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Navigating Ethics and Innovation: The Role of AI in Cultural Heritage

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ABSTRACT: The preservation of cultural heritage has become increasingly reliant on Artificial Intelligence and digital technologies, reflecting a global shift toward AI-enabled and digital-based conservation strategies that emphasize innovation and sustainability. This narrative review synthesizes evidence from diverse academic sources to examine how AI is being applied to safeguard both tangible and intangible heritage. Literature searches were conducted using Scopus, Web of Science, and Google Scholar, employing keywords such as "Artificial Intelligence," "cultural heritage preservation," "digital archiving," and "machine learning." Studies were screened based on inclusion criteria emphasizing empirical research, case studies, and reviews published within the last decade. Results reveal four dominant themes: tangible heritage conservation, intangible heritage preservation, environmental monitoring and risk management, and museum and archive engagement. AI has demonstrated strong potential in artifact restoration, predictive maintenance, and revitalization of traditional practices through immersive technologies. However, systemic barriers, including limited financial resources, fragmented governance, and lack of standardized ethical frameworks, hinder its broader adoption. Ethical challenges, particularly concerning cultural representation, data privacy, and inclusivity, further complicate implementation. Innovative solutions such as public-private partnerships, community-driven digitization, and interdisciplinary collaborations present promising pathways forward. The findings highlight both the opportunities and challenges of integrating AI into heritage preservation and emphasize the need for urgent, coordinated strategies to enhance cultural sustainability. This study contributes to the discourse by underscoring the dual imperative of advancing technological adoption while ensuring cultural sensitivity and inclusivity.

Keywords: Artificial Intelligence, Cultural Heritage Preservation, Machine Learning, Immersive Technologies, Digital Twin, Community-Driven Heritage.

INTRODUCTION

In recent years, there has been a marked shift in the strategies employed to preserve cultural heritage, reflecting broader transformations within the field of conservation studies. Traditional

methods, which historically emphasized manual documentation, physical restoration, and material conservation, are increasingly being complemented—or in some cases replaced—by advanced technological interventions. Among these, Artificial Intelligence (AI) and digital archiving have gained prominence as essential tools for safeguarding both tangible and intangible cultural heritage (ICH). This growing trend reflects the recognition that conventional approaches, though valuable, are insufficient to address the accelerating environmental, social, and technological challenges that threaten cultural assets on a global scale (Ghaith & Hutson, 2024; Harisanty et al., 2024; Gîrbacia, 2024). The digitization of heritage, supported by AI, offers not only enhanced preservation capabilities but also improved accessibility, interpretation, and community engagement, positioning technology as a cornerstone in contemporary cultural heritage conservation.

The integration of AI into cultural heritage preservation has been catalyzed by significant advances in machine learning, computer vision, and natural language processing. These technologies enable the creation of digital surrogates of heritage objects and sites, facilitate predictive conservation strategies, and promote new forms of cultural participation. As Laužikas et al. (2019) argue, the adoption of AI techniques has introduced a paradigm shift that extends beyond conservation to the reimagining of how cultural heritage is experienced, studied, and transmitted across generations. This shift is particularly relevant given the intensification of global risks—such as climate change, natural disasters, and armed conflict—that increasingly undermine preservation efforts (Laohaviraphap & Waroonkun, 2024; Stein, 2015). Thus, AI is not only a technical enhancement but also a necessary adaptation to ensure the long-term sustainability of cultural heritage in rapidly changing environments.

The urgency of this transition is underscored by alarming data regarding the vulnerability of cultural heritage worldwide. Studies estimate that approximately 150,000 cultural heritage sites are at risk of deterioration due to climate change alone (Laohaviraphap & Waroonkun, 2024). Rising sea levels, increased frequency of floods, and extreme temperature fluctuations accelerate the decay of architectural heritage, while intangible practices face extinction as communities confront displacement and social disruption (Pansoni et al., 2023). Beyond environmental threats, anthropogenic factors such as urbanization, industrial expansion, and armed conflicts have led to the irreversible destruction of historical sites in numerous global regions (Stein, 2015). These pressing challenges highlight the limitations of traditional conservation strategies that rely heavily on periodic inspections and physical interventions. As Münster et al. (2024) observe, AI-enabled digital twins and photogrammetric modeling provide innovative alternatives by offering real-time monitoring, predictive analytics, and proactive risk assessment. These technologies not only anticipate potential deterioration but also allow for precise simulations of conservation scenarios, thereby improving decision-making processes.

The application of AI in heritage preservation extends beyond monitoring and risk management. Recent studies demonstrate the effectiveness of AI in restoration and documentation efforts. For instance, photogrammetry and digital twin mapping have been employed to generate high-resolution models of historical structures, facilitating accurate reconstructions (Themistocleous & Abate, 2024; Harisanty et al., 2024). Generative algorithms and advanced data processing techniques have similarly been applied to recreate missing details in artifacts, paintings, and manuscripts, ensuring continuity of cultural narratives (Talamo et al., 2020; Zhao et al., 2020).

These innovations are not confined to tangible heritage; intangible practices, such as traditional music, performance arts, and oral traditions, are also being documented, analyzed, and transmitted using AI-driven platforms (Dai et al., 2024). By enabling new forms of preservation that transcend physical limitations, AI fosters resilience in cultural practices and expands the accessibility of heritage knowledge to global audiences.

Nevertheless, the integration of AI into cultural heritage preservation is fraught with significant challenges. A primary obstacle is data scarcity, particularly the lack of comprehensive and labeled datasets necessary for training AI algorithms. This issue is exacerbated in the domain of intangible heritage, where documentation has historically been limited, fragmented, or excluded from formal archiving systems (Laužikas et al., 2019; Dai et al., 2024). Without sufficient datasets, AI models risk being biased, incomplete, or ineffective in addressing preservation needs. Moreover, many heritage sites, particularly those located in developing regions, lack the technical infrastructure to collect and maintain robust digital records, perpetuating disparities in the representation and conservation of cultural resources.

Ethical concerns further complicate the application of AI in this domain. The ownership and control of cultural data—especially when derived from Indigenous and community-generated content—raise questions about consent, cultural sensitivity, and the potential for misuse (Pansoni et al., 2023; Hannaford et al., 2024). As Taj and Gala (2024) caution, AI technologies may inadvertently reinforce existing inequities if they prioritize efficiency over inclusivity, thereby marginalizing vulnerable communities. Furthermore, cultural heritage is not only a technical resource but also a living practice imbued with meaning and identity. Applying AI without sensitivity to these dimensions risks reducing heritage to data points, stripping it of its cultural and symbolic significance (Greco et al., 2024).

Technological barriers also remain formidable. The rapid evolution of AI tools often outpaces the ability of heritage professionals to acquire the necessary expertise for their application. As Sankar et al. (2023) and Münster et al. (2024) note, many organizations struggle to integrate AI into existing preservation frameworks, facing issues of interoperability, lack of standardization, and limited financial resources. Du (2024) highlights the organizational challenges of adapting traditional management systems to accommodate AI applications, while Greco et al. (2024) emphasize the risks posed by fragmented data collection methods that hinder collaborative preservation efforts. Together, these challenges underscore the complexity of embedding AI within the institutional and practical realities of heritage conservation.

Despite the growing body of literature on AI applications in cultural heritage, several critical gaps persist. Much of the existing research focuses on isolated case studies or specific technological tools, often neglecting to situate findings within broader interdisciplinary and global contexts (Laohaviraphap & Waroonkun, 2024; Zhao et al., 2020). For instance, while studies have explored the potential of AI in risk assessment or artifact restoration, few have examined how these innovations interact with governance frameworks, community participation, and ethical considerations. Similarly, while bibliometric analyses provide valuable insights into trends, they often lack the narrative synthesis needed to understand the holistic implications of technological adoption in heritage preservation (Calicchia et al., 2024; Ghaith & Hutson, 2024). This

fragmentation highlights the need for integrative reviews that bridge disciplinary divides and offer comprehensive perspectives on the opportunities and challenges of AI in cultural heritage.

The present study seeks to address these gaps by conducting a narrative review that synthesizes emerging practices, challenges, and future directions in AI-enabled cultural heritage preservation. Its primary objective is to examine how AI technologies are being integrated into conservation strategies across both tangible and intangible heritage contexts, while critically analyzing their effectiveness, limitations, and broader implications. By situating AI within the interdisciplinary discourse of heritage studies, the review aims to provide a balanced understanding of the potential of digital technologies to transform conservation practices, while also emphasizing the ethical, social, and cultural dimensions that must guide their application (Harisanty et al., 2024; Marchello et al., 2023).

In terms of scope, the review focuses on global perspectives, with particular attention to diverse geographic and cultural contexts. Research from Asia, such as Wang and Liu (2022), illustrates how AI has been adapted to local cultural identities, while Turner-Jones et al. (2024) highlight the use of citizen science and machine learning in Indigenous Australian communities. European studies, including Croce et al. (2021), explore technical innovations such as Building Information Modeling (H-BIM) and 3D classification for architectural heritage, whereas contributions from the Middle East and Africa emphasize the role of AI in managing heritage under conditions of conflict and environmental stress. Additionally, emerging research on underwater heritage preservation (Ababneh, 2024) broadens the scope to encompass unique thematic domains. By analyzing these diverse cases, the review aims to illuminate the varied ways in which AI is shaping cultural heritage preservation globally, while offering insights into the localized adaptations and cultural sensitivities that underpin successful implementation.

Through this integrative approach, the review not only synthesizes technological developments but also contributes to a more holistic understanding of how AI can be ethically and effectively leveraged in heritage preservation. By bridging disciplinary boundaries and incorporating perspectives from conservation science, cultural studies, ethics, and technology, this study aspires to advance scholarly and practical debates on the future of cultural heritage in the digital age.

METHOD

The methodological framework for this narrative review was designed to ensure a comprehensive and critical synthesis of literature concerning the applications of Artificial Intelligence (AI) in cultural heritage preservation. Given the interdisciplinary nature of the topic, encompassing fields such as computer science, archaeology, cultural studies, and conservation science, the methodology involved systematic approaches to literature identification, selection, and evaluation. Emphasis was placed on gathering empirical studies, case analyses, and reviews that directly address the intersection of AI and cultural heritage, thereby ensuring both depth and breadth of coverage across global contexts.

The literature collection process relied on three principal academic databases: Scopus, Web of Science, and Google Scholar. Scopus and Web of Science were prioritized due to their rigorous indexing systems, extensive coverage of peer-reviewed journals, and capabilities for citation analysis and trend mapping (Themistocleous & Abate, 2024; Pansoni et al., 2023). These platforms provided a robust foundation for tracing scholarly contributions and identifying influential works. Google Scholar was employed to complement these databases, particularly in capturing grey literature, conference proceedings, and interdisciplinary studies that might not be comprehensively indexed in Scopus or Web of Science (Croce et al., 2021). Together, these databases allowed for a balanced corpus that integrates established academic sources with emerging research outputs.

Search strategies were carefully structured to optimize both specificity and comprehensiveness. Keywords were selected based on preliminary scoping of the field and previous bibliometric analyses. Terms such as "Artificial Intelligence," "cultural heritage preservation," "digital archiving," "photogrammetry," "machine learning," and "digital twin" were frequently employed. Boolean operators were used to refine searches and enhance the precision of results. For example, queries such as ("Artificial Intelligence" AND "cultural heritage" AND ("digital preservation" OR "archival technologies")) were designed to capture articles that not only reference AI but explicitly link it to heritage preservation (Harisanty et al., 2024). This approach minimized the retrieval of irrelevant materials and ensured that studies addressing both technological innovation and cultural context were included.

To maintain the relevance and rigor of the review, specific inclusion and exclusion criteria were established. Inclusion criteria focused on studies published within the last ten years, recognizing the rapid evolution of AI technologies and their growing role in cultural heritage contexts (Ababneh, 2024; Nag, 2024). Eligible studies included empirical research, case studies, and review articles that examined AI applications in the preservation, documentation, or interpretation of tangible and intangible heritage. Articles published in English were prioritized to ensure consistency of analysis and accessibility of sources. Exclusion criteria eliminated studies that addressed preservation methods without any connection to AI, works that exclusively discussed digital technologies unrelated to heritage, or papers lacking sufficient methodological transparency (Brutto et al., 2018; Laohaviraphap & Waroonkun, 2024). This deliberate narrowing of scope allowed the review to remain focused while retaining sufficient diversity in the selected literature.

The types of research included in the review encompassed a wide array of methodological designs. Empirical studies, particularly those involving AI-driven restoration, monitoring, or risk assessment of cultural assets, provided critical insights into the practical implementation of technologies. Case studies highlighted localized practices, such as the use of AI to preserve traditional crafts, music, or architecture, offering context-specific applications that reflect cultural sensitivities (Farella et al., 2024; Chen et al., 2024). Systematic reviews and bibliometric analyses contributed broader perspectives on global trends, identifying areas of concentration and gaps in research productivity (Harisanty et al., 2024). By incorporating this diverse range of study types, the review ensured that both micro-level case evidence and macro-level analytical findings informed the synthesis.

The literature selection process unfolded through multiple stages of screening and evaluation. Initially, search queries across the three databases generated a wide pool of articles. Titles and abstracts were then screened to eliminate studies outside the defined scope. This first-level screening significantly reduced the dataset by excluding works that referenced AI or heritage superficially without substantive focus on preservation. The second-level screening involved full-text reviews to assess methodological quality, relevance to the review objectives, and empirical or theoretical contributions. Articles that met these criteria were retained for in-depth analysis, while those lacking clarity, rigor, or contextual specificity were excluded. This multi-tiered approach facilitated a curated dataset of high-quality studies suitable for synthesis.

Evaluation of the selected literature involved both qualitative and contextual analysis. Each article was examined for its contribution to understanding the role of AI in heritage preservation, with attention paid to methodological rigor, clarity of findings, and contextual applicability. Studies were analyzed in terms of the technologies applied—such as computer vision, deep learning, or generative models—as well as the heritage contexts they addressed, ranging from built environments and artifacts to intangible practices like music and oral traditions. Geographic diversity was also considered during the evaluation process. For example, European studies frequently concentrated on architectural heritage and Building Information Modeling (BIM), while Asian research emphasized the application of AI in traditional arts and cultural practices (Zhao et al., 2020; Farella et al., 2024). Indigenous-centered research introduced perspectives on ethical considerations and the ownership of digital heritage data (Ghaith & Hutson, 2024; Hannaford et al., 2024). This multidimensional analysis ensured that the synthesis reflects the richness and diversity of global contributions.

The methodological rigor of this review also required attention to potential biases and limitations. Given the reliance on English-language publications, certain regional contributions, particularly those from non-English-speaking contexts, may have been underrepresented. Similarly, the rapid pace of technological innovation means that some emerging applications of AI may not yet be fully documented in peer-reviewed sources. Nevertheless, the combination of Scopus, Web of Science, and Google Scholar searches, coupled with well-defined criteria, provided a sufficiently robust foundation to capture the state of the field as of the review's timeframe. Furthermore, by including grey literature and conference proceedings where relevant, the review sought to mitigate potential publication bias and integrate diverse scholarly voices.

Ultimately, the methodological design of this study ensures that the synthesis presented in subsequent sections is both comprehensive and critically grounded. By systematically sourcing, screening, and evaluating literature from multiple databases, applying precise search strategies, and maintaining clear inclusion and exclusion criteria, the review constructs a reliable and nuanced foundation for analyzing the intersections of AI and cultural heritage preservation. This methodological approach not only guarantees academic rigor but also supports the broader aim of providing an integrative narrative that situates technological advancements within cultural, ethical, and geographical contexts. In doing so, it ensures that the findings are both globally relevant and sensitive to the localized realities of heritage conservation practices.

RESULT AND DISCUSSION

Tangible Heritage Conservation

The application of Artificial Intelligence in tangible cultural heritage conservation has been particularly prominent in the domains of artifact restoration, structural monitoring, and the digital reconstruction of deteriorated sites. Empirical studies illustrate that machine learning algorithms can analyze high-resolution images of paintings to identify damages such as cracks, fading, and discoloration. Khalid et al. (2024) reported that AI-based classification methods achieved significant accuracy in detecting deterioration patterns, providing valuable data for conservation experts. Such advances complement manual inspection methods by automating the detection process, thereby reducing human error and improving efficiency.

Photogrammetry integrated with AI further enhances the conservation of built heritage. Themistocleous and Abate (2024) demonstrated that photogrammetric techniques combined with computational models enable the creation of highly detailed three-dimensional reconstructions of architectural features. These reconstructions not only facilitate documentation but also provide precise blueprints for restoration efforts. In China, Zhang (2024) applied AI-driven LoRA and Stable Diffusion techniques to restore Yangshao pottery. The study highlighted the significant improvement in restoration quality, with AI enabling the reconstruction of patterns and details otherwise difficult to recover through traditional methods.

Comparative analyses underscore regional variations in AI's effectiveness. For example, Zhang (2024) noted that the tailored use of AI in China's Yangshao pottery restoration yielded highly successful outcomes, whereas European initiatives focusing on Building Information Modeling (BIM) demonstrated more varied results. Croce et al. (2021) observed that BIM applications in European heritage projects faced challenges due to disparities in infrastructure and resources. This suggests that while AI technologies possess broad applicability, their success rates depend heavily on contextual factors, including available technical infrastructure, funding, and the cultural specificity of conservation practices (Pansoni et al., 2023). Thus, tangible heritage conservation outcomes highlight both the promise and the contextual dependency of AI implementation.

Intangible Heritage Preservation

The preservation of intangible cultural heritage (ICH), encompassing practices such as oral traditions, performance arts, and traditional crafts, has increasingly benefited from generative AI and immersive technologies. Dai et al. (2024) demonstrated how generative AI has been successfully employed to digitally replicate Chinese paper-cutting art, thereby enhancing the dissemination and understanding of this cultural form. Such innovations ensure that intangible traditions, which are often vulnerable to generational decline, are documented and revitalized through digital platforms.

In addition, immersive technologies such as virtual reality (VR) and augmented reality (AR) offer transformative tools for preserving and promoting intangible heritage. Du (2024) highlighted how VR installations have been used to recreate traditional performance arts, allowing users to experience cultural narratives in interactive formats. These experiences enhance user engagement by providing a multisensory understanding of cultural practices. Turner-Jones et al. (2024) provided a notable example with the "Digitizing the Deep Past" project, which employed machine

learning to classify Indigenous rock art while simultaneously engaging Indigenous youth in educational programs. This participatory model illustrates how AI can foster intergenerational knowledge transfer while promoting inclusivity.

Furthermore, the use of AI-powered interactive archives has enhanced community engagement with intangible heritage. Ghaith and Hutson (2024) noted that such tools allow users to interact with digital representations of cultural traditions, thereby deepening public involvement and fostering cultural continuity. These efforts illustrate a paradigm shift from preservation as mere documentation toward preservation as a dynamic, participatory process that strengthens cultural identity and accessibility across global contexts.

Environmental Monitoring and Risk Management

AI's integration with the Internet of Things (IoT) has been pivotal in monitoring and managing environmental threats to heritage sites. Laohaviraphap and Waroonkun (2024) conducted a systematic review of 92 studies and found that AI-IoT systems significantly enhance conservation efforts by providing real-time monitoring of structural and environmental conditions. These systems track factors such as air quality, temperature, and humidity, which are critical determinants of heritage site integrity. Predictive analytics derived from AI enable proactive responses to risks, allowing heritage managers to mitigate damage before it occurs.

Similarly, Greco et al. (2024) emphasized the value of combining IoT sensors with machine learning algorithms to interpret climatic data for preservation purposes. This integration has proven particularly useful in sites vulnerable to rapid environmental fluctuations, such as those exposed to rising sea levels and increased flooding. The proactive capacity of AI-IoT systems represents a significant advancement over traditional methods, which often rely on retrospective assessments and reactive interventions.

Heritage Building Information Modeling (H-BIM) and Digital Twin (DT) frameworks further exemplify the capacity of AI to facilitate predictive maintenance. Croce et al. (2021) demonstrated how H-BIM provides detailed three-dimensional digital representations of heritage buildings, enabling continuous monitoring and long-term conservation planning. Khalid et al. (2024) similarly reported that H-BIM facilitates the integration of environmental data with maintenance schedules, producing more effective preservation strategies. Digital Twin technologies add a dynamic dimension by creating real-time replicas of heritage assets that simulate deterioration patterns under different environmental scenarios. Marchello et al. (2023) showed that these simulations empower heritage managers to develop tailored preservation plans, ensuring sustainable management of cultural heritage in diverse contexts.

Museums, Archives, and Public Engagement

AI has also revolutionized the way museums and archives interact with the public by enhancing accessibility and inclusivity. Hannaford et al. (2024) described the "Our Heritage, Our Stories" project, which employs AI to connect community-generated digital content with national archives. This initiative not only expands access to cultural collections but also ensures that marginalized voices are represented within heritage narratives. Such approaches highlight AI's potential to democratize cultural heritage by integrating diverse perspectives into formal archival systems.

In parallel, advancements in digital archive searchability have improved user experiences. Yi et al. (2024) demonstrated how AI algorithms enhanced the retrieval and presentation of digitized cultural documents, enabling broader engagement with historical materials. This functionality underscores AI's role in bridging the gap between heritage institutions and public audiences, making cultural heritage more discoverable and meaningful.

Community-generated digital content (CGDC) projects further reinforce the inclusive potential of AI-driven preservation. Turner-Jones et al. (2024) highlighted efforts to digitize Indigenous heritage with AI-powered participatory platforms, which empowered communities to document and preserve their narratives. Such projects ensure that heritage preservation is not a top-down process but rather a collaborative endeavor that respects cultural ownership and fosters inclusivity. By leveraging AI's data-processing capabilities, these initiatives enrich global heritage archives with underrepresented cultural perspectives while reinforcing community agency.

In summary, results across the four thematic areas demonstrate the transformative role of AI in cultural heritage preservation. Tangible heritage conservation has benefited from AI's capacity to restore artifacts and reconstruct architectural features, while intangible heritage preservation has been revitalized through generative and immersive technologies. Environmental monitoring has advanced significantly with AI-IoT integration, predictive analytics, and the use of H-BIM and DT frameworks. Finally, museums and archives have become more accessible and inclusive through AI-enabled virtual museums and participatory digital projects. Despite contextual differences in implementation, the collective findings underscore AI's potential to reshape cultural heritage preservation practices globally while highlighting the importance of tailoring technologies to local conditions, ethical considerations, and community involvement.

Influence of Systemic Factors on AI Adoption in Heritage Preservation

The adoption of AI technologies in heritage preservation is deeply influenced by systemic factors such as policy frameworks, funding mechanisms, and governance structures. International policy agendas, such as the UNESCO 2030 Agenda for Sustainable Development, underscore the importance of leveraging technological innovation for the safeguarding of cultural heritage (Pansoni et al., 2023). Yet, while these policies establish ambitious goals, their translation into practice often encounters substantial challenges, particularly in developing regions where financial constraints limit access to advanced technologies. Khalid et al. (2024) emphasize that although AI tools such as Heritage Building Information Modeling (H-BIM) and Digital Twin (DT) offer substantial potential for predictive maintenance and risk management, their adoption has been hindered by a lack of sustained funding and limited institutional support. This discrepancy between policy aspirations and ground-level realities highlights the structural inequities that shape technology adoption in heritage contexts.

Governance also plays a decisive role in shaping the extent to which AI technologies are successfully integrated into heritage management. Effective governance models promote collaboration among governmental agencies, heritage institutions, and local communities, creating frameworks for resource sharing and the diffusion of expertise (Ghaith & Hutson, 2024). By contrast, fragmented governance structures often lead to disjointed initiatives, where isolated

projects fail to build upon one another or to incorporate local knowledge in meaningful ways. Croce et al. (2021) observe that this fragmentation can result in the duplication of efforts, wasted resources, and ultimately diminished effectiveness of AI-based preservation strategies. These findings suggest that systemic factors do not merely influence the technical feasibility of AI adoption but also determine the inclusivity and sustainability of conservation initiatives.

Ethical and Cultural Sensitivity Challenges in AI Applications

Beyond systemic barriers, the integration of AI into heritage preservation raises profound ethical and cultural sensitivity concerns. A recurring theme in the literature is the risk of misrepresenting or commodifying cultural narratives through AI-driven projects. Greco et al. (2024) caution that if cultural heritage is treated merely as data to be processed, it risks losing its symbolic and social value, particularly for Indigenous and marginalized communities. Misrepresentation may occur when AI algorithms trained on limited datasets fail to capture the nuances of cultural expressions, resulting in homogenized or distorted digital outputs.

Community involvement emerges as a crucial factor in mitigating such risks. Pansoni et al. (2023) argue for the establishment of ethical frameworks that prioritize authenticity and cultural integrity in AI applications. This involves ensuring that restoration processes respect historical accuracy while also reflecting the perspectives of the communities whose heritage is being preserved. Projects such as "Our Heritage, Our Stories" (Hannaford et al., 2024) provide models of how collaborative methodologies can ensure marginalized voices are not only included but prioritized in digital archiving initiatives. These projects underscore the necessity of shifting from top-down preservation models to participatory approaches that empower communities to shape the ways in which their heritage is represented.

The literature also highlights the importance of establishing clear ethical guidelines and standards of practice for AI implementation in heritage contexts. Ababneh (2024) and Harisanty et al. (2024) emphasize the need for protocols that address issues of data privacy, informed consent, and the safeguarding of cultural expressions. Without such standards, there is a danger that AI applications may inadvertently exacerbate cultural inequities, undermining rather than supporting preservation objectives. This underscores the importance of fostering ongoing dialogue among technologists, cultural experts, policymakers, and local communities to ensure that AI serves as a tool for empowerment rather than exploitation.

Proposed Solutions and Innovations to Overcome Barriers

To address the multifaceted challenges associated with AI adoption in heritage preservation, scholars propose a range of solutions that combine technological innovation, policy reform, and community engagement. On the technological front, advancements in AI algorithms are expanding the capacity for real-time monitoring and predictive maintenance. Applications of H-BIM and Digital Twin technologies illustrate how AI can be employed to continuously assess structural integrity and forecast potential deterioration, thereby enabling proactive conservation strategies (Khalid et al., 2024; Farella et al., 2024). These tools not only enhance technical efficiency but also reduce long-term conservation costs by minimizing reactive interventions.

At the policy level, increasing access to funding and creating incentives for AI adoption remain central to overcoming structural barriers. Zhang (2024) highlights the potential of crowdfunding

models and public-private partnerships to mobilize resources for heritage projects that might otherwise lack sufficient institutional support. Such approaches demonstrate how diversified funding mechanisms can bridge the resource gap, particularly in regions where governmental investment in cultural preservation is limited. Furthermore, international collaborations facilitated through policy frameworks can support knowledge exchange and capacity building, ensuring that less-resourced regions are not excluded from the benefits of technological innovation.

Community-driven initiatives represent another promising avenue for overcoming barriers to AI adoption. Hannaford et al. (2024) document how participatory digitization projects can foster a sense of ownership among local communities, encouraging them to engage actively in preservation efforts. These initiatives align with the principles of citizen science, wherein public participation not only enriches datasets but also strengthens the social legitimacy of preservation practices. By integrating local knowledge and community priorities into AI projects, these initiatives counteract the risk of cultural misrepresentation and reinforce the social value of heritage preservation.

Interdisciplinary collaboration also emerges as a key strategy in overcoming barriers. By integrating AI technologies with traditional conservation knowledge, researchers and practitioners can develop hybrid approaches that balance innovation with cultural sensitivity. Pansoni et al. (2023) and Brutto et al. (2018) highlight how such interdisciplinary frameworks can generate innovative solutions that are both technically effective and culturally resonant. For instance, combining machine learning tools with Indigenous knowledge systems not only enhances the accuracy of AI models but also ensures that technological interventions respect and reflect the cultural contexts they seek to preserve.

Limitations of Current Research and Directions for Future Study

Despite the progress documented in recent literature, significant limitations remain in the research on AI and cultural heritage preservation. One notable limitation is the predominance of case studies focused on specific regions or technologies, which, while valuable, do not always provide a comprehensive picture of global trends. Laohaviraphap and Waroonkun (2024) note that many studies emphasize technical applications without adequately considering how these tools interact with governance structures, community dynamics, or ethical frameworks. This lack of integrative analysis limits the ability to generalize findings across contexts.

Another limitation concerns the scarcity of longitudinal research assessing the long-term impacts of AI applications in heritage preservation. While short-term outcomes, such as improved restoration accuracy or enhanced public engagement, are well-documented, less is known about the sustainability of these interventions over time. As Münster et al. (2024) and Greco et al. (2024) suggest, the absence of longitudinal evaluations makes it difficult to assess whether AI-driven projects deliver enduring benefits or whether they require continuous technological updates that may strain institutional capacities.

Furthermore, the literature often highlights technological success without adequately addressing the sociocultural dimensions of adoption. Studies such as those by Turner-Jones et al. (2024) demonstrate the importance of participatory approaches, yet many technological evaluations neglect to incorporate community perspectives or to analyze how AI projects affect cultural identity and continuity. This gap underscores the need for future research that foregrounds the

lived experiences of communities and explores how AI interventions shape cultural practices and values.

Future research directions should therefore include broader comparative analyses across diverse geographic regions, with attention to variations in policy environments, resource availability, and cultural contexts. Additionally, interdisciplinary approaches that integrate conservation science, ethics, anthropology, and computer science will be essential in developing holistic frameworks for AI adoption. Expanding research on ethical guidelines and establishing standardized protocols for data management, community consent, and cultural representation also represent critical areas for future exploration. By addressing these gaps, future scholarship can build a more comprehensive understanding of how AI can be effectively, ethically, and sustainably integrated into cultural heritage preservation.

CONCLUSION

This review highlights the transformative role of Artificial Intelligence and digital technologies in the preservation of cultural heritage, encompassing both tangible and intangible forms. Evidence demonstrates that AI enables significant advancements in artifact restoration, architectural modeling, and the monitoring of heritage sites through technologies such as photogrammetry, Heritage Building Information Modeling, and Digital Twin frameworks. Equally, intangible heritage benefits from generative AI and immersive tools that revitalize oral traditions, music, and performance arts while promoting inclusive participation. Nevertheless, systemic barriers—including limited funding, uneven policy implementation, and fragmented governance—continue to constrain adoption. Ethical concerns related to cultural representation, data privacy, and the marginalization of Indigenous voices remain pressing challenges. To address these barriers, multi-pronged strategies are required, combining technological innovation with policy support, inclusive governance, and community-driven initiatives. Future research should pursue longitudinal studies assessing the long-term impacts of AI on heritage, while also expanding comparative analyses across diverse cultural and geographic contexts. Developing standardized ethical frameworks and integrating traditional knowledge systems will further ensure that AI-driven preservation efforts remain both effective and culturally sensitive. Ultimately, AI's integration into heritage conservation represents an urgent priority, offering tools to safeguard cultural legacies while demanding sustained efforts to address ethical and systemic challenges.

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