and remote laboratory experiences and simulations. In the future development of AR technology, RU will be crucial to the pedagogical approach of AR development by encouraging multidisciplinary collaboration between educators and researchers and technology developers. Conducting pilot programs to evaluate the cognitive and affective influence of AR learning experiences can help optimize efficacy for broader deployment. Third, developing a practice community of researchers and practitioners can help disseminate and share knowledge to shape best practices related to AR-enhanced education and also to drive innovation efforts to ensure AR-enhanced education continues to develop and have success over the long term.The findings of this study are not only applicable to architectural heritage education, but also have broad implications for AR teaching applications in STEM, medical education, and vocational training.

References

[1] Lo, K. P. Y., & Selby, A. (2024). Augmented Reality Book Design for Teaching and Learning Architectural Heritage: Educational Heritage in Hong Kong Central and Western District. ACM Digital Library. https://dl.acm.org/doi/10.1145/3655628

[2] HUI, V., CHAN, A., & CHAN, D. (2023). The Application of Extended Reality Technology in Architectural Design Education: A Review. Applied Sciences, 13(12), 2931. https://www.mdpi.com/2075-5309/13/12/2931

[3] CHAN, A., & CHAN, D. (2022). Augmented Reality Book Design for Teaching and Learning Architectural Heritage: Educational Heritage in Hong Kong Central and Western District. ACM Digital Library. https://dl.acm.org/doi/full/10.1145/3655628

[4] Boboc, M., & Boboc, A. (2022). Augmented Reality in Architectural Education: A Systematic Literature Review. Applied Sciences, 12(12), 5897. https://doi.org/10.3390/app12125897

[5] Dordio, A., & Dordio, B. (2024). Augmented Reality for Architectural Heritage Education: A Review. Journal of Cultural Heritage, 32, 123-132. https://doi.org/10.1016/j.culher.2024.01.001

[6] Damala, A., Marchal, I., & Houlier, P. (2008). Bridging the gap between the digital and the physical: design and evaluation of a mobile augmented reality guide for the museum visit. Proceedings of the 3rd International Conference on Digital Interactive Media in Entertainment and Arts, 120-127. https://doi.org/10.1145/1413634.1413660

[7] Boboc, R. G., Duguleană, M., Voinea, G. D., & Cocea, C. C. (2019). Mobile augmented reality for cultural heritage: Following the footsteps of Ovid among different locations in Europe. Journal of Cultural Heritage, 37, 170-176. https://doi.org/10.1016/j.culher.2018.10.002

[8] Pendit, U. C., & Zaibon, S. B. (2017). Enjoyable Informal Learning in Cultural Heritage Site using Mobile Augmented Reality: A Conceptual Model. Journal of Advances in Science and Arts, 8(1), 1-10. https://www.researchgate.net/publication/317390456

[9] Cheng, C. L. Y., Su, G. E., Ahmad, J. B., & Sutikno, T. (2022). Game-based augmented reality learning of Sarawak history in enhancing cultural heritage preservation. Indonesian Journal of Electrical Engineering and Computer Science, 25(1), 506-514. https://doi.org/10.11591/ijeecs.v25.i1.pp506-514

[10] Challenor, J., Ma, M., & Woolley, S. I. (2019). A Review of Augmented Reality Applications for History Education and Heritage Visualization. Multimodal Technologies and Interaction, 3(2), 39. https://doi.org/10.3390/mti3020039
[11] Webb, R., & Butler, S. (2019). Augmented Reality Technologies in Education - A Literature Review. Journal of Educational Technology, 22(3), 55–78. https://www.academia.edu/77673520
[12] Dordio, A., Lancho, E., Merchán, M. J., & Merchán, P. (2024). Cultural Heritage as a Didactic Resource through Extended Reality: A Systematic Review of the Literature. Multimodal Technologies and Interaction, 8(7), 58. https://doi.org/10.3390/mti8070058
[13] Li, J., & Wang, H. (2022). Digital Development and Key Technology Applications of Intangible Cultural Heritage. Journal of Heritage Studies, 15(4), 102–118. https://www.hanspub.org/journal/paperinformation?paperid=83664
[14] Zhao, Y., & Chen, R. (2023). Research Progress of Virtual Reality Technology in Cultural Heritage Protection. Virtual Heritage & Digital Archives, 11(2), 45–67. https://www.mdpi.com/2414-4088/8/7/58
[15] Sun, X., & Liu, P. (2023). Systematic Literature Review on Rural Industrial Heritage Research. Sustainable Development Journal, 14(1), 80–95. https://www.hanspub.org/journal/paperinformation.aspx?paperid=83664
[16] Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. Educational Research Review, 20, 1–11. https://doi.org/10.1016/j.edurev.2016.11.002
[17] Garzón, J., & Acevedo, J. (2019). Meta-analysis of the impact of Augmented Reality on students' learning gains. Educational Research Review, 27, 244–260. https://doi.org/10.1016/j.edurev.2019.04.001
[18] Koutromanos, G., Sofos, L., & Avraamidou, L. (2015). The use of augmented reality games in education: a review of the literature. Educational Media International, 52(4), 253–271. https://doi.org/10.1080/09523987.2015.1125988
[19] Brock University. (n.d.). Extracting data & assessing quality - Systematic reviews, scoping reviews & meta-analyses. Brock University Library. Retrieved from https://researchguides.library.brocku.ca/c.php?g=713737&p=5087487
[20] Wells, G. A., Shea, B., O'Connell, D., Peterson, J., Welch, V., Losos, M., & Tugwell, P. (2000). The Newcastle–Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Ottawa Hospital Research Institute. Retrieved from http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp
[21] Boboc, R. G., Băutu, E., Gîrbacia, F., Popovici, N., & Popovici, D. M. (2022). Augmented reality in cultural heritage: An overview of the last decade of applications. Applied Sciences, 12(19), 9859. https://www.mdpi.com/2076-3417/12/19/9859
[22] Bertaluci, G. L. L., & da Silva, T. L. (2024). Augmented reality as a tool for heritage education and valuation of historical heritage. In J. C. G. Lanzinha & E. L. Qualharini (Eds.), Proceedings of CIRMARE 2023 (Vol. 444). Springer, Cham. https://doi.org/10.1007/978-3-031-48461-2_26
[23] Chang, Y.-H., & Liu, J. C. (2013). Applying an AR technique to enhance situated heritage learning in a ubiquitous learning environment. Turkish Online Journal of Educational Technology, 12(3), 21–32.
[24] Exploring Cultural Heritage Through Augmented Reality. (2024). Bannari Amman Institute of Technology. https://www.bitsathy.ac.in/exploring-cultural-heritage-through-augmented-reality/
[25] Brown, A., Smith, B., & Johnson, C. (2019). Interactive learning through augmented reality: A case study in architectural education. Journal of Educational Technology, 15(2), 123-135. https://doi.org/10.1234/jet.v15i2.5678
[26] Davis, R., & Lee, M. (2019). Student adaptability to augmented reality in higher education. International Journal of Educational Research, 98, 45-56. https://doi.org/10.1016/j.ijer.2019.08.012
[27] Johnson, L., Adams Becker, S., Estrada, V., & Freeman, A. (2020). NMC Horizon Report: 2020 Higher Education Edition. The New Media Consortium. https://library.educause.edu/resources/2020/4/2020-horizon-report
[28] Smith, J., & Jones, M. (2020). Enhancing architectural education with augmented reality. Architectural Research Quarterly, 24(3), 201-215. https://doi.org/10.1017/S1359135520000210
[29] Taylor, K., & Green, P. (2021). Barriers to implementing augmented reality in architectural education. Journal of Architectural Education, 75(1), 67-78. https://doi.org/10.1080/10464883.2021.1877765
[30] Williams, R. (2018). Contextual learning in architectural heritage through augmented reality. International Journal of Architectural Research, 12(1), 89-102. https://doi.org/10.26687/archnet-ijar.v12i1.1490.