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Augmented Reality and Digital Documentation in Urban Heritage Preservation: Current Trends, Challenges, and Future Directions

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ABSTRACT

This paper explores the innovative potential of Augmented Reality (AR) in the context of urban heritage conservation. The text further presents an exposition of prevailing trends in contemporary augmented reality heritage applications, in conjunction with the challenges and prospects that are currently being experienced in this field. The utilisation of augmented reality (AR) as a mechanism for the conservation, documentation and display of heritage assets to the public has been identified as a potential successful tool. The user is situated within this immersive environment, which has been determined to be situated within a quotidian location, with a view to rendering the historical context more compelling and easier to comprehend. In this environment, digital information becomes integrated into physical space with which we are largely unacquainted. The research encompasses a comprehensive range of augmented reality (AR) applications, including virtual restoration and real-time analytics. The text goes on to inquire into cost-related obstacles, the technical expertise necessary in the handling of digital media procedures, and the cultural implications that arise when different places are highlighted by means of the object. The core of the paper centred on the concepts of user-centred design (UCD) and sustainability in the context of AR heritage applications. The study also indicates a requirement for further research, including the decoupling of augmented reality (AR) from multi-layered historical accounts and the establishment of a template for the evolution of AR-based methods in the cultural heritage sector. The findings of this study indicate that augmented reality (AR) has the potential to play a substantial role in the conservation of cultural heritage and the creation of novel interactive educational environments within the context of the developing information society.

Keywords: Augmented Reality (AR), Urban Heritage Preservation, Digital Documentation, User-Centric Design, Cultural Heritage Conservation

INTRODUCTION

Overview of Augmented Reality (AR)

Augmented Reality (AR) technology has become a major tool of interest in many applications and fields, including heritage popularisation, especially in relation to urban heritages. The technology is situated at the intersection of augmented reality (AR) and live data, enabling users to witness the return of historical context in real-time, through three-dimensional reconstructions and interactive media. This will further enrich the visitors' and users' experience, i.e. more in-depth engagement and understanding of cultural heritage tourism. As Mazzetto

(2024) observes, the integration of novel tools, including digital twins, within augmented reality (AR) for heritage preservation applications, is a salient example. The author emphasises the utilisation of these tools to spearhead the emerging wave of conservation. In a similar vein, Ariza-Colpas et al. (2023) have introduced augmented reality (AR) in the domain of tourism and conservation. The authors present an example of a cultural heritage site that has been "empowered" through technological interaction with users, whereby participants encounter the site in a unique and independent manner from other visitors. The utilisation of augmented reality (AR) in the domain of heritage tourism has been shown to engender a number of advantageous effects on visitors' experiences, satisfaction levels, and the assimilation of cultural narratives and historical information (Zhang et al., 2023).

The integration of augmented reality (AR) with other digital technologies is indicative of its growing application in the domain of urban heritage preservation. In the 2025 study by Yu et al., the application of augmented reality (AR), in conjunction with other tools such as Geographic Information Systems (GIS) and Building Information Modeling (BIM), in the domain of architectural heritage risk management is examined. The primary objective of this study is to ensure the sustainability and preservation of cultural structures. Furthermore, Alviz-Meza et al. (2022) emphasise that, as part of the Fourth Industrial Revolution, augmented reality (AR) has become a central research focus in heritage studies, driven by advances in remote sensing and AR technologies. These technological integrations are reshaping the future of heritage preservation, rendering augmented reality (AR) a vital element in the conservation of cultural landmarks, as well as enhancing the overall visitor experience through immersive and contextually rich interactions.

Significance of AR in Heritage Conservation

Augmented Reality (AR) technology has the potential to offer sustainable solutions that transform the manner in which we comprehend, exhibit and safeguard cultural heritage. It has the capacity to transform static sites into digital ones, and digital spaces into semi-real physical places, thereby maximising the impact of a heritage space. For instance, Turkoglu and Alp (2025) examined the potential of augmented reality (AR) technology, utilising the Kaisereia-AR application, to enhance the presentation and conservation of Kayseri Castle. This interpretive methodology facilitates visitor interaction with historical narratives and architectural features in a dynamic, explanation format using hands-on devices—as well as less comfortable inputs (see left)—which permit greater engagement without compromising the site's historic veracity. The AR navigation application developed for Han Yu-related sites in Chaozhou, as utilised by Liu (2022), serves as a pertinent example, elucidating the manner in which AR can assist visitors in navigating heritage institutions and cultivating a more profound comprehension of the cultural milieu. The interactive nature of this application, developed by English Heritage and Timelooper, serves to bring a site to life for the visitor. In addition, it facilitates awareness-raising regarding the preservation and enhancement of shared spaces, thereby rendering them more conducive to visitation and education.

Furthermore, AR has been instrumental in redefining digital heritage and developing sustainable solutions for conservation and tourism. As demonstrated by Liu, Katsoni and Sypridakis (2020), augmented reality has been employed as a means of safeguarding the ancient heritage of Chinese villages. It has been demonstrated that the technology has the potential to be advantageous to both villagers and tourists who wish to prospect. This is due to the integration of diverse digital technologies, including 3D digitising and cloud computing. Evidently, this integration contributes significantly to the preservation of culture through digital documentation, virtual visits and sustainable conservation approaches. Augmented reality (AR) has been regarded as a potentially effective tool for the conservation of heritage. The capacity to establish a connection between the real world and virtual domains offers a promising approach to the conservation of ancient ruins in their original environments. Furthermore, it facilitates the utilisation of these ruins as valuable educational and cultural resources for future generations. These illustrative cases demonstrate the increasing importance of augmented reality in the preservation of cultural heritage, offering practical and interactive solutions to ensure the enduring legacy of past events.

Research Gaps and Objectives

Despite the evident potential of augmented reality (AR) in the preservation of cultural heritage, there are still research gaps that must be addressed if the technology is to be fully utilised to this end. Turkoglu and Alp (2025) observe that, whilst AR applications in heritage contexts have chiefly concentrated on single sites or issues, there has been an absence of exploration into the integration of AR with multi-layered historical narratives, nor the representation of complex architectural histories over a range of time periods in different cultural landscapes. This observation underscores the necessity for more integrated strategies that encompass diverse cultural contexts and the intricate interrelationships between history, architecture, and cultural heritage. Furthermore, Muthanna et al. (2018) observe that despite augmented reality (AR) systems being developed for heritage monitoring and conservation, there is a paucity of standard guidelines placing these activities within sustainable engagement with cultural heritage. Moreover, the long-term implications of AR in terms of audience development, educational

benefits and visitor experience are frequently not adequately contemplated at this stage. Furthermore, the potential for AR to facilitate the development of richer, interactive learning systems has not been fully realised.

The objectives of this paper are as follows: The objective of this study is to ascertain the latest advancements in augmented reality (AR) applications for the conservation of urban heritage. Capecchi et al. (2024) underscore the pivotal role of augmented reality (AR) systems in fostering user engagement and cultivating awareness of heritage conservation, particularly among younger demographics. The present paper makes a contribution to the extant body of knowledge by examining technological developments, challenges in integrating augmented reality (AR) with heritage conservation, and potential future developments. This paper draws upon recent research and case studies in order to provide useful information on best practices for heterogeneous AR implementation. Moreover, it presents the major challenges encountered in the adoption of AR in this domain, and suggests practical solutions for encouraging its use in the heritage preservation and presentation sector. The utilisation of augmented reality (AR) in the domain of cultural heritage is delineated in the chronology presented in Figure 1. This chronology encompasses a period extending from the early 20th century, when conventional documentation and preservation methodologies were employed, to the present era, wherein augmented reality (AR) applications have commenced exerting an influence on user engagement while concurrently augmenting conservation endeavours.

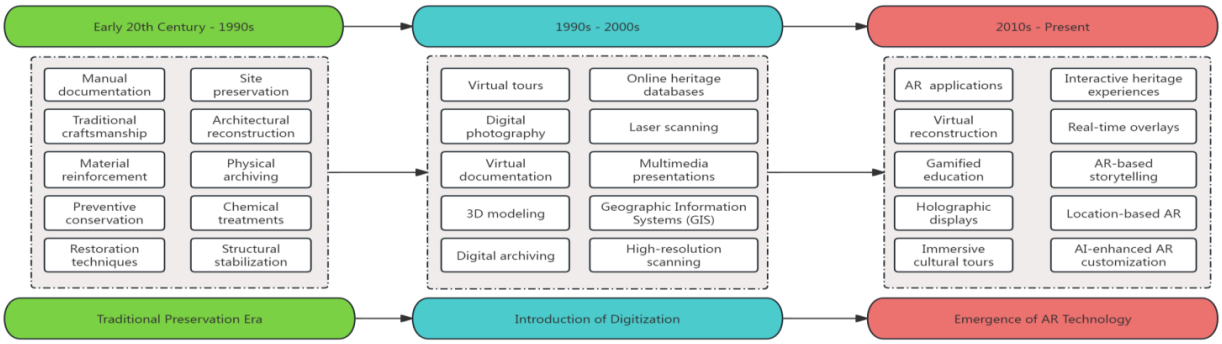

Figure 1. Timeline of AR technology in cultural heritage preservation

METHODOLOGY

Literature Review

Recent advancements in augmented reality (AR) and virtual reality (VR) technologies have had a significant impact on the field of cultural heritage conservation. These developments have introduced novel methodologies for documentation, education, and restoration, opening new avenues for the preservation and study of cultural assets. For instance, Su and Huang (2025) investigated the use of augmented reality (AR) and virtual reality (VR) to enhance learning about non-heritage cultures, demonstrating that immersive technology could facilitate student engagement with cultural artefacts and materials. The research drew on the example of AR/VR, which has the capacity to connect traditional cultural experiences with modern educational needs. Yunuskhodjaeva et al. (2025) concentrated on the utilisation of digital technologies, including augmented reality (AR) and virtual reality (VR), for the archiving of ethno-touristic landmarks. Furthermore, the importance of 3D scanning and photogrammetry in preserving the authentic appearance of cultural sites for future generations, who will be able to visit and appreciate these attractions remotely, was emphasised. The present study explores the pursuit of efficiency, cost-effectiveness and quality in the domain of heritage documentation. In their 2025 publication, Liu et al. presented a practical framework for the implementation of TLS in the context of heritage documentation. This guidance provides practitioners with the necessary context to utilise scanning techniques on their advanced machines without the need for additional machinery in the domain of heritage preservation.

Furthermore, Cocco et al. (2025) concentrated digital media in the study of industrial building heritage, moving from direct methods to information and then to parametric modelling and interactive viewing. The final objective of this research was to determine how to maintain architectural value and the historically significant nature of industrial buildings. Chi et al. (2025) conducted an examination of the relationship between historical value and structural safety in the context of tunnel heritage restoration. The study presented innovative digital twin and XR solutions to ensure the maintenance of structural integrity and antique nature. When considered collectively, these studies illustrate how augmented reality (AR), virtual reality (VR) and other digital technologies are transforming the domain of cultural heritage preservation. It is asserted that these technologies offer significant opportunities

for the preservation, education and understanding of cultural heritage. Furthermore, it is argued that they provide new approaches that can inform both research and practice in the field of digital heritage conservation.

AR Systems Analysis

Augmented reality (AR) technologies have become essential tools for the preservation and understanding of cultural heritage sites. It is evident that a significant number of augmented reality (AR) systems and platforms, including ARCore [GCWS18b] and SLAM devices, are the primary drivers in the development of the digital-physical ecosystem. For instance, Liu et al. (2022) developed augmented reality (AR) navigation software applied to Han Yu-related site scenes in Chaozhou, China. The application utilised ARCore to facilitate the utilisation of interactive maps and contextual information in an outdoor environment, thereby providing an overlay of historic perspective for each location. The present paper sets forth the findings of a research project that sought to demonstrate the capacity of augmented reality (AR) to assist visitors in their navigation and interaction processes within cultural heritage sites.

In a similar vein, Muthanna et al. (2018) presented a system that combined augmented reality (AR) and the Internet of Things (IoT) to facilitate the monitoring of the environment and weather conditions as a set of preventive measures. This system was developed for the purpose of enhancing the cultural heritage experience in tourism and conservation. (12).The utilisation of this system by museums was for the purpose of providing exhibitors and visitors with updated information, without causing damage to cultural objects. These AR systems illustrate the adaptability and advantages of technologies such as ARCore and SLAM, not only in terms of engaging site visitors but also in the sustainable preservation and prior management of heritage sites, thereby providing dynamic and informative experiences.

Case Studies

AR Function	Technical Methods	Impact/Benefits	Challenges
Cultural Artifact Restoration	3D Modeling	Enhances engagement and authenticity	High cost, requires technical expertise
Historical Scene Recreation	Virtual Overlay Technology	Immerses users in historical contexts	Complex data collection, requires high-precision design
Guidance and Navigation	AR Path Guidance	Improves touring efficiency and experience	Requires accurate positioning and frequent updates
Education and Knowledge Dissemination	Multimedia Interaction	Promotes learning and attracts younger audiences	Needs to balance depth and entertainment in content design
Cultural Custom Demonstration	Dynamic Videos and Augmented Imagery	Preserves and promotes intangible cultural heritage	Difficult data collection, requires interdisciplinary collaboration
Gamified Experience	Gamification Design and Interaction	Increases user engagement and interest in learning	Balancing gamification with cultural depth

Table 1. Comparison of AR functions in cultural heritage

The utilisation of augmented reality (AR) in a diverse array of cultural heritage applications has yielded notable success, as evidenced by its capacity to engage visitors and augment their comprehension of historical subjects. The following narrative renders the solution highly efficient. The utilisation of augmented reality (AR) in the domain of museum applications has proven to be a remarkably effective endeavour. The "Story of the Forest" at the National Museum of Singapore serves as a prime exemplar, incorporating augmented reality functionality that enables users to experience the natural history drawings in a manner that is both superficial and constrained. This experience facilitates direct interaction with the exhibited works, which are depicted through animated visualisation. This mixed reality (AR) interaction facilitates a dynamic and varied relationship between visitors and cultural content, thereby enriching the visitor experience. Furthermore, the Cleveland Museum of Art employs augmented reality (AR) technology to facilitate visitor interaction with ancient artefacts in a non-intrusive, three-dimensional manner, thereby enhancing their comprehension of the cultural significance these artefacts possess over time. As demonstrated in Table 1, for AR museum applications, a wide array of technical approaches, such as the use of 3D models and multimedia interaction, support the aim to augment, educate and entertain visitors during their visit. Nevertheless, such applications encounter numerous challenges, including the necessity for advanced technical expertise and considerable development expenses that are often beyond the financial reach of many individuals or organisations.

Augmented reality (AR) can be defined as a novel method of perceiving and communicating with individuals in different temporal periods within historical settings. The Archaeological Park Carnuntum in Austria employs augmented reality (AR) technology to reconstruct Roman gladiator schools and villas in a virtual environment.

This innovative approach offers visitors a unique opportunity to experience historical periods as they would have been in real time. Applications such as those produced by AR-Locations combine digital reconstructions of ancient ruins with their modern-day counterparts, thereby providing users with a sense of what these places would have looked like in antiquity. These applications serve to augment the learning process occurring within the physical environment by providing a contextual framework. It is evident that a number of articles have been published which demonstrate how the imaginative conception of urban landscapes has been influenced by augmented reality (AR). In the context of projects such as Zubr's AR trails, which have been implemented in European cities including Ostrava and Kosice, it is possible to explore hidden tales and local histories using mobile devices. As demonstrated in Figure 2, this type of DS serves as an illustration of the growing utilisation of AR in enhancing the user experience (23%) and educational outcomes (14%) within the domain of cultural heritage applications. The utilisation of augmented reality (AR) technology has been demonstrated to enhance the interactivity and accessibility of urban heritage sites. The efficacy of this approach is predicated on its ability to facilitate a more profound connection between contemporary visitors and historical cityscapes.

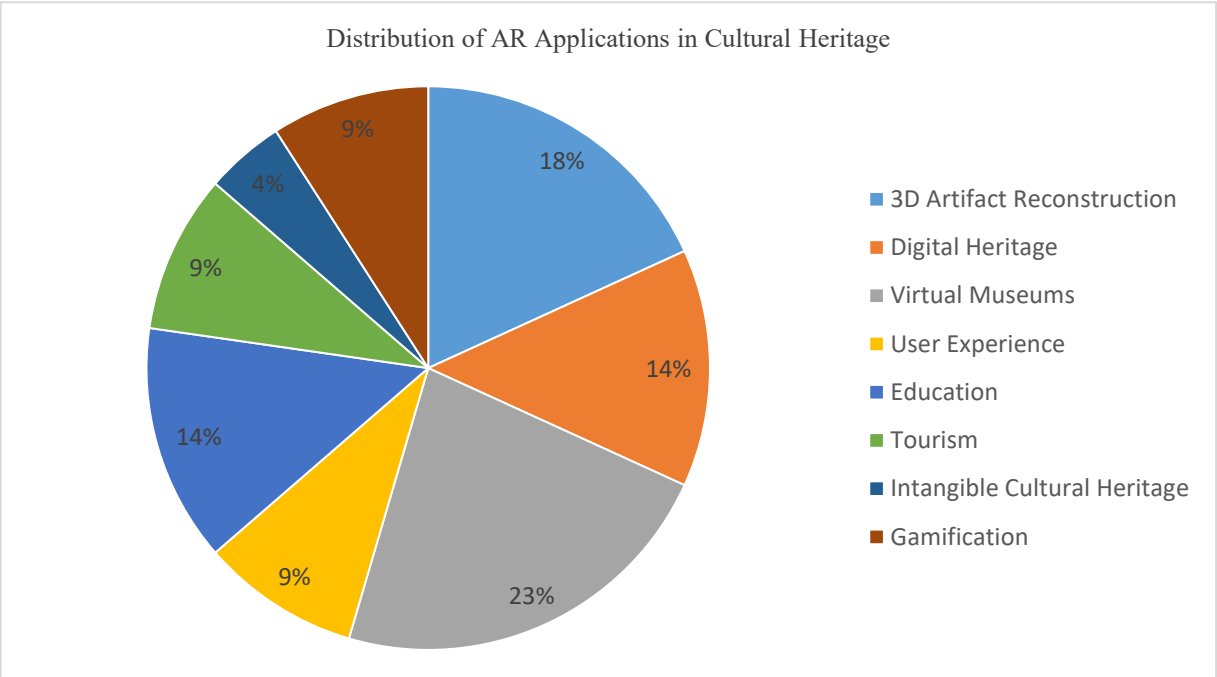

Figure 2. Distribution of AR Applications in Cultural Heritage

FINDINGS

Technological Advancements in AR

The recent development of augmented reality (AR) technology has had a transformative effect on URH, significantly enhancing documentation and visitor experience. The seminal works of A8uma et al. In 2001, the foundational framework for this novel augmented reality (AR) domain was delineated, with an initial emphasis on the superimposition of digital data onto the physical world. This research initiative has established a foundation for future advancements in the domain of augmented reality (AR), with significant applications across a diverse range of sectors, including but not limited to the cultural heritage sector. The preceding research by scholars has established the foundation for the integration of augmented reality (AR) technology in traditional historic sites. This integration facilitates the incorporation of extended visual components, thereby enriching the visitor experience and enhancing the educational value of these historical sites. The initial advancements in the field of augmented reality (AR) rendered it a potent instrument for the documentation and interpretation of heritage. This is due to the capacity of AR to facilitate the capture of time-based documentation of the intangible facets of cultural property. The increasing utilisation of Augmented Reality (AR) in the domain of Cultural Heritage conservation is facilitated by recent technological advancements that have rendered this technology more dependable and more straightforward to implement as a tool for cultural heritage conservation, learning and engagement.

Recent studies of Grassini et al. (2024) have provided an extensive general view of the use of augmented reality (AR) in workplaces, especially with regard to the enhancement of situational awareness and operational processes. The conclusions of this study have the potential to be extrapolated to the heritage domain, thereby demonstrating

the efficacy of augmented reality (AR) as a potent instrument in educational and immersive methodologies, particularly as a medium for investigation in authentic cultural settings. Stefanidi et al. (2025) further elaborate on this phenomenon by examining the utilisation of augmented reality (AR) beyond the confines of formal education. They illustrate how AR is employed to engage learners through techniques designed to motivate and stimulate learning, thereby fostering an enjoyable and interactive learning experience. The paper posits the hypothesis that Augmented Reality (AR) and Virtual Reality (VR) have the potential to reinvigorate historical sites, transforming them into interactive learning hubs within urban environments. These nodes facilitate augmented pieces, providing visitors with access to information regarding place and people, thereby enabling them to learn through shared real-time narratives. Moreover, Saha et al. (2025) hypothesised the potential for augmented reality (AR) to function as a disruptive technology within the manufacturing sector. This hypothesis was formulated during the course of an exploration of emergent technological fusion and its relevance to heritage domains. It is hypothesised that analogous techniques may also be applicable to the realm of virtual tours of urban heritage sites. This will facilitate imaginary voyages to these locations and enable exploration and engagement with them in ways that were previously unfeasible. Moreover, within a medical context, Azad et al. (2024) employed spine surgery as a case study for the implementation of augmented reality (AR), emphasising the organic progression of AR and its enhancement of precision in intricate environments. These developments underscore the extensive potential of augmented reality (AR) across a diverse range of applications, including within the domain of heritage. Moreover, the authors emphasise the disruptive role of augmented reality (AR) in the context of urban heritage conservation. They propose novel strategies for visitor experience and cultural heritage documentation. Augmented reality (AR) is an evolving technology with the potential to play a significant role in the preservation of urban heritage in the near future. Secondly, it can function as a tool for educational projects that promote involvement and an understanding of culture. This technological innovation has the potential to contribute to the preservation and dissemination of cultural heritage, with a particular emphasis on the transmission of cultural sensibilities.

User Experience (UX) and User-Centric Design (UCD)

In contemporary augmented reality (AR) technologies designed for the conservation of urban heritage, considerations of user experience (UX) and user-centred design (UCD) have been incorporated directly. In the context of augmented reality (AR) applications for cultural heritage, there is a need to develop applications that are accessible to a broader range of end users. This necessitates an intuitive experience that is respectful of regional habits. Lee et al. (2025) posit that a user-centred approach is necessary to enrich the applications of Extended Reality (XR), a concept which also appears to be particularly well-suited to the field of heritage. The research also underscores the potential of machine learning methodologies to be integrated within augmented reality (AR) systems, enabling the customisation of experiences based on the interests and requirements of end users. This issue assumes even greater significance in the context of heritage sites, where meeting the needs of visitors from diverse cultural backgrounds and with varied expectations is of paramount importance. The utilisation of machine learning algorithms within the domain of augmented reality (AR) facilitates the adaptation of content to align with the cultural context and accessibility requirements of individual users. This is a significant development for those seeking to create an educational experience that can be accessed and enjoyed by all, irrespective of cultural or accessibility differences.

Furthermore, Marino et al. (2010) investigated the development of AR systems for individual user requirements. (2024), which concentrate on the role of augmented reality (AR) in aiding Industry 5.0 operators while assembling products. Notwithstanding the fact that the primary focus of their work pertains to industrial applications, the principles they describe are highly applicable to the field of urban heritage preservation. In this context, augmented reality (AR) has the potential to assist user groups in navigating complex historical narratives. The integration of augmented reality (AR) with user-friendly interfaces is of paramount importance for enhancing accessibility and engagement at cultural heritage sites. This method has also been corroborated by Han et al. (2019), who expound the manner in which mobile AR applications can be designed with tourists' needs in mind according to QFD. The necessity of translating user requirements into technical design specifications is emphasised in their work, with the objective of ensuring that AR applications are technologically advanced and also meet the needs and cultural backgrounds of heritage site visitors. Additionally, Opoku-Baah et al. (2022). Augmented Reality in Ophthalmic Applications: The binocular augmented reality (AR) model is hereby presented for the purpose of evaluating the user experience of prescription lens designs. The findings of the study on the comfort and interaction of users can be transferred to A/R systems in cultural heritage, where the customisation of comfort via visitors' AR experiences is important. As Almadi (2025) further contributes to the discourse by examining the broader ramifications of augmented reality (AR) technologies in the domain of financial innovation, a subject which may hold particular pertinence in the context of cultural analysis. The adoption of a user-oriented strategy in the development of AR systems has the potential to address the practical needs and cultural preferences of tourists, thereby promoting the creation of more engaging and inclusive interactive experiences. When considered

holistically, the findings underscore the pivotal role of UX and UCD in the design of AR applications intended not only to support the preservation of urban heritage but also to enhance access to and cultural sensitivity in such experiences for diverse user groups.

Sustainability and Environmental Impact

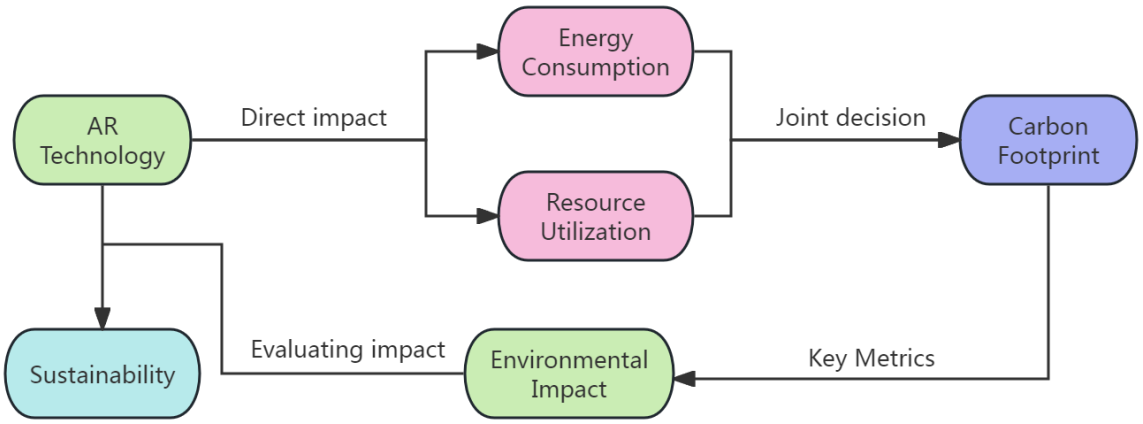

Figure 3. Sustainability Environmental Impact Assessment Model

Augmented Reality (AR) has also been recognised as a useful mechanism within the context of sustainability and the minimisation of environmental impacts during heritage conservation. The primary benefits of augmented reality (AR) are its capacity to minimise the requirements for physical planning, consequently reducing the consumption of materials, labour, and energy. As posited by Joerss et al. (2021), the integration of augmented reality (AR) and other emerging digital technology applications within the domain of cultural heritage facilitates a novel form of virtual maintenance, thereby diminishing the necessity for physical interventions that are known to exert environmental impacts. The utilisation of augmented reality (AR) technology in the preservation and presentation of heritage in digital form offers several advantages. Firstly, it prevents damage to the original structure, and secondly, it has a more environmentally friendly impact than traditional methodologies. Furthermore, it is a more straightforward and cost-effective process. From an ecological perspective, it is imperative to safeguard the cultural heritage of future generations. This imperative should be addressed through the utilisation of non-destructive methodologies that do not involve the utilisation of virgin resources.

The utilisation of augmented reality (AR) has the potential to significantly minimise the necessity for physical restoration, concurrently enhancing resource recycling. This is a matter of critical importance to the conservation and management of heritage. In their 2025 study, Nadeem et al. described their investigation into augmented reality (AR) as a medium for stimulating consumer engagement with sustainable marketing. The scientists evaluated the efficacy of this technological platform in facilitating communication regarding climate change and environmental conservation. Augmented Reality: The concept of augmented reality (AR) is analogous to that of virtual reality (VR), with the distinction that it is designed to engage tourists in the domain of heritage preservation. It is evident that digital interventions have the potential to contribute to the conservation of cultural heritage, thereby promoting sustainable use of resources. For instance, visitors may have had the opportunity to engage with virtual models of objects or sites. This would serve to reduce the degree of wear and tear on the edifice itself, whilst concomitantly diminishing the quantity of materials required for restorations. As demonstrated in Figure 3, a salient implication of augmented reality (AR) technology with regard to sustainability can be observed in Figure 3, encompassing the domains of energy utilisation, resource utilisation and carbon emission. This lens provides a valuable framework for comprehending and addressing the environmental implications of heritage preservation in augmented reality systems.

Furthermore, Sorcaru et al. (2025) emphasise the significance of cognitive and behavioural aspects in supporting sustainable tourism, which could be translated into QL heritage preservation. The advent of augmented reality (AR) has given rise to a range of applications with the potential to influence the adoption of sustainable behaviours, whilst concomitantly showcasing the capacity of AR to facilitate the acquisition of knowledge pertaining to cultural heritage. The utilisation of augmented reality (AR) in the domain of physical interventions to facilitate the maintenance of human conservators has been demonstrated to be advantageous, as it has led to a reduction in resource-intensive tasks. Moreover, it has been demonstrated that this approach can effectively raise awareness regarding sustainability in relation to heritage themes. This alignment with sustainable operations is imperative, as it ensures the continuous aspiration towards enhanced preservation and conservation in heritage

management. This approach safeguards the historic value of the sites while concurrently supporting environmentally responsible use. The utilisation of augmented reality (AR) within the context of urban heritage provides a compelling illustration of how technological innovation has the capacity to facilitate the construction of diverse social futures and contribute to the enhancement of urban sustainability. This is achieved by adhering to principles such as minimising environmental impact, optimising resource efficiency, and fostering public engagement (Schafers et al.). Consequently, it can be posited that AR assumes a dual function in relation to the preservation of cultural identity, on the one hand, and the global struggle against further environmental degradation, on the other.

DISCUSSION

Challenges of AR in Heritage Preservation

Augmented reality (AR) has been identified as a medium with the potential to assist in the conservation of urban heritage. However, the development of such technology is hindered by significant challenges in the design process. A salient issue that has been identified is the exorbitant expense associated with the deployment of augmented reality (AR) systems. In a study by Gong et al. (2025), an economic analysis was performed on the integration of augmented reality (AR) technology in the field of cultural heritage, with a particular focus on agricultural heritage. The study utilised the following methodology: "%lut=``detect". The preliminary financial investment required for the procurement of hardware, encompassing augmented reality (AR) equipment and high-definition displays, along with software and dedicated hardware, can prove to be a substantial financial burden for numerous heritage organisations, particularly those with constrained budgets. The issue is further complicated by the necessity of servicing, updating and training personnel in order to operate these systems. In certain instances, the obligations imposed by these responsibilities can exert a significant influence on the determination of the value of heritage sites, particularly for those of smaller scale and limited financial resources. Consequently, effective AR content preservation methods that can maintain the quality and precision of AR contents are necessary to facilitate the application of AR technology in heritage preservation activities.

Cross-discipline collaboration represents a further challenge that AR must confront in the context of heritage. Cheng et al. (2024) emphasise the importance of collaboration between technologists, heritage sector professionals, educators and exhibit designers. They assert that such cooperation is essential for ensuring that AR applications are not only technically sound but also culturally appropriate. The utilisation of augmented reality (AR) in heritage settings necessitates a diverse array of competencies, encompassing domains such as architecture, history, computer science, and user experience design. It is imperative that such an interdisciplinary approach is employed in order to create immersive, content-rich augmented reality (AR) experiences that respect the cultural significance of heritage sites. Despite the potential for teams to develop sophisticated AR applications, effective communication and collaboration across academic disciplines are essential for achieving optimal results. Without these, the outcome may fall short of the expectations of heritage professionals and tourists, compromising the intended experience. Furthermore, ascertaining the optimal equilibrium between technological sophistication and cultural authenticity in the features of a station presents a significant challenge. In their 2024 study, Al-Gurashi and Shatwan examined the equilibrium between vernacular architecture and local customs, juxtaposed against contemporary technological advancements. While augmented reality (AR) facilitates novel forms of interaction and visitor education, it is imperative that it preserves the authenticity of cultural heritage. The application of technology to the delivery of content within the context of a moveable heritage museum has the potential to disrupt the connection between individuals and the tactile and physical culture of a place. This disruption can result in a loss of significance, both historical and emotional, to the museum's content for the visitors. It is imperative to strike a balance between innovation and authenticity in the delivery of this technology, ensuring that it does not impede, but rather empowers, the cultural heritage of iconic places.

Future Directions

The role of augmented reality (AR) in the domain of heritage is an emerging theme. This is due to the rapid progress of related technologies, such as machine learning, real-time data analysis and the provision of personalised visitor experiences. These technologies contribute to the discussion surrounding the role of AR in heritage. This paper proposes the utilisation of augmented reality (AR) and machine learning (ML) technologies to enhance the precision and authenticity of virtual reconstruction and representation of heritage sites. Fu et al. (2018) investigated the potential of Augmented Reality (AR) in conjunction with Virtual Reality (VR) technologies to mitigate project schedule risk in the construction industry. The study also explored the application of AR in the monitoring and preservation of heritage sites, with a focus on forecasting future preservation needs. The utilisation of machine learning (ML) algorithms has the potential to enhance the responsiveness of augmented reality (AR) systems in

real time, thereby facilitating customised visitor experiences. The provision of information regarding past individual interactions or behaviour may be a means to achieve this objective. This bespoke AR model has the potential to significantly enhance user engagement and facilitate the development of user-led experiences, which are pivotal in shaping the future of preservation.

Moreover, the application of real-time data analytics within augmented reality (AR) is poised to play a pivotal role in the effective management and monitoring of heritage sites. In the present study, Liu et al. (2024) explore the potential of augmented reality (AR) in the context of vocational education, with a particular emphasis on the manner in which real-time data analytics and interactive learning environments can optimise the end user experience. This concept may be associated with the preservation of heritage. It is recommended that users and heritage professionals be provided with brief feedback on their perceptions of AR professionalism as a form of maintenance. It is imperative that this feedback encompasses the identification of any potential attacks on artefacts or life history in the context of restoration. Furthermore, gamification has evolved as an effective means of enhancing visitor engagement; AR Apps are employing game mechanics to direct exploration and interaction. Wut and Ng (2024) place significant emphasis on the mounting importance of augmented reality (AR) and virtual reality (VR) within the tourism sector. It is evident that gamification methodologies have the capacity to substantially enhance user engagement and satisfaction. The integration of these solutions with augmented reality (AR) technology has the potential to transform heritage site visits into dynamic learning experiences, whereby users can actively contribute to the preservation of the past. As augmented reality (AR) continues to evolve, it will be integrated with machine learning (ML), real-time data analytics and gamification, thereby transforming the manner in which heritage sites are comprehended. This transformation will also extend to the methods by which these sites can be safeguarded and appreciated by future generations.

Cultural Sensitivity and Ethical Considerations

The application of Augmented Reality (AR) in the domain of cultural heritage: a case for ethnomethology and epistemology. 4. It is imperative to utilise augmented reality in a manner that respects these cultural narratives and the historical significance of the heritage site. As posited by Seneviratne et al. (2024), the advent of immersive technologies, such as augmented reality (AR), has been demonstrated to engender a marked augmentation in the confidence with which decisions are made. However, it is imperative to calibrate the degree of presence in order to safeguard the cultural foundation. This is of particular pertinence in the domain of urban heritage conservation, as it posits that augmented reality (AR) applications are founded upon an extensive understanding of local history, culture, and values. Consequently, this ensures a degree of respect for, and sensitivity towards, not merely the depiction of the sites, but also their historical context. In order to accurately depict the scenes in question, it is imperative that collaboration occurs with cultural consultants, historians and the community. While digital interventions may not overshadow historical narratives, augmented reality (AR) has the potential to offer visitors a more immersive and respectful experience, honoring the historical accuracy of these accounts.

Furthermore, ethical implications should be the primary concern when developing AR for heritage preservation. Sombilon et al. (2024) posit that the ethical considerations intrinsic to the utilisation of immersive technologies within an educational environment also pertain to heritage sites. The argument is posited that any immersive work should serve as a vehicle for educating audiences to understand and respect the cultural heritage being represented (rather than using it as a marketing tool or reducing complicated historical realities to clichés). In the context of urban heritage, it is essential to recognise that ethical challenges also extend to the impact of digital technologies on public perceptions of a cultural site. As illustrated in Figure 4, drawn from the User Experience Theory schema (Guo, 2025), the augmented reality (AR) paradigm comprises multiple layers concerning user interaction, including content structure, interface usability and visual aesthetics. These factors exert a direct influence on the accessibility, usability and cultural authenticity of the experience. It is imperative that all of the aforementioned factors are given due consideration in order to avoid the reinforcement of stereotypes and the presentation of a distorted portrayal of the heritage site. It is imperative to recognise the profound significance of the narratives embodied by these locations, and to acknowledge the potential of augmented reality (AR) as a medium for both education and preservation. In this particular instance, it is imperative to avoid the misrepresentation of these historical figures and events. This serves to illustrate the importance of incorporating cultural awareness into the implementation of technology. In the context of a burgeoning culture of augmented reality (AR) within the domain of cultural heritage tourism, this ethical approach is poised to assume paramount importance. The technology in question is expected to serve the purpose of augmenting the historical significance of preserved locations, rather than diminishing it.

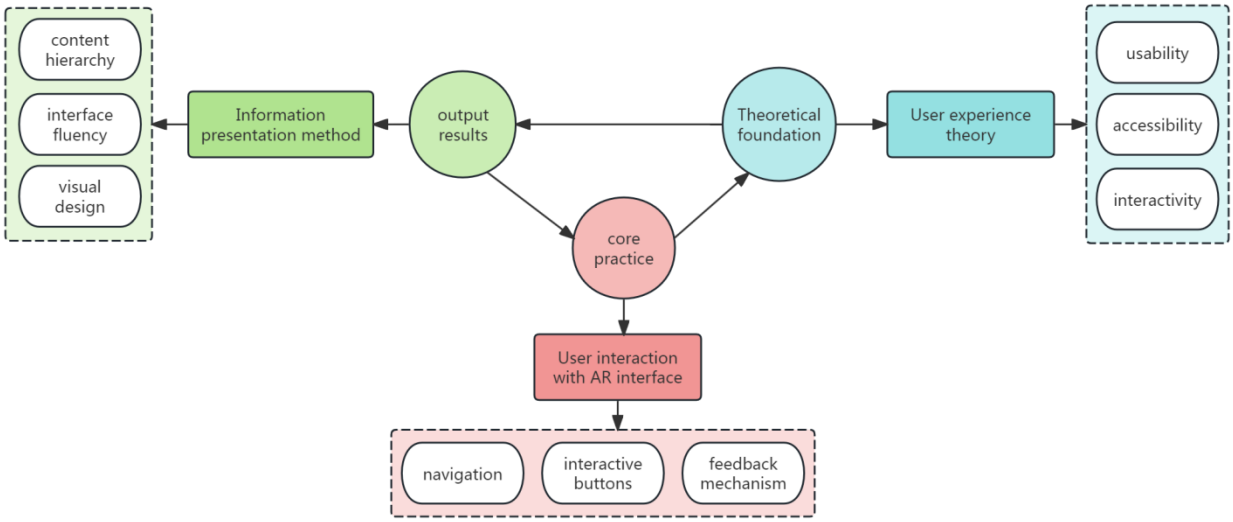

Figure 4. Schematic diagram of User Experience Theory in AR

CONCLUSION

Summary of Key Findings

The advent of augmented reality (AR) has precipitated a paradigm shift within the domain of urban heritage preservation, engendering a plethora of prospects for the augmentation and conservation of cultural heritage sites. One of the most remarkable results of this review is the finding that augmented reality (AR) technologies have the potential to provide novel solutions for the restoration of virtual reality (VR) and the documentation of historical sites. These solutions were based on the use of electronic data formats so as to avoid the need for physical intervention at the site. As asserted by Markopoulos et al. (2021), augmented reality and virtual reality technologies are of paramount importance in the dissemination and management of African cultural heritage. The results of the study indicate that augmented reality (AR) has the potential to provide experiential interaction, thereby immersing users in cultural heritage sites without compromising their historical value. This methodology can be extrapolated to encompass all urban heritage sites, thereby illustrating the efficacy of augmented reality (AR) in preserving artefacts and generating added value through active visitor engagement with educational content.

Moreover, in the domain of vernacular building conservation (Al-Gurashi and Shatwan, 2024), it is evident that augmented reality (AR) technology has the potential to transform tourism and heritage management. The case study, situated in the Matbouli House Museum in Al-Balad, demonstrates the potential of augmented reality (AR) to revitalise local heritage, thereby providing visitors with a more profound experience of the historical and cultural context of the location. This finding is consistent with the report by Gong et al. (2025), which examined the use of AR in relation to agricultural heritage. The report demonstrated the potential of augmented reality (AR) in various domains of cultural heritage, particularly in the creation of educational experiences and the promotion of sustainable conservation methods. The collective analysis of these studies lends support to the hypothesis that augmented reality (AR) serves not only as a medium for digital documentation and preservation but also as a tool for rendering cultural heritage more accessible and engaging to previously untapped demographics. The potential implications for research and practice are evident – augmented reality (AR) technologies have the potential to transform the manner in which cultural heritage is documented, understood and learned, through a range of multidisciplinary opportunities for advancing innovation in heritage conservation.

Recommendations for Policymakers and Practitioners

The utilisation of augmented reality in the context of tourism and cultural heritage experiences has the potential to be revolutionary. Nevertheless, effective, sustainable and user-centred implementation must be founded upon a robust design paradigm. It is evident that policymakers and practitioners can play a pivotal role in fostering an environment conducive to the responsible and effective utilisation of augmented reality (AR) technologies. The promotion of inclusive and sustainable models is a significant approach that could be employed in this direction. Richardson et al. (2024) emphasise the significance of cultivating the tenets of responsible innovation through a natural science 'lens' in virtual worlds, with the objective of establishing fundamental frameworks to facilitate the transfer of these principles into augmented reality and heritage applications. The design principles are intended to ensure that AR does not cause harm, whilst also protecting the cultural heritage and ensuring the accessibility of

applications to a wide range of users. The present study puts forward the hypothesis that these principles could be pertinent to political action. In the future, they may have implications with regard to heritage in the context of augmented reality (AR) technology. It is imperative that the implementation of AR technologies is executed in a manner that safeguards the historical, social and cultural significance of these sites. Furthermore, it is essential to explore novel approaches to attract contemporary visitors.

Consequently, it is imperative that the sustainability of AR in cultural heritage preservation is prioritised at the core of policy and practice. In 2023, the first book by Khan et al. was published. This seminal work highlighted the role of new technologies, and more particularly augmented reality (AR), in supporting sustainable activities across a range of sectors, including libraries and educational institutes. The findings of recent research indicate that the implementation of smart and responsive technologies in heritage sites could assist in the achievement of long-term conservation objectives, with minimal environmental impact. From a sustainability standpoint, there is a requirement for the development of AR applications and methods that are more energy-efficient. In order to maintain minimal resource use, it is essential to limit physical restoration needs accurately. Moreover, as Zhu et al. (2018) emphasise, Continuing Professional Development (CPD) is instrumental in facilitating the adoption of novel technologies, such as Augmented Reality (AR), within the context of primary care. This insight can be transferred to the domain of heritage preservation. To this end, it is recommended that stakeholders and professionals continue to receive training in augmented reality (AR). This will ensure that high cost-benefit ratios are maintained for both educational and conservation ends. It is evident that the effective incorporation of augmented reality (AR) at cultural heritage locations is contingent on a robust technological foundation and the availability of the requisite human capital. Consequently, the decision maker must assume a significant responsibility to guarantee that this adoption will safeguard the conservation of cultural heritage for posterity.

Call for Further Research

The application of augmented reality (AR) in the domain of cultural heritage preservation represents a nascent and auspicious research trajectory. As demonstrated in the research of this thesis, augmented reality (AR) is a particularly powerful tool for enhancing the preservation, dissemination and interaction of cultural heritage places. However, further research is required to explore the consequences of AR in a variety of different cultural contexts. A comprehensive literature review is required to ascertain the extent to which cognitive theory can inform multimedia learning. The primary objective of this review is to examine the manner in which augmented reality (AR) is designed to facilitate efficient learning and mitigate cognitive load. In the context of the future development of augmented reality (AR) for cultural heritage, this approach has the potential to be of significant value. It is anticipated that it will facilitate the presentation of a structured and engaging experience to users, thereby ensuring two key elements. Firstly, it is expected to enhance accessibility, given the potential complexity of AR experiences and the risk of users not comprehending what they are seeing. Secondly, it is projected to provide richer content viewing experiences. The utilisation of augmented reality (AR) applications within cultural heritage settings is undergoing a period of accelerated growth. In order to address the diverse requirements of access and usability across a broad spectrum of potential users, there is an imperative for the ongoing development and refinement of these tools.

Furthermore, the findings of Wu et al. (2025) on future developments of advanced learning technologies are relevant to this discussion. Augmented reality (AR) in education. Augmented reality (AR) is poised to transform the experience of visiting historical sites, offering interactive and immersive experiences designed to facilitate unparalleled engagement. It is imperative that future studies investigate the impact of augmented reality (AR) technology in cultural heritage settings on the educational experience. The present study should concentrate on the manner in which augmented reality (AR) can enhance visitors' comprehension of the website and the event. It is evident that this outcome aligns with the findings presented in Table 2, which pertains to contributions and applications concerning augmented reality (AR) technologies for cultural heritage. The recommendation regarding the creation of AR applications was deemed significant enough to be included in this summary. The user experience is subject to variation according to individual interests, cultural heritage and wishes (Practical Implementations and Personalisation). In addition, Kang et al. (2025) investigated the potential of augmented reality (AR) in nursing education. The study demonstrated that the utilisation of head-mounted display-based AR enhances the learning performance of learners. The implementation of such a system at heritage sites has the potential to enhance the visitor experience by making it more enjoyable and interactive. In light of the recent advancements in augmented reality (AR) technology with regard to heritage preservation, it is imperative to consider the educational potential of AR technologies and their role in the conservation of heritage sites. This research programme suggests that in the future, scholars and practitioners could focus on the latest developments in AR technologies, as well as how these technologies are used in other contexts and cultures. This would allow the full potential of AR to be realised in the field of CH preservation.

Section	Key Insights
Theoretical Underpinnings and UCD Principles	AR integration in cultural heritage must follow User-Centered Design (UCD) principles, emphasizing user expectations, behaviors, and cultural relevance. Well-executed UCD promotes engagement, usability, and emotional resonance.
Practical Implementations and Personalization	AR app design should personalize the experience based on users' interests, preferences, and cultural backgrounds, enhancing engagement and improving visitor satisfaction.
Sustainability Assessment and Cultural Impact	A framework is needed to assess AR's economic, environmental, and cultural sustainability. The goal is to ensure AR contributes positively to both heritage preservation and visitor experience without compromising cultural integrity.
Conclusion and Contribution of Thesis	This thesis contributes to the field by proposing a UCD framework for AR in cultural heritage, developing a sustainability assessment model, and performing cultural impact analysis, offering practical insights for practitioners, policymakers, and academics.

Table 2. Summary of the Contributions and Practical Applications of AR in Cultural Heritage

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