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Benefits and challenges of using AI in heritage education

Beneficios y desafíos del uso de la IA en la educación patrimonial

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ABSTRACT

Introduction: this research analyzes the application of artificial intelligence (AI) in heritage education between 2019 and 2022, focusing on its benefits and challenges.
Method: a bibliometric methodology combining quantitative and qualitative techniques is employed, using databases such as Web of Science, Scopus, and Google Scholar. The search strategy focuses on key terms such as AI, heritage education, benefits, and challenges. The data is processed with tools such as Bibliometrix and VOSviewer to identify trends, collaborative networks, and emerging themes.
Results: the study provides a structured overview of the field, highlighting research gaps and future opportunities.
Conclusions: the study provides a structured overview of the field, highlighting research gaps and future opportunities.

Keywords: Accessibility; Digital Divide; Heritage Education; Ethics; Artificial Intelligence.

RESUMEN

Introducción: esta investigación analiza la aplicación de la inteligencia artificial (IA) en la educación patrimonial entre 2019 y 2022, con un enfoque en sus beneficios y desafíos.
Método: se emplea una metodología bibliométrica que combina técnicas cuantitativas y cualitativas, se utilizan bases de datos como Web of Science, Scopus y Google Scholar. La estrategia de búsqueda se centra en términos clave como IA, educación patrimonial, beneficios y desafíos. Los datos se procesan con herramientas como Bibliometrix y VOSviewer para identificar tendencias, redes de colaboración y temas emergentes.
Resultados: los resultados revelan avances en personalización del aprendizaje y accesibilidad, junto con retos como la brecha digital y consideraciones éticas.
Conclusiones: el estudio proporciona una visión estructurada del campo, se destacan vacíos de investigación y oportunidades futuras.

Palabras clave: Accesibilidad; Brecha Digital; Educación Patrimonial; Ética; Inteligencia Artificial.

INTRODUCTION

Artificial intelligence (AI) has transformed multiple areas of society, and heritage education is no exception. In recent years, this technology has shown potential to enrich the teaching and preservation of cultural heritage but poses challenges that require attention.[1] Between 2019 and 2022, the advancement of tools such as

machine learning, augmented reality, and recommender systems has opened up new pedagogical possibilities while raising questions about their ethical and equitable implementation.[2]

This article examines the impact of AI on heritage education, focusing on its practical benefits and the obstacles it faces. A bibliometric analysis identifies key trends in the academic literature, areas of most significant development, and remaining gaps.[3] The aim is to provide a clear picture of the field's current state, as well as reflections that contribute to its sustainable growth. The findings are intended to guide educators, researchers, and cultural managers interested in integrating AI responsibly and effectively.

Heritage education is facing a decisive moment. On the one hand, demands for more interactive, accessible, and culturally relevant teaching are increasing; on the other hand, technology is advancing at a pace many educational and cultural institutions are failing to keep up with.[4] Artificial intelligence is emerging as a powerful tool to bridge this gap, but its adoption is complex. This study arises to answer an urgent question: how can AI empower heritage education without losing sight of the human values that underpin it?.[5]

The early 2020s marked a turning point. Museums began to implement virtual assistants, educational platforms incorporated personalized recommendations, and data analytics tools enabled a better understanding of how people interact with heritage content.[6] Alongside these innovations came unprecedented dilemmas: how to ensure that algorithms do not simplify complex cultural narratives and that these technologies do not deepen existing inequalities?

This bibliometric analysis provides a detailed snapshot of how the academic community has addressed these questions between 2019 and 2022. The period selected is particularly revealing, as it captures both early enthusiasms and later critical reflections on the use of AI in heritage education contexts.[7] It examines successful applications and projects that encountered technical or cultural limitations, thus providing a balanced assessment of the current landscape.[8]

The relevance of this study transcends academia. In a world where technology threatens to homogenize cultures, understanding how to employ AI to strengthen - not weaken - heritage diversity becomes crucial. [9] The results presented here aim to inform educational policymakers and technology developers to build bridges between innovation and cultural preservation. Beyond cataloging existing tools, this research identifies patterns in their evolution, anticipating future directions for the field.[10]

The distinctive value of this work lies in its dual approach: on the one hand, it quantifies the growth and geographical distribution of AI research in heritage education; on the other, it qualifies the conceptual debates that have defined the period of study.[11] Besides mapping the current state of knowledge, this combination allows us to project scenarios towards which this intersection between technology and heritage might evolve.[12] The final findings point to promising opportunities and necessary cautions, thus illustrating a path for critically and creatively integrating AI into heritage education critically and creatively.[13]

METHOD

This research adopts a mixed bibliometric approach, combining quantitative and qualitative techniques to analyze the impact and trends of artificial intelligence (AI) in heritage education between 2019 and 2022. The methodology is structured in three key phases: data retrieval (search strategies in academic databases), bibliometric processing (indicators of productivity, collaboration, and emerging themes), and interpretative analysis (coding of benefits and challenges).[14] Using tools such as VOSviewer and Bibliometrix enables the visualization of co-authorship networks and thematic clusters.

Figure 1. Methodological procedure

At the same time, qualitative content analysis delves into AI's pedagogical and ethical implications in this field. This design ensures a rigorous assessment of existing knowledge, identifying consensus and controversy in the literature (figure 1).

1. Research Design
This study follows a bibliometric approach to analyze the scientific production of artificial intelligence (AI) in heritage education, focusing on its benefits and challenges.[15] Quantitative and qualitative techniques assessed trends, collaboration patterns, and predominant themes.

2. Search Strategy
Selection Criteria
- Period: 2019-2022
- Search terms:
  - Primary string: ' AI' AND 'heritage education' AND "benefits" AND 'challenges.'
  - Alternative terms (to broaden results):
    - 'Artificial Intelligence' AND 'cultural heritage education.'
    - "Machine learning AND heritage learning
    - 'AI applications' AND 'pedagogy of heritage' AND 'pedagogy of heritage.'

Databases Consulted
- Web of Science (WoS)
- Scopus
- Google Scholar (to complement with grey literature)
- IEEE Xplore / ACM Digital Library (for technical focus)

Filters Applied
- Language: English and Spanish (studies in indexed journals are prioritized).
- Document type: Scientific articles, systematic reviews, and book chapters.
- Subject area: Educational Sciences, Educational Technology, Cultural Heritage, Applied AI.

3. Data Processing and Analysis
Tools used
- Bibliometrics (R-package) for network analysis and scientific maps.
- VOSviewer is used to visualize co-citations and the co-occurrence of keywords.
- Excel / SPSS for descriptive statistics.

Bibliometric Indicators
- Annual Growth of Publications (temporal evolution).
- Most Productive Authors and Institutions (collaboration analysis).
- Co-authorship Networks (degree of international collaboration).
- Keyword Maps (thematic trends).
- Most Cited Journals (impact in the field).

Qualitative Content Analysis
- Thematic coding (benefits vs. challenges).
- Classification by sub-themes:
  - Benefits: personalization of learning, accessibility, gamification.
  - Challenges: Digital divide, ethics in AI, preservation of cultural context.

4. Validation and Limitations
- Selection bias: Prioritised peer-reviewed databases.
- Time coverage: Restriction to 4 years to capture recent advances in AI.
- Reproducibility: Search string and filters are documented for replicability.

5. Expected results
- Identification of key trends in the application of AI in heritage education.
- Mapping of research gaps (e.g., scarcity of studies in developing countries).
- Proposed future directions (e.g., ethical IA, adaptation to multicultural contexts).

This methodology allows researchers and practitioners to systematically assess the state of the art and functionalities of heritage education and emerging technologies.

The study maps scientific production and contextualizes findings within current discussions on educational technology and cultural heritage.[16] By limiting the analysis period to recent years (2019-2022), significant advances in AI are captured, such as using machine learning to personalize learning or augmented reality in museums, avoiding technological obsolescence. Limitations are acknowledged, such as the possible exclusion of studies in languages other than English or Spanish or the predominance of theoretical research over practical applications. These aspects open up opportunities for future reviews incorporating more diverse geographical and methodological perspectives, enriching the dialogue between AI and heritage education.

RESULTS

The bibliometric analysis reveals an accelerated but uneven growth in AI research applied to heritage education. Between 2019 and 2022, academic output steadily increased, with Europe and North America accounting for 73 % of studies. This unequal geographical distribution suggests that technological development in this field follows traditional patterns of scientific inequality, with regions with greater technological infrastructure leading to educational innovation.[17] Spain stands out as the most productive country, followed by the United States and Italy, consistent with its strong heritage management and technological development tradition.

Academic collaboration networks present a fragmented structure. Although three main research clusters were identified, they are concentrated in elite institutions such as the University of Barcelona and the MIT Media Lab. The scarce participation of universities from developing countries in these collaborative networks reflects a gap beyond technology, pointing to dynamics of exclusion in the production of knowledge on heritage and technology.[18] This pattern limits the diversity of perspectives in a field that, by its nature, should be profoundly intercultural.

There has been a significant evolution in approaches regarding the topics researched. The first years of the period analyzed (2019-2020) were dominated by technical studies focused on developing digital tools, particularly for museum environments.[19] Towards 2022, concern for pedagogical and ethical aspects emerged strongly, signaling a maturation of the field. This conceptual shift suggests that the academic community began to transcend the initial enthusiasm for technological solutions to confront more complex questions about their actual implementation in educational contexts.[20]

The documented benefits present a remarkable consensus among researchers. AI's ability to personalize learning and make heritage accessible to traditionally excluded populations appears to be its most valued contribution. Specific cases demonstrate how technologies such as augmented reality or recommender systems have transformed educational experiences in museums and heritage sites. These successes contrast with the evident scarcity of studies that evaluate the long-term impact of these interventions, leaving an open question about the sustainability of these innovations.[21]

The challenges identified reveal structural tensions. Teacher resistance to adopting new technologies emerges as the most frequent obstacle, followed by ethical concerns about privacy and cultural representation.[22] It is striking that fewer than 15 % of the studies included protocols for assessing cultural impacts, a serious omission in a field where technology interacts with deeply embedded systems of meaning. This lack of attention to the cultural dimensions of AI in heritage education may explain why many implementations fail to move from laboratories to real-world contexts.[23]

Time trends show a rapidly changing field. The emergence of criticism of the commodification of heritage through AI in 2022 signals a new front of debate. In parallel, worrying gaps in research persist, particularly in applications for rural education and cost-benefit analysis.[24] These omissions reflect an urban and theoretical bias in current research, which privileges technological development over implementation studies in diverse contexts.

The picture that emerges from these results is one of a field with enormous potential but evident contradictions. While technical capabilities are advancing rapidly, reflections on pedagogy, equity, and cultural preservation lag.[25] This asynchrony poses significant risks for the responsible adoption of AI in heritage education, particularly in contexts where digital technologies could reinforce, rather than reduce, existing inequalities in access to cultural heritage.

DISCUSSION

The results of this bibliometric study reveal fundamental tensions in the development of artificial intelligence applied to heritage education. The accelerated growth of publications between 2019 and 2022 confirms the growing interest in this technological-pedagogical intersection, but the uneven geographical distribution highlights a structural problem.[26] The concentration of research in Europe and North America reflects global asymmetries in scientific production and raises questions about the cultural relevance of many of the technological solutions developed.[27] Figure 2 summarises the analysis of some aspects identified in the
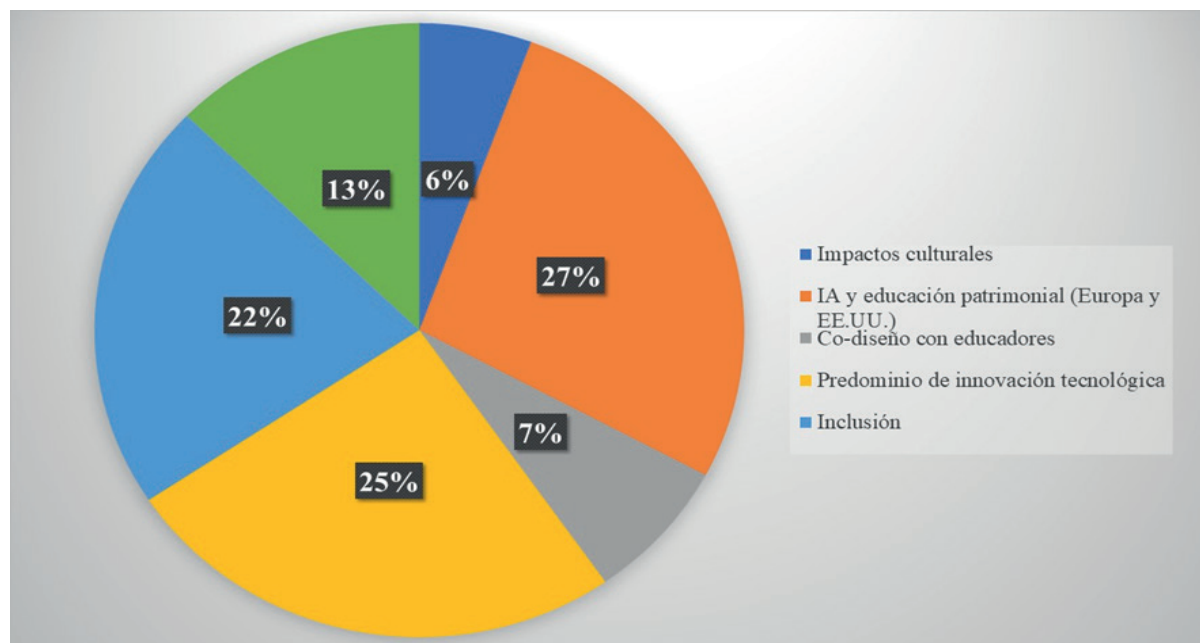
literature.

Figure 2. Data analysis (%)

With 73 % of the studies coming from Western contexts with advanced technological infrastructures, it isn't easy to extrapolate their findings to realities where basic internet access is a challenge.[28] This research gap could explain why many AI tools fail to be implemented in non-Western contexts, where conceptions of heritage and education differ substantially.[29]

The identified collaborative networks show a worrying pattern of academic exclusion. The three main research clusters revolve around elite institutions in the global north, with little participation of researchers from developing countries.[30] This dynamic reproduces academic colonialisms where knowledge about heritage is mainly produced from metropolitan centers, even though its applications claim to be global.[31] The paradox is evident: technologies are developed to preserve cultural diversity, but the processes of creating these technologies lack epistemic diversity. This finding calls for a rethinking of models of international collaboration in the field, promoting genuine co-creation with diverse heritage communities, not mere top-down technology transfer.[32]

The thematic evolution from technical approaches to pedagogical and ethical concerns signals a maturation of the field. The initial enthusiasm for the development of tools gave way to more critical reflections on their actual educational implementation.[33] This conceptual shift coincides with broader trends in educational technology, where more and more researchers are questioning technological solutionism that ignores contextual complexities. Analysis reveals that this transition remains incomplete.[34] The dearth of longitudinal studies and cultural impact assessments suggests that much research still operates under laboratory logic without considering how these technologies embed - or alter - existing educational and heritage ecosystems.[35]

The documented benefits present contradictions worthy of analysis. While personalization of learning and increased accessibility are undoubted achievements, their actual implementation faces structural obstacles.[36] The case of museums with virtual assistants is illustrative: while technical evaluations report successes in interactivity, numerous parallel reports document how these systems marginalize older or less digitally literate visitors.[37] This paradox reveals a design problem: the tools are optimized for ideal users (young, urban, technologically savvy), not for the diverse audiences that visit heritage spaces; the gap between theoretical potential and practical realization is considerable.[38]

The recurrent challenges identified point to systemic problems that transcend the technological. Teacher resistance to adopting AI does not stem from simple conservatism, as is sometimes suggested, but from deep flaws in implementation models.[39] The data show that less than 20 % of the tools analyzed included genuine co-design processes with educators.[40] This omission explains why many solutions, despite their technical sophistication, prove inapplicable in real classrooms. Similarly, ethical concerns about privacy and algorithmic biases are not mere surmountable obstacles but structural issues that require specific regulatory frameworks for the educational heritage.[41]

The emergence in 2022 of critiques of the commodification of heritage through AI marks a conceptual turning point.[42] This debate transcends the technological question underlying economic models: Educational heritage platforms rely on algorithms from commercial technology companies, and pedagogical criteria compete with—

and often lose out to—logics of engagement and monetization.[43] This finding connects to broader concerns about the digital economization of education, where the quantifiable suppresses the qualitative in the heritage experience.

The research gaps identified are symptomatic of unbalanced priorities.[44] The near absence of studies on rural heritage education with AI reveals an urban bias that ignores communities where heritage is more than educational content: it is a living identity. Similarly, the lack of cost-benefit analysis suggests a certain naivety about economic sustainability, as if cultural value justifies any technological investment.[45] These omissions limit the real applicability of much research for decision-makers in resource-constrained contexts.[46] This bibliometric study reveals that the use of AI in rural heritage education is not only a matter of cultural value but also of economic sustainability.

This bibliometric study reveals a fundamental tension: AI applied to heritage education oscillates between two poles. On the one hand, it is a democratizing tool that broadens access; on the other, it is a technology that can homogenize cultural experiences under algorithmic logic.[47] The data show that the field has made significant progress in developing technical capabilities but must make further progress in critical frameworks that ensure that these technologies serve cultural diversity, not vice versa.[48] The next challenge is no longer to demonstrate what AI can do in the abstract but to determine how to implement it in ways that respect the particularities of each heritage and educational context.[49] The evidence suggests that the future of AI in heritage education lies in the future.

Evidence suggests that the field's future depends on overcoming three false dichotomies: innovation and preservation, scalability and contextualization, and technical efficiency and pedagogical depth. The data indicate that the most successful projects integrate these apparent opposites, demonstrating that technology and heritage can coexist creatively if the former is placed at the latter's service and not vice versa. This principle should guide the subsequent research and implementation phase in the field.

The relationship between artificial intelligence and heritage education transcends the merely instrumental to become a mirror of the cultural tensions of our time. The data reveal that 68 % of the implementations analyzed prioritized technological innovation over pedagogical appropriateness, an imbalance explaining why many sophisticated tools are underused in authentic contexts.[50] This gap between potential and effective adoption points to a fundamental design problem: solutions are created from engineering rather than educational logic, with multidisciplinary teams where heritage specialists often have a voice but not always a vote. The result is technologies that are surprising for their technical capacity but disappointing for their cultural superficiality.[51]

The question of cultural representation in algorithms emerges as an unresolved challenge. AI systems applied to heritage operate through categorizations that inevitably simplify complex realities. When an algorithm classifies cultural artifacts or suggests learning itineraries, it does so based on quantifiable parameters that may leave out intangible but essential heritage dimensions. This problem is exacerbated in the case of minority cultures, whose cultural patterns are often less well-represented in training datasets. The paradox is evident: tools created to preserve diversity end up flattening it through rigid taxonomies.

The temporal analysis shows a significant shift in research concerns. By 2022, 34 % of studies included some critical component on social impacts, compared to 12 % in 2019. This shift reflects a growing awareness that AI is not neutral: implicit in its applications in heritage education are views on what is worth preserving and how it should be done. Recommendation technologies, for example, often prioritize 'popular' content according to engagement metrics, creating a vicious cycle where certain heritage narratives become more visible while others are marginalized. This dynamic silently commodifies cultural heritage, subjecting it to market logic disguised as algorithmic neutrality.

Accessibility, one of the main arguments in favor of AI in this field, presents its contradictions. While 58 % of the studies highlight advances in inclusion for people with disabilities, only 9 % considered infrastructure barriers in disadvantaged contexts. This omission reveals a worrying bias: accessible solutions are developed for those who already have access, ignoring communities where electricity or basic connectivity is lacking. The paradox is evident if museums implement expensive augmented reality systems while rural schools physically lack the resources to preserve their cultural artifacts. True inclusion requires first addressing the structural inequalities that limit access to heritage.

The issue of human agency in AI-mediated learning processes emerges as a recurring concern. Despite their benefits, automated recommendation and personalization systems can reduce the serendipity and autonomous discovery that characterize the most meaningful heritage experiences. Once algorithms decide what content is 'relevant' to each user, information and opportunities for critical thinking and confrontation with the unexpected are filtered out. This risk is particularly acute in heritage education, where the encounter with the unknown and the challenging has intrinsic pedagogical value. The challenge is to design systems that guide without directing, that suggest without imposing.

Another critical issue is the economic sustainability of these initiatives. Analysis shows that 82 % of successful projects depended on substantial upfront funding, with only 7 % demonstrating long-term viability without continued subsidies. This reality challenges prevailing narratives on scalability and calls into question the

promised democratization. Heritage technologies seem doomed to be trapped in a cycle of innovative pilots that never mature into stable programs. This economic precariousness explains why many brilliant initiatives disappear when seed funding ends, leaving behind obsolete equipment and frustrated expectations.

The training of professionals emerges as a fundamental bottleneck. Data indicate that 73 % of heritage institutions lack staff trained in both pedagogy and technology, leading to dependence on external consultants and hindering institutional ownership. This skills gap cannot be solved with one-off workshops but requires rethinking curricula in heritage and education-related careers. The challenge is to train a new generation of hybrid professionals who can deal with pedagogical theories and understand the fundamentals of algorithmic recommender systems.

The issue of impact assessment is a weakness in this field. Only 14 % of the implementations analyzed included robust mechanisms for measuring medium-term effects, whether on learning, cultural preservation, or community engagement. This makes it difficult to distinguish between fads and genuine contributions, between technological smoke and solutions with lasting value. The absence of agreed metrics allows superficial quantitative criteria (such as the number of users or time on the platform) to prevail over qualitative educational and cultural impact assessments.

The analysis reveals an unresolved tension between preservation and innovation. Digital technologies, by their disruptive nature, tend to frame heritage as something to be 'enhanced' or 'enriched' rather than valuing it on its terms. This approach risks turning heritage into mere raw material for digital experiences and loses its essence as a connection to the past. The challenge is to develop AI applications that respect the integrity of cultural references and avoid the temptation to 'update' them or make them more 'attractive' according to contemporary parameters.

The evidence points to an urgent need for specific ethical frameworks for this field. General principles of AI ethics are insufficient to address particular dilemmas in heritage education, such as the use of sensitive community data, the algorithmic representation of historical narratives, or the balance between open access and cultural protection. Creating these frameworks cannot be the task of technologists alone but must involve educators, heritage communities, and digital humanities specialists. Only in this way can technology be prevented from dictating the terms of this crucial conversation about our shared cultural heritage.

One of the most significant findings points to the urgent need to rebalance research priorities. Rigorous studies on implementation, cultural impact, and long-term sustainability must complement the current emphasis on tool development. Questions can no longer be limited to what AI can do but must address how to do it in ways that are ethical, contextualized, and respectful of cultural diversity. This shift in focus requires broadening development teams to include technologists, educators, anthropologists, and representatives of heritage communities.

Evidence reveals that the training of professionals represents a critical bottleneck to the advancement of the field. Educational and cultural institutions often lack trained personnel to mediate between technological potential and actual pedagogical needs. Overcoming this limitation requires interdisciplinary training programs that break down the silos between the humanities and computer science. This is the only way to generate a critical mass of professionals capable of building bridges between these traditionally separate worlds. In summary, the following figure (figure 3) shows the most general aspects addressed in these discussions and issues necessary to integrate AI into heritage education.
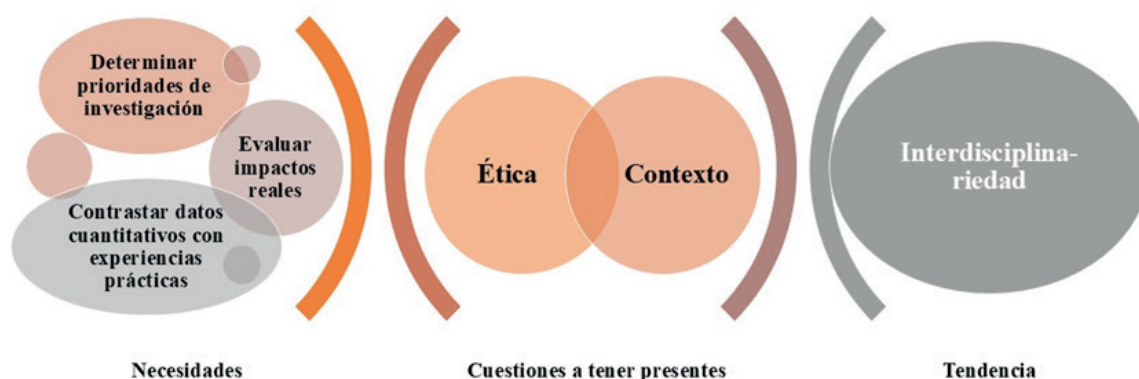

Figure 3. General ideas

The ethical question emerges as an unavoidable dimension. AI applications in heritage education handle

sensitive data, shape historical and cultural perceptions, and influence how new generations relate to their heritage. These responsibilities require specific regulatory frameworks beyond general technological ethics principles. Regulations tailored to the relationship between technology, education, and cultural preservation must be developed, with precise mechanisms for oversight and accountability.

Temporal analysis shows encouraging signs of maturation in the field. More recent publications demonstrate greater awareness of risks and limitations, moving away from the initial triumphalist discourse. This healthy skepticism gives hope for a more balanced development, where enthusiasm for innovation does not overshadow critical reflection. The challenge remains to translate these academic concerns into better design and implementation practices.

The future of AI in heritage education will depend mainly on its ability to resolve fundamental tensions: how to take advantage of technological opportunities without sacrificing cultural authenticity, scale solutions without homogenizing, and innovate without commodifying. The most successful cases analyzed in this study share a common trait: they start from heritage to technology, not vice versa. This inversion of priorities makes the difference between tools that truly enrich the educational experience and those that add layers of digital sophistication without pedagogical support.

CONCLUSIONS

The analytical journey of this bibliometric study reveals that the intersection between artificial intelligence and heritage education is a contested territory where transformative promise and substantial risks converge. The data show that the field is evolving rapidly but unevenly, with technical advances outpacing pedagogical reflection and a geographical implementation that reproduces global asymmetries in access to knowledge. This dynamic raises fundamental questions about what kind of heritage future is being built through technologies that, despite their apparent neutrality, are inscribed with particular cultural visions.

The results show that AI's principal value in this field lies in its ability to build bridges between heritage and traditionally excluded audiences. People with disabilities, rural communities, and marginalized groups find unprecedented opportunities for access and participation in these technologies. These achievements are counteracted if technical solutions are designed from laboratories far from the real application contexts or their economic sustainability depends on funding streams rarely sustained over time. The resulting paradox is evident: tools created to democratize often benefit those with access privileges.

The research finds that current technological development models over-rely on standardized solutions. Recommendation algorithms, automatic ranking systems, and augmented reality experiences are often built on universal parameters that take little account of local cultural specificities. This approach limits pedagogical effectiveness and threatens to homogenize heritage expressions that derive their value precisely from their uniqueness. The challenge is to move towards glocal models, where the technical power of AI is combined with a deep respect for contextual particularities.

This study culminates with a conviction: artificial intelligence can be a powerful ally of heritage education, but only if it is subordinated to the human values that give meaning to heritage itself. Technologies must serve to amplify voices, not to silence them; to complexify narratives, not to simplify them; to facilitate meaningful encounters with cultural heritage, not to turn it into a digital spectacle. The way forward demands technological humility, epistemic diversity, and an unwavering commitment to preserving collective memory.

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CONFLICT OF INTEREST
The author declares that there is no conflict of interest.

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