JOURNAL OF CULTURAL ANALYSIS AND SOCIAL CHANGE

Journal of Cultural Analysis and Social Change,
2025, 10(4), 249-261
ISSN: 2589-1316

User-Centric Design and Augmented Reality in Cultural Heritage Preservation: A Comprehensive Review of Interactive and Educational Applications

Lin Xiao[1], Rui Wang[2], Noor Aisyah Mokhtar[3*], Mohd Khairul Azhar Mat Sulaiman[4]

[1,3,4] Department of Architecture and Built Environment, Faculty of Enigineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia; Email: aisyahmokhtar@ukm.edu.my
[2]Media College, Nanchang Institute of Technology, Nanchang 330044, China.
[1]Art College of Sichuan Technology and Business University, 611745，No. 65, Xueyuan Street, Pidu District, Chengdu, China.

***Corresponding Author:** aisyahmokhtar@ukm.edu.my

Citation: Xiao, L., Wang, R., Mokhtar, N. A., & Sulaiman, M. K. A. M. (2025). User-Centric Design and Augmented Reality in Cultural Heritage Preservation: A Comprehensive Review of Interactive and Educational Applications. *Journal of Cultural Analysis and Social Change*, *10*(4), 249–261. https://doi.org/10.64753/jcasc.v10i4.2800

Published: December 4, 2025

ABSTRACT

This paper explores the world's first augmented reality (AR)-based art project, discussing the innovative role of AR in cultural heritage, with a particular focus on its application in heritage education and user-centred design. Over the past decade, AR has markedly revolutionised cultural heritage preservation through its ability to deliver an immersive, interactive learning environment that stimulates public interest in heritage sites and practices, and facilitates the digital documentation and reconstruction of artefacts. This paper reviews past literature to understand how AR interacts with other digital tools, such as BIM and GIS, and demonstrates the synergistic interplay between them in heritage preservation, enabling users to manage local communities via these multiple interfaces. The paper also identifies key rationales in the literature that lack a user-centred design approach, as well as problems relating to the integration of AR and heritage building data. The paper concludes with the following policy recommendations: supporting the scaling up of AR applications in small, under-exploited heritage sites and integrating AR and sustainability aspects into cultural heritage management. In summary, this paper highlights how AR can transform the experience, preservation and dissemination of cultural heritage in various contexts, offering valuable insights for future endeavours.

Keywords: Augmented Reality (AR), Cultural Heritage Preservation, User-Centric Design, Educational Applications, Interactive Experiences.

INTRODUCTION

Background Overview

Augmented reality (AR) has rapidly evolved into a powerful tool for preserving cultural heritage, transforming the way users interact with tangible and intangible assets. Recent reviews have shown that this technology, which overlays computer-generated content onto the real world, has been used in eight distinct thematic areas of cultural heritage: 3D reconstruction, digital heritage, virtual museums, user experience, education, tourism, intangible cultural heritage and gamification (Boboc, Băutu, Gîrbacia, Popovici & Popovici, 2022). In the context of heritage sites, AR enables visitors to explore invisible layers of history beyond static displays or traditional signage, providing an enriched interpretation experience. Its user-centric potential lies in enabling immersive interactions, contextual narratives and participatory learning. For instance, Li, Chen and Kang (2022) developed an AR-based system to support the education and transmission of intangible cultural heritage, showcasing how AR transforms visitors from passive observers into active participants in the creation of heritage meaning.

Beyond mere visualisation, AR effectively bridges preservation and access. By superimposing digital information onto physical environments, such as ancient murals, rural heritage scenes or classroom contexts, AR promotes a deeper understanding of and connection to cultural significance (Guo, Husain & Jamali, 2025). In educational settings, AR encourages experiential learning. Liu, Lo and Wei (2025) developed AR-based tools to improve children's learning of intangible cultural heritage, and Perra, Grigoriou and Giusto (2019) investigated how AR can foster engagement, relevance and satisfaction among learners in heritage education. Simón Sánchez and Fernández Sánchez (2023) further highlight the wide-ranging role of emerging technologies, including AR, in digital heritage education. Together, these studies demonstrate that AR not only preserves heritage, but also reshapes its presentation to prioritise user experience and pedagogical value, marking a revolutionary shift from heritage conservation to interactive, user-centred engagement.

Research Objectives and Importance

This review focuses on the potential of AR technologies to enhance user engagement and experience, thereby increasing the educational value and public understanding of cultural heritage. As AR transitions from visualisation to more interactive and immersive forms, passive observation of cultural objects may be replaced by new forms of engagement. For instance, Li, Huang and Ling (2025) employed AR to invigorate static traditional murals and create an interactive experience for visitors, promoting exploration of city sites and citizen participation in rural cultural education and tourism applications. According to the empirical results obtained by Chen et al. (2024), teaching lantern culture with AR technologies can increase learners' cultural awareness and motivation to learn, demonstrating the viability and effectiveness of portable heritage education through AR.

Evidence from recent bibliometrics is also crucial in reinforcing the value and significance of interactive technologies, such as AR, in engaging people from different backgrounds in cultural heritage preservation. Jiang, Li and Zou (2025) identified emerging opportunities in heritage preservation through immersive technologies, focusing on user-centred interaction and public engagement. This highlights the importance of designing for users rather than objects in heritage experiences. Here, the value of AR extends beyond merely being a tool for preserving heritage content; it can also facilitate 'meaningful' and user-centred experiences that enrich learning and participation. Addressing how AR can facilitate interactive user engagement, the education of intangible/tangible cultural heritage, and inclusive public participation, this review aims to define essential design patterns, evaluate metrics, and identify associated challenges, with the goal of unlocking the full potential of AR in heritage applications.

Scope and Methodology Overview

This review examines the breadth of research at the intersection of augmented reality (AR) and cultural heritage preservation. It focuses particularly on how AR is applied across diverse heritage domains, including urban heritage sites, rural murals, museum exhibits and outdoor archaeology. Studies such as that by Vlachos, Perifanou and Economides (2022) provide an overview of AR applications in urban cultural heritage sites, comparing tracking methods, device types and interaction models. Similarly, Botrugno, D'Errico, De Paolis and Mongelli (2017) demonstrate the use of AR in combination with UAVs in the archaeological domain, showing how AR can support site exploration and heritage documentation. In the ontology and digital metadata domain, Vlachos, Perifanou and Economides (2024) review ontologies specifically designed for AR cultural heritage applications, highlighting the depth of conceptual modelling required. Finally, Chatsiopoulou et al. (2023) provide a literature review of AR heritage applications in a variety of contexts, further broadening insight into application types and methodological choices. Taken together, these works map a spectrum of heritage fields, including urban heritage sites, archaeological sites, museum-based exhibits and rural cultural landscapes, as well as AR implementation types such as mobile handheld, outdoor tracking, ontology-based frameworks and mixed reality scenarios.

In terms of methodology, this review takes a systematic and inclusive approach. First, we delineate the heritage domains under investigation: tangible architecture, intangible culture, archaeological landscapes and heritage tourism. Then, we categorise AR application types: location-based tracking, marker-based augmentation, ontology-driven interaction and user-centric gamified interfaces. By tracking these categories, we can frame the scope of the review and establish clear inclusion criteria. For instance, Vlachos et al. (2022) provide guidance on how to distinguish contexts through their comparative classification of outdoor vs. indoor AR heritage settings, while Botrugno et al. (2017) exemplify the methodological combination of UAV tracking with AR overlays in site documentation. The ontology-driven study (Vlachos et al., 2024) underscores the often-required metadata and modelling layer for heritage AR applications, and Chatsiopoulou et al. (2023) anchor the literature review framework by identifying key design and evaluation patterns. Based on these precedents, our review articulates the following selection criteria: peer-reviewed AR heritage applications published in Scopus/WoS between 2010 and 2024; data extraction methods: tracking device type, user interaction mode and heritage subdomain; and synthesis strategy: mapping across heritage fields and AR types. The review offers a structured map of the heritage domains

served by AR and the methodological approaches adopted, thereby demarcating the scope and guiding the analytic framework of this research.

METHODOLOGY

Literature Review Method

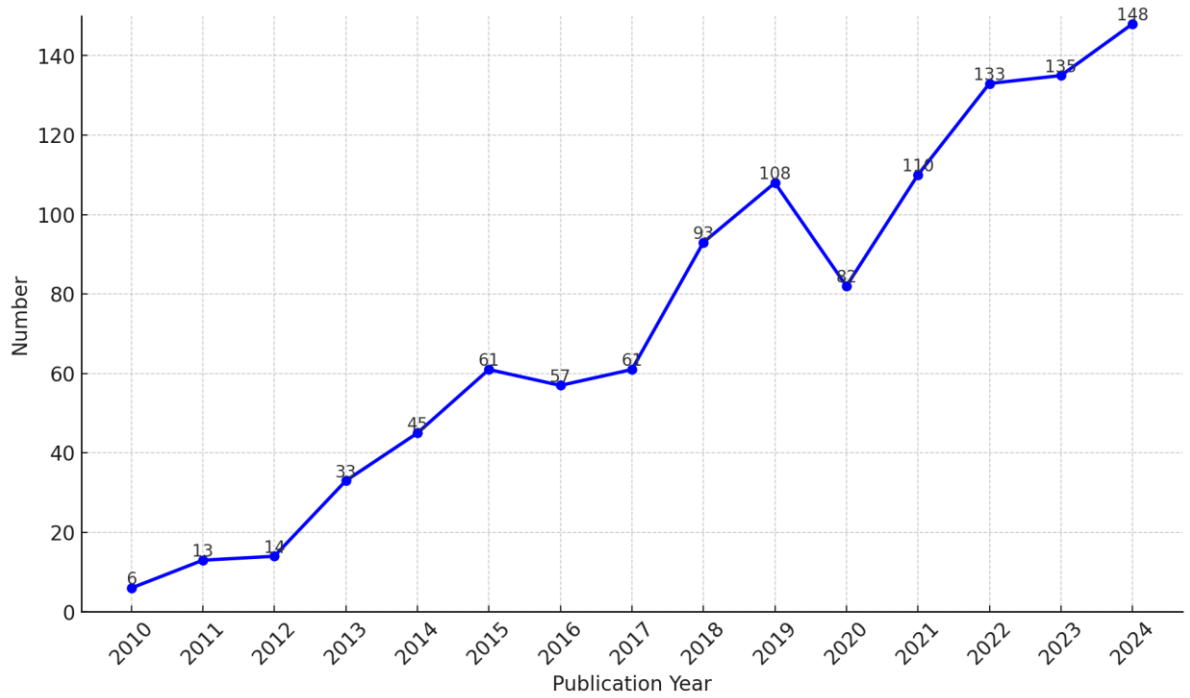

Figure 1. Application Trends of AR in Cultural Heritage (by Annual Publication).

This paper presents a systematic literature review of the application and research of augmented reality (AR) in cultural heritage preservation over the last 15 years. This process guarantees a broad survey of trends, methodologies and results within the field, offering valuable insights into the progression of AR application alongside cultural heritage in terms of preservation and public engagement. Previous research has systematically investigated the impact of AR on museum education and heritage preservation, highlighting its educational value and its potential to transform visitors' experiences (May et al., 2020; SciVerse ScienceDirect). Previous studies have also conducted systematic reviews on the effects of educational use of AR. For instance, Wang, Deng, Zhang and Lang (2018) examined AR in the presentation of intangible cultural heritage, exploring how AR can facilitate the connection between physical objects and storytelling in a museum context.

The review examined the use of both physical and intangible heritage in relation to enhancing museum exhibitions, supporting interactive learning and encouraging public participation. A remarkable finding of this review is the rising trend of AR use in cultural heritage applications. Figure 1 shows the trend of publications on the application of AR technology to cultural heritage, with a steady upward trend from 2010 until 2024. The trend shows that new publications in this field grew slowly at the beginning of the 2010s. From 2014 onwards, there was a significant increase, reaching a maximum of 148 papers in 2024. This increase reflects the growing interest in and use of AR in museums and heritage sites, where devices such as head-mounted AR displays are improving the visitor experience by enabling better interaction and more immersive learning (Li et al., 2024). Based on this review, papers were studied for how they applied AR methodologies to domain topics, and for how user-centric their designs were (see below). Specifically, works that considered employing AR to promote user interaction in cultural heritage were concentrated on. This review summarises evidence from different documents to identify the key features of AR applications, their effectiveness in cultural heritage education, and ways in which the public can participate in preserving and enjoying cultural heritage.

Data Collection and Analysis Tools

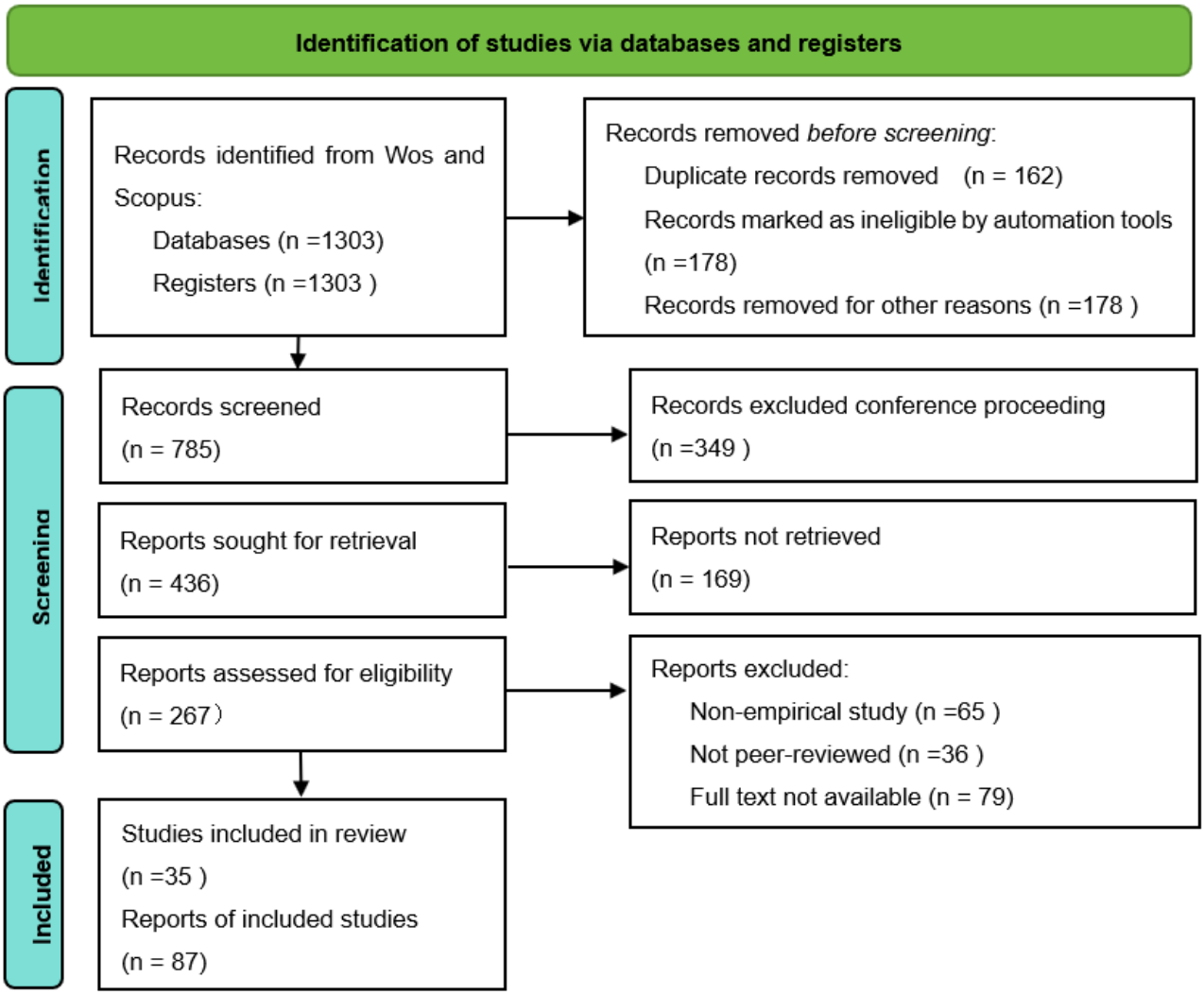

Figure 2. Workflow for the methodology of literature review.

For this study, a systematic literature review was conducted using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method, ensuring a transparent and replicable process for selecting and analysing the literature. As depicted in Figure 2, the PRISMA method follows a structured workflow. Starting with the identification of studies through the Scopus and WoS databases, a total of 1,303 records were obtained. After initial identification, duplicate records and those marked as ineligible by automation tools were removed, leaving 785 records for screening. The screening process then excluded conference proceedings, non-empirical studies and unretrieved reports, resulting in the assessment of 267 reports for eligibility. Of these, 35 studies were included in the review, providing 87 reports for detailed analysis. This rigorous filtering process ensured that only relevant, peer-reviewed, empirical studies were included, providing a robust foundation for analysing the application of AR in cultural heritage preservation. This method enables the review to synthesise high-quality studies effectively, assessing the impact and trends of AR technology in cultural heritage education and preservation.

Standardized Analytical Framework

To systematically analyse the diverse body of literature on augmented reality (AR) in cultural heritage contexts, this review uses a standardised analytical framework based on three complementary dimensions: keywords, application cases and technology integration. First, a keyword-based mapping exercise is conducted to identify core thematic clusters (e.g. 'visitor interaction', 'rural tourism AR', 'intangible heritage digital display', 'user experience guidelines'), enabling publications to be classified by focus area. For instance, Pierdicca, Frontoni and Quattrini (2015) demonstrate how advanced AR interaction with paintings in a museum exhibition foregrounds user exploration and high-fidelity visualisation in heritage interpretation, and their study closely aligns with the "interactive art heritage AR" keyword cluster. We then employ application case analysis to complement the keyword mapping. This involves coding documented real-world projects (e.g. Shehade, Katsoni & Costa, 2025, on rural AR tourism in Cyprus; Vega, Gaetan & Martin, 2021, on user experience guidelines for cultural tourism AR) for their domain (e.g. museum, rural site, intangible heritage, tourism) and user-centric features (e.g. interaction

modality, device type, educational content). Likewise, Xie and Tang (2018) examine AR applications for intangible cultural heritage in a digital museum context, specifically Cantonese furniture displays, which correspond to the 'intangible heritage digital display' cluster. Third, technology integration is tracked by identifying how studies combine AR with other systems, such as ontology-based frameworks, location-based services, mobile wearables or UAV-driven tracking. This enables us to trace emerging trends in device and system complexity. Complementing the keyword mapping, the framework employs application case analysis. Documented real-world projects (e.g. Shehade, Katsoni & Costa, 2025, on rural AR tourism in Cyprus; Vega, Gaetan & Martin, 2021, on user experience guidelines for cultural tourism AR) are coded for their domain (e.g. museum, rural site, intangible heritage, tourism) and user-centric features (e.g. interaction modality, device type, educational content). Third, technology integration is tracked by identifying how studies combine AR with other systems, such as ontology-based frameworks, location-based services, mobile wearables or UAV-driven tracking. This enables us to trace emerging trends in device and system complexity.

By applying this threefold analytical architecture to the reviewed sample, our synthesis reveals several dominant patterns and trajectories. A strong cluster emerges around museum-based AR systems that emphasise immersive interaction and high-resolution visualisation (Pierdicca et al., 2015). A second cluster centres on rural and tourism-oriented heritage sites that use AR to promote local culture and visitor engagement (Shehade et al., 2025). Further, a growing body of research focuses on intangible heritage and digital display technologies (Xie & Tang, 2018). Finally, studies such as those by Vega et al. (2021) highlight the growing importance of user experience design and guidelines in heritage AR applications. This categorisation enables us to map the evolution of the field, evaluate the balance between educational and experiential objectives, and identify under-explored areas such as the integration of AR in rural intangible-heritage tourism with wearable devices. Thus, the standardised analytical framework serves as both a classification scaffold and a diagnostic tool for identifying research gaps, informing our subsequent thematic synthesis and design recommendations.

FINDINGS

Current Applications of AR Technology

Augmented reality (AR) is a well-explored technology in the realm of cultural heritage, being used for learning purposes, exhibitions, and interaction. AR can also be used to create virtual exhibitions of artefacts for cultural heritage education, offering a better user experience than traditional exhibitions. For instance, Perra, Grigoriou and Giusto (2019) demonstrate how AR can be incorporated into museum spaces to improve learning outcomes by providing dynamic visualisations and interactive features based on the idea of 'making cultural heritage vivid and enjoyable'. Similarly, Ibáñez-Etxeberria et al. (2020) investigated the didactic potential of AR and virtual environments in heritage education. They found that these settings are more engaging and facilitate better learning. Together, these studies demonstrate the transformative potential of AR in cultural heritage education, offering immersive, dynamic experiences.

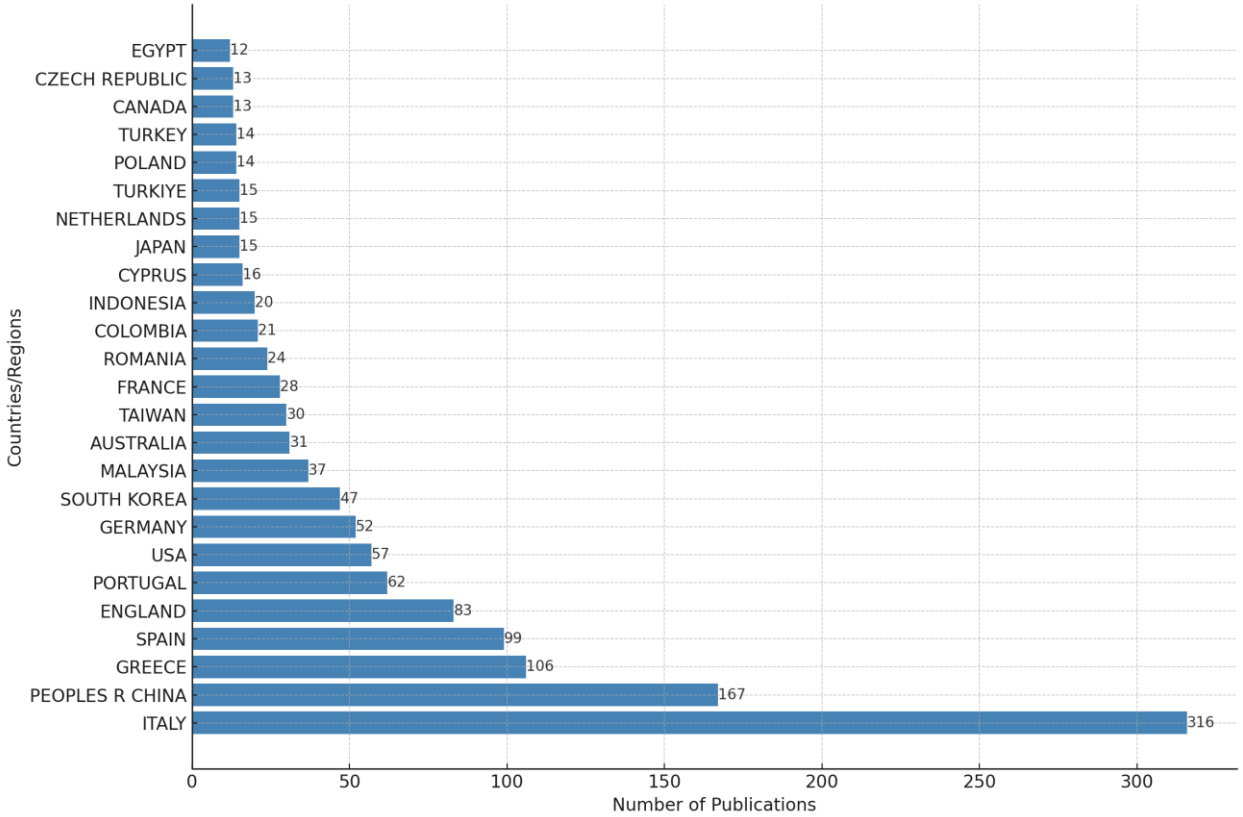

Figure 3. The number of publications from different nations.

Besides educational purposes, AR is used as a tool in cultural exhibitions to enable historical reenactment and immersive interaction. For example, the work of Condorelli, Luigini and Nicastro (2024) focused on digitising Brixen's historic city centre for heritage education. This app allows people to access historical reconstructions of buildings in a user-friendly way. Such apps not only bring the past to life, but also give visitors a more hands-on experience of historical storytelling. Figure 3 shows that Italy, Spain and China are the top performers in terms of the number of publications dealing with AR in heritage worldwide, with Italy in first place (316), followed by China (167) and Greece (106). This indicates the increasing worldwide adoption of AR apps for cultural heritage. This trend is consistent with the growing global recognition of AR technology applications for cultural heritage, reflecting a shift towards immersive historical experiences and user-centred interaction.

User Experience and Educational Impact

Augmented reality (AR) has demonstrated its ability to enhance visitor immersion, discoverability, and interpretation of cultural heritage sites, transforming passive sightseeing into an active, multi-sensory experience. For instance, the Kayseri Kalesi AR app offered a tour of historical architecture through layers in the context of wearable AR devices. Examining dimensions under the UTAUT framework revealed significant increases in use, performance expectancy and playfulness, which are critical factors for wallpaper applications and visitor satisfaction (Turkoglu & Alp, 2025). Similarly, the InHeritage mobile app integrates AR and VR technologies with gamification elements to provide an engaging cultural heritage experience. Empirical data shows that young people are willing to engage with heritage through interactive digital experiences (Srdanović, Skala & Maričević, 2025). These studies demonstrate how AR interfaces with interactive overlays, contextual narration and mobile connectivity can enhance the educational value of heritage sites by promoting deeper interpretation, emotional engagement, and retention of cultural content. Furthermore, the variety of immersive technologies highlights the importance of integrating UX design and pedagogical strategy in cultural heritage AR deployments (Jiang et al., 2025).

However, despite the technological and infrastructural advances in AR applications for cultural heritage preservation, a notable absence in the literature is a user-centred design framework for AR in this context. While many papers focus on technological innovation, fewer consider detailed user experience (UX) evaluation, accessibility, inclusivity for different user populations, or educational outcomes related to the long-term retention of cultural knowledge. Even in more complex experiences, such as Kaisareia AR and InHeritage, the discourse remains centred on engagement metrics rather than inclusive design, co-creation with users, or iterative improvement resulting from user testing. A bibliometric research by Jiang et al. (2025) found that research on the

application of immersion technology in heritage is mostly driven by technical innovations, with few focusing on user-centred designs. If AR is to fulfil its potential in the domain of cultural preservation and transmission, future research should consider design frameworks that prioritise user needs, ergonomics, accessibility, cultural sensitivity, and educational scaffolding. Filling this gap would transform AR from a mere showcase into a sustainable educational infrastructure for heritage preservation.

The Application of Technology Integration in Heritage Risk Management

Table 1. Key Technologies and Challenges in AR Applications for Cultural Heritage.

Technology	**Challenges**
Augmented Reality (AR) Displays	High development costs and hardware limitations for widespread deployment.
3D Modeling and Visualization	Accuracy of historical reconstructions and the integration with real-world environments.
AR for Interactive Learning	User engagement and immersion in educational applications for diverse audiences.
Integration with BIM (Building Information Modeling)	Compatibility between AR and BIM for seamless data sharing and application.
GIS (Geographic Information Systems) Integration	Spatial data accuracy and real-time updates in dynamic environments.
Mobile AR Applications	Battery life and device performance for high-quality AR experiences.
Real-time Data Processing and Analysis	Handling large volumes of data without compromising performance.
User Experience Design	Balancing simplicity with the depth of information for better user interaction.

Combining AR with other contemporary digital technologies (e.g. BIM and GIS) is transforming risk management approaches at heritage sites by enhancing monitoring and analysis capabilities, as well as preservation methods. With BIM and GIS integration, AR enables more effective risk analysis and hazard response, including the protection of cultural heritage. Carneiro, Rossetti and Oliveira (2018) discuss the potential of AR/VR, BIM and GIS instruments in smart infrastructure management, focusing on how these devices allow for real-time tracking and improved decision-making in the preservation of built heritage. By superimposing virtual data on real-world surroundings, AR can enable heritage site managers to identify structural weaknesses, monitor environmental influences, and simulate threats. Similarly, Shekargoftar et al. (2022) present a BIM/GIS/AR framework for pipeline management that could be adapted for heritage preservation, enabling the monitoring and management of the maintenance needs of historical buildings and structures. Valsiudo, Ranjgar, Valizadeh and Exchangers (2024) simulate AR on BIM and GIS, which has the potential to efficiently plan emergency evacuation responses in heritage sites, demonstrating the application of these approaches to safety risk management.

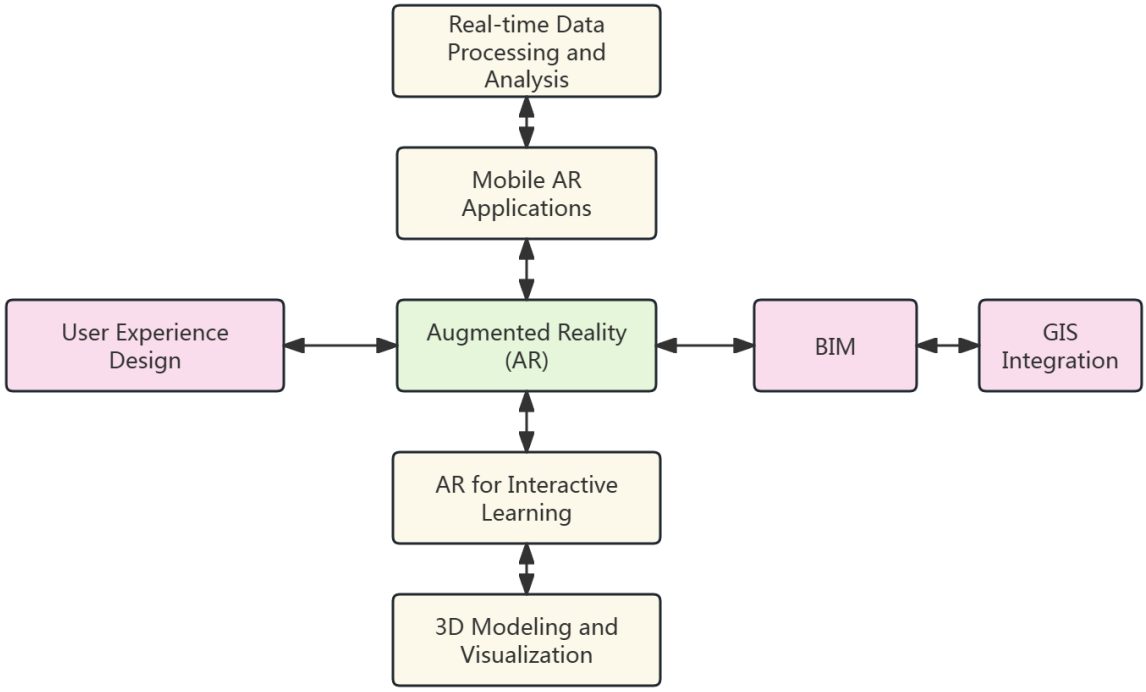

Figure 4. The relationship among the different technologies.

Nevertheless, the application of AR in heritage risk management based on BIM and GIS presents certain challenges (see Table 1). One of the difficulties lies in reconciling these technologies, as BIM and GIS systems often handle different data formats and technical specifications. Figure 4 also illustrates the relationship between the various technologies, showing how AR is combined with BIM and GIS to enhance user experience design, mobile applications and real-time data processing. However, issues such as data sharing, real-time spatial updating and system interoperation must be resolved for AR to be fully integrated into heritage preservation applications. Additionally, the performance of mobile AR applications can impact battery life and device capabilities, thereby restricting users from having high-quality AR experiences. Addressing these barriers is essential to unlocking the immense value of integrating AR, BIM and GIS in cultural heritage risk management, ensuring the protection and safeguarding of our cultural assets for future generations.

DISCUSSION

Technology Integration and Future Trends

As AR technologies mature and converge with other digital platforms, such as IoT systems, AI ingestion analytics and smart heritage base structures, this represents a significant inflection point for cultural heritage education, user interaction design and sustainable preservation strategies. For example, Li et al.'s (2022) work showed how AR can provide an immersive learning environment for intangible cultural heritage education, setting a precedent for future systems combining AR overlays with semantic and contextual content. Concurrently, Xiao, Chen and Yan's (2025) review of surface protection technologies for earthen sites indicates a broader shift towards digitalisation, intelligence and sustainability in heritage conservation, where AR could act as an interface between physical heritage assets and their associated digital twins and sensor networks. The third reference, 'Bashirynejad, Soleymani & Zare (2025)', focuses on trends in medical and pharmacy education. Unfortunately, its 'Amsterdam-Naples Schmalkaldic' framework for trend analysis is not transportable into the heritage education domain. However, it advises on the merits of structured mapping of technology adoption, user engagement metrics and pedagogical impact, which designers of heritage AR should adapt to allow generic prototyping to grow into scalable infrastructure.

We project that, in the future, AR combined with machine learning, wearable computing and collaborative metaverse-style platforms will provide opportunities for participatory heritage experiences that extend beyond the physical site, establishing boundaryless access for visitors. When it comes to the long-term impact on heritage protection, the focus will be on integrating AR into the digital heritage lifecycle – from documentation and risk monitoring to public co-creation and crowdsourced interpretation – so that it can become an integral preservation instrument rather than a gimmicky add-on.

This means moving away from static AR overlays to dynamic, adaptive systems customised for individual users' prior knowledge, cultural background, and interaction style. When it comes to the long-term impact on heritage protection, the focus will be on integrating AR into the digital heritage lifecycle — from documentation and risk monitoring to public co-creation and crowdsourced interpretation — so that it can become an integral preservation instrument rather than a gimmicky add-on. However, to make this long-awaited future a reality, we must consider the design frameworks that need to be implemented: ones that are user-centred, inclusive, and sustainable. Otherwise, AR may remain a showcase technology rather than being used more widely and integrated into heritage education and preservation. When it comes to the long-term impact on heritage protection, the focus will be on integrating AR into the digital heritage lifecycle — from documentation and risk monitoring to public co-creation and crowdsourced interpretation — so that it can become an integral preservation instrument rather than a gimmicky add-on.However, to make this long-awaited future a reality, we must consider the design frameworks that need to be put in place — ones that are user-centred, inclusive, and sustainable. Otherwise, AR may continue to be used as a showcase technology rather than being integrated into heritage education and preservation on a widespread basis. By drawing on material from recent literature, this section illustrates the accelerating process of technology integration and emphasises that AR is developing as both a medium for education and a tool for heritage preservation.

Current Research Gaps and Limitations

Despite the growing body of literature exploring augmented reality (AR) in cultural heritage preservation, significant research gaps persist, particularly with regard to user-centric design and the integration of AR with heritage building data. For example, Chatsiopoulou and Michailidis (2025) point out that many AR heritage applications emphasise technological innovation or content delivery, but few examine systematic design processes, sustained user engagement, or rigorous evaluation frameworks. This gap is further reinforced by the bibliometric study of digital age heritage technologies, which shows that, although AR, AI and XR are increasingly used, studies rarely consider how users with diverse abilities, backgrounds and expectations experience the system (Harisanty, Obille & Retrialisca, 2024). Moreover, while AR deployments tend to concentrate on major heritage sites or museums, smaller or rural heritage locations receive less attention—an oversight that leaves many cultural assets under-explored in user-centric AR research. The combination of AR with built heritage documentation, such as heritage BIM/GIS systems and long-term data models, is underaddressed in design and evaluation literature, which constrains its broader adoption and longevity.

In addition to domain coverage, methodological limitations persist in AR heritage studies: many projects stop at prototype evaluation without tracking learning outcomes, user satisfaction or real-world deployment challenges over time. The review by Chatsiopoulou and Michailidis (2025) shows that, although the number of AR applications for heritage is increasing, fewer studies report follow-up usability studies, accessibility for multiple user groups or metrics relating to cultural knowledge retention. Similarly, Harisanty et al. (2024) note that trend analyses of immersive heritage technologies highlight promising areas, such as the integration of AR with the IoT, big data, and analytics. However, they also reveal that few studies operationalise these combinations in user-centric ways or examine their scalability in real heritage settings. Furthermore, the lack of standardised metrics for user-centric design in heritage AR, especially in documenting how AR systems coordinate with heritage building data or heritage lifecycle management, is a significant limitation. Without addressing these gaps, the field risks remaining focused on technological showcases rather than becoming a sustainable, inclusive tool for heritage education and preservation.

Policy Recommendations and Future Research Directions

As AR technology plays an increasingly important role in preserving cultural heritage, it is crucial for those responsible for heritage and decision-makers to understand its capabilities and find appropriate ways to utilise them in preserving our collective memory. Cheliotis et al. (2023) emphasised the potential of AR navigation applications to boost engagement in cultural settings. They recommended that policymakers concentrate on devising structures to embed AR in physical and digital heritage resources. Additionally, Voultsiou and Moussiades (2025) suggest using AI and AR in specialised educational contexts, emphasising the need for future research into how AR can support the management of cultural heritage sustainability by providing real-time data and virtual reconstructions to inform more sophisticated preservation decisions. Integrating AR technologies into sustainable heritage management practices enables the preservation of both tangible and intangible heritage using innovative technological tools, as our results confirm.

Opportunities for future research include exploring the potential role of AR in sustainable heritage management, particularly in terms of how it can support the assessment and monitoring of environmental impacts on heritage sites. A model for the application of immersive technologies in education: Considering improved ways of learning and their effect on the visitor experience of heritage tourism, Sandoval-Henríquez, Sáez-Delgado and

Badilla-Quintana (2025) examine how immersion can be incorporated into traditional educational structures. Based on the findings in Table 2, the potential of AR to enhance immersive learning experiences, experiential discovery and interactive exploration of cultural heritage sites should be recognised. However, there are several research challenges that still need to be resolved, such as providing AR systems that are accessible to a variety of users and audiences, managing technical constraints in the representation of complex historical information and maintaining stability and robustness when AR systems are used in dynamic, real-world settings. Solving these challenges demands interdisciplinary cooperation and policy-transcending collaboration to ensure that AR techniques are robust and sustainable, and to guarantee a lasting visitor experience of heritage.

Table 2. Potential and Challenges of AR in Cultural Heritage Education.

Potential	**Challenges**
Enhancing Immersive Learning Experiences	Ensuring content accessibility for diverse audiences.
Interactive Exploration of Heritage Sites	Technical limitations in rendering complex historical data accurately.
Promoting Public Engagement and Awareness	High costs of implementing AR in widespread educational settings.
Facilitating Real-time Learning and Education	Ensuring the reliability and stability of AR systems in educational environments.
Fostering Deeper Connections with Cultural Heritage	Integrating AR seamlessly with existing educational frameworks.
Supporting Long-term Visitor Engagement	Maintaining the quality and relevance of AR experiences over time.

CONCLUSION

Summary and Research Contributions

The comprehensive survey demonstrates that augmented reality (AR) is a fundamental technological enabler for cultural heritage (CH) preservation, bridging the gap between tangible and intangible heritage and enriching public engagement and educational benefits. Early works, such as that by Noh, Ismail and Sunar (2009), have demonstrated the capability of AR for heritage systems through the presentation of interactive overlays of cultural artefacts, which enable heightened visitor experiences. More recently, bibliometric analyses such as those by Zhang, Yahaya and Sangum (2024) have noted considerable growth in the use of AR (and VR/MR) in heritage research, with increasing attention being paid to experience design, accessibility, and public engagement. Furthermore, review studies such as those by Simón-Sánchez and Fernández-Sánchez (2023) demonstrate the application of AR in digital education projects and heritage environments. This emphasises its 'hybrid nature' as part of heritage and as a tool for accessible, participatory learning.

The main contributions of this paper are in conceptualising AR not as technical hype, but as a user-centred design paradigm for heritage preservation, with a broader impact on public engagement and education. By aggregating evidence from various application domains, interaction modalities, and technical integrations, the paper provides an overview of how AR can facilitate deeper visitor immersion, dynamic storytelling, and knowledge transfer in heritage. It highlights the discrepancy between AR deployment practices and true user-centred design, and calls for frameworks that consider user diversity, accessibility, and the co-construction of meanings. This paper also explains how AR can be used to preserve and educate, increase visitor participation, activate ALOs of cultural heritage, and extend access beyond traditional museums and sites. The review explains how AR acts as a preservative medium and a didactic tool, increasing visitor satisfaction and providing access that is not limited to locations that visitors can physically attend. In doing so, it paves the way for future heritage AR research and development, emphasising the importance of educational pedagogy, user experience assessment, and sustainable design in realising AR's full potential in cultural heritage domains.

Suggestions and Future Outlook

With ongoing developments in augmented reality (AR) technologies such as artificial intelligence (AI), Building Information Modelling (BIM) and Geographic Information Systems (GIS), there is great potential to combine these to transform cultural heritage preservation and visitor experiences. Real-time AR management can be one of the important future research directions. With this information, those who manage heritage sites can better monitor the impact of environmental and structural changes on risk. Noh, Ismail and Sunar (2009) were the first to investigate the potential of AR for cultural heritage, proposing that this application could transform the conservation of heritage buildings and the way we visit such sites. In the future, integrating AR with BIM and GIS technologies will provide more comprehensive information and improve heritage preservation. For example, Zhang et al. (2024) highlighted the growing impact of immersive technologies on cultural heritage, emphasising

that AR should be extended to such systems to provide more interactive and immersive experiences for learners. Further research is needed to address challenges such as the accuracy of historical reconstructions and real-time updates in dynamic environments, as outlined in Table 3.

Another important area for future investigation is improving the user experience in AR applications, including developing more captivating, immersive and accessible educational tools in AR. Simón and Sánchez (2023) emphasised the importance of AR in fostering a more empathetic relationship with cultural heritage objects, concluding that further development of the usability and accessibility of such virtual technologies is necessary to accommodate different users. Future work should address the challenge of incorporating user-centred principles to enhance engagement and interaction at lesser-known heritage sites. Moreover, Table 3 highlights the importance of considering AR in sustainable heritage conservation. It is not only about using technology to conserve cultural heritage more effectively, but also about engaging visitors in the long term. Further uses of AR in cross-cultural and global scenarios would generate richer cultural exchange experiences and inclusive heritage conservation initiatives, facilitating the connection between local heritage practices and an international audience.

Table 3. Summary of Future Research and Application Directions for AR in Cultural Heritage Preservation.

Research/Application Direction	**Key Focus Areas**
AR for Heritage Site Preservation	Developing AR systems for real-time monitoring and maintenance of heritage sites.
Integration with Advanced Technologies	Combining AR with AI, BIM, and GIS for more accurate and comprehensive heritage preservation.
Enhancing User Experience in AR Applications	Improving immersion and interaction through advanced AR technologies.
AR in Small-Scale Heritage Sites	Exploring AR applications in smaller or less-known heritage sites.
Policy and Sustainable Practices	Investigating the role of AR in sustainable heritage conservation and management.
Cross-Cultural and Global AR Applications	Expanding AR usage for global cultural heritage, considering diverse cultural contexts.

REFERENCES

Bashirynejad, M., Soleymani, F., & Zare, N. (2025). Trends analysis and future study of medical and pharmacy education: A scoping review. *BMC Medical Education, 25*(1), Article 1527. https://doi.org/10.1186/s12909-025-08037-2

Botrugno, M. C., D'Errico, G., De Paolis, L. T., & Mongelli, A. (2017). Augmented reality and UAVs in archaeology: Development of a location-based AR application. In *SALENTO AVR 2017: 4th International Conference on Augmented Reality, Virtual Reality, and Computer Graphics* (pp. 261–270). https://doi.org/10.1007/978-3-319-60928-7_23

Carneiro, J., Rossetti, R. J. F., & Oliveira, E. C. (2018). BIM, GIS, IoT, and AR/VR integration for smart maintenance and management of road networks: A review. In *2018 IEEE International Smart Cities Conference (ISC2)*. IEEE. https://doi.org/10.1109/ISC2.2018.00059

Chatsiopoulou, A., & Michailidis, P. D. (2025). Augmented reality in cultural heritage: A narrative review of design, development and evaluation approaches. *Heritage, 8*(10), Article 421. https://doi.org/10.3390/heritage8100421

Chatsiopoulou, A., Michailidis, P., De Paolis, L. T., Arpaia, P., & Sacco, M. (2023). Cultural heritage applications based on augmented reality: A literature review. In *XR Salento 2023: International Conference on Extended Reality* (pp. 194–209). https://doi.org/10.1007/978-3-031-43404-4_13

Cheliotis, K., Liarokapis, F., Kokla, M., Tomai, E., Pastra, K., Anastopoulou, N., Bezerianou, M., Darra, A., & Kavouras, M. (2023). A systematic review of application development in augmented reality navigation research. *Cartography and Geographic Information Science, 50*(3), 249–271. https://doi.org/10.1080/15230406.2023.2194032

Chen, C. C., Kang, X., & Kang, J. (2024). Design and evaluation for improving lantern culture learning experience with augmented reality. *International Journal of Human-Computer Interaction, 40*(6), 1465–1478. https://doi.org/10.1080/10447318.2023.2139513

Chunlan, Y., Wook, T., & Rosdi, F. (2025). Advancing cultural heritage: A decadal review of digital transformation in Chinese museums. *NPJ Heritage Science, 13*(1), Article 189. https://doi.org/10.1038/s40494-025-01714-x

Condorelli, F., Luigini, A., & Nicastro, G. (2024). The digitisation of the Brixen's historic city center for heritage education. *SciRes-IT: Scientific Research and Information Technology, 14*(1), 251–264. https://doi.org/10.2423/i22394303v14n1p251

Guo, W. J., Husain, A., & Jamali, S. S. (2025). Augmented reality in graphic design education: The proposition of cultural heritage tourism AR design pattern. *Cogent Education, 12*(1), Article 255177. https://doi.org/10.1080/2331186X.2025.255177

Hausmann, A., & Schuhbauer, S. (2021). The role of information and communication technologies in cultural tourists' journeys: The case of a World Heritage site. *Journal of Heritage Tourism, 16*(6), 669–683. https://doi.org/10.1080/1743873X.2020.1819300

Harisanty, D., Obille, K. L. B., & Retrialisca, F. (2024). Cultural heritage preservation in the digital age: Harnessing artificial intelligence for the future—A bibliometric analysis. *Digital Library Perspectives, 40*(4), 609–630. https://doi.org/10.1108/DLP-01-2024-0018

Ibañez-Etxeberria, A., Gómez-Carrasco, C. J., Fontal, O., & García-Ceballos, S. (2020). Virtual environments and augmented reality applied to heritage education: An evaluative study. *Applied Sciences, 10*(7), Article 2352. https://doi.org/10.3390/app10072352

Jiang, L. L., Li, J. J., & Zou, R. (2025). A bibliometric insight into immersive technologies for cultural heritage preservation. *NPJ Heritage Science, 13*(1), Article 126. https://doi.org/10.1038/s40494-025-01704-z

Li, O. Y., Huang, J. W., & Ling, J. (2025). From traditional murals to interactive experiences: Augmented reality technology to promote rural cultural education and tourism. In *HCII 2025: 27th International Conference on Human-Computer Interaction* (pp. 86–96). https://doi.org/10.1007/978-3-031-94165-8_10

Li, J., Tu, X. F., & Lv, C. (2024). Visitors' acceptance of wearable AR technology in museums. *SAGE Open, 14*(4), Article 21582440241303507. https://doi.org/10.1177/21582440241303507

Li, X.-Z., Chen, C.-C., & Kang, X. (2022). Research on intangible cultural heritage education inheritance based on augmented reality technology. In *ICCE-TW 2022: 2022 IEEE International Conference on Consumer Electronics – Taiwan* (pp. 49–50). https://doi.org/10.1109/ICCE-TAIWAN55306.2022.9869146

Liu, J. R., Lo, C.-H., & Wei, J.-Q. (2025). Designing augmented reality-based tools for enhancing children's art learning of intangible cultural heritage. In *Cross-Cultural Design, CCD 2025* (Vol. 15785, pp. 114–127). https://doi.org/10.1007/978-3-031-93736-1_8

May, P. M., Schmidt, W., Vlachopoulos, D., & Chova, L. G. (2020). The use of augmented reality (AR) in museum education: A systematic literature review. In *INTED2020: 14th International Technology, Education and Development Conference* (pp. 3179–3186). https://doi.org/10.21125/inted.2020.0220

Noh, Z., Ismail, A. W., & Sunar, M. S. (2009). Exploring the potential of using augmented reality approach in cultural heritage system. In *ICACTE 2009: 2nd International Conference on Advanced Computer Theory and Engineering* (Vols. 1–2, pp. 711–718). https://doi.org/10.1109/ICACTE.2009.5231900

Perra, C., Grigoriou, E., & Giusto, D. (2019). Augmented reality for cultural heritage education. In *ICCE-BERLIN 2019: 9th IEEE International Conference on Consumer Electronics* (pp. 333–336). https://doi.org/10.1109/icce-berlin47944.2019.8966211

Pierdicca, R., Frontoni, E., & Quattrini, R. (2015). Advanced interaction with paintings by augmented reality and high-resolution visualization: A real case exhibition. In *AVR 2015: Augmented and Virtual Reality* (pp. 38–50). https://doi.org/10.1007/978-3-319-22888-4_4

Sandoval-Henríquez, F. J., Sáez-Delgado, F., & Badilla-Quintana, M. G. (2025). Systematic review on the integration of immersive technologies to improve learning in primary education. *Journal of Computers in Education, 12*(2), 477–502. https://doi.org/10.1007/s40692-024-00318-x

Shekargoftar, A., Taghaddos, H., & Ghorab, K. (2022). An integrated framework for operation and maintenance of gas utility pipeline using BIM, GIS, and AR. *Journal of Performance of Constructed Facilities, 36*(3), Article 04022023. https://doi.org/10.1061/(ASCE)CF.1943-5509.0001722

Shehade, M., Katsoni, V., & Costa, C. (2025). Enhancing cultural heritage tourism in rural areas through augmented reality: A case study from Cyprus. In *Innovation and Creativity in Tourism, Business and Social Sciences, IACuDiT* (Vol. 2, pp. 281–294). https://doi.org/10.1007/978-3-031-87019-4_19

Simón-Sánchez, M. T., & Fernández-Sánchez, M. R. (2023). Emerging technologies for a digital education project: A systematic review on augmented reality and cultural-historical heritage. *Education in the Knowledge Society, 24*, e30613. https://doi.org/10.14201/eks.30613

Srdanovic, P., Skala, T., & Maricevic, M. (2025). InHeritage—A gamified mobile application with AR and VR for cultural heritage preservation in the metaverse. *Applied Sciences, 15*(1), Article 257. https://doi.org/10.3390/app15010257

Turkoglu, H. D., & Alp, N. C. (2025). Evaluating cultural heritage preservation through augmented reality: Insights from the Kaisareia-AR application. *Architecture, 5*(3), Article 59. https://doi.org/10.3390/architecture5030059

Valizadeh, M., Ranjgar, B., & Hakimpour, F. (2024). Indoor augmented reality (AR) pedestrian navigation for emergency evacuation based on BIM and GIS. *Heliyon, 10*(12), Article e32852. https://doi.org/10.1016/j.heliyon.2024.e32852

Vega, M., Gaetan, G., & Martin, A. (2021). User experience guidelines to cultural tourism applications based on augmented reality. *Informes Científicos y Técnicos, 13*(2), 26–43. https://doi.org/10.22305/ict-unpa.v13.n2.812

Vlachos, A., Perifanou, M., & Economides, A. A. (2022). Augmented reality applications for urban cultural heritage sites: An overview. In *ICALT 2022: International Conference on Advanced Learning Technologies* (pp. 322–324). https://doi.org/10.1109/ICALT55010.2022.00102

Vlachos, A., Perifanou, M., & Economides, A. A. (2024). A review of ontologies for augmented reality cultural heritage applications. *Journal of Cultural Heritage Management and Sustainable Development, 14*(2), 160–174. https://doi.org/10.1108/JCHMSD-06-2021-0110

Voultsiou, E., & Moussiades, L. (2025). A systematic review of AI, VR, and LLM applications in special education: Opportunities, challenges, and future directions. *Education and Information Technologies, 30*(13), 19141–19181. https://doi.org/10.1007/s10639-025-13550-4

Wang, Y. W., Deng, X., Zhang, K., & Lang, Y. (2018). The intangible cultural heritage show mode based on AR technology in museums: Take the Li nationality non-material cultural heritage as an example. In *ICIVC 2018: 3rd International Conference on Image, Vision and Computing* (pp. 936–940). https://doi.org/10.1109/ICIVC.2018.00008

Xiao, Y. Z., Chen, Y., & Yan, Y. (2025). Surface protection technologies for earthen sites in the 21st century: Hotspots, evolution, and future trends in digitalization, intelligence, and sustainability. *Coatings, 15*(7), Article 855. https://doi.org/10.3390/coatings15070855

Xie, X., & Tang, X. Y. (2018). The application of augmented reality technology in digital display for intangible cultural heritage: The case of Cantonese furniture. In *HCI International 2018: Interaction in Context* (pp. 334–343). https://doi.org/10.1007/978-3-319-91244-8_27

Zhang, J. R., Yahaya, W. A. J. W., & Sanmugam, M. (2024). The impact of immersive technologies on cultural heritage: A bibliometric study of VR, AR, and MR applications. *Sustainability, 16*(15), Article 6446. https://doi.org/10.3390/su16156446

