Artificial Intelligence for Conserving and Preserving Artefacts

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Abstract: *Artificial Intelligence (AI) is revolutionising the preservation and conservation of cultural artefacts by introducing innovative, non-invasive and highly efficient solutions. The integration of AI has transformed traditional approaches to the preservation, documentation and restoration of artefacts. Contemporary AI-based technologies and applications vary from computer vision and machine learning to natural language processing and high-fidelity digital surrogates. Applications such as AI-assisted imaging, 3D reconstruction, environmental data analytics and semantic metadata linking enhance both the physical and digital safeguarding of cultural assets. AI-driven platforms support provenance verification, forgery detection and adaptive preventive conservation, ensuring sustainable stewardship of heritage collections. This paper reviews current AI tools and applications in heritage institutions and fine-art contexts, highlighting their role in improving conservation accuracy, accessibility and long-term resilience of artefacts.*
KEYWORDS: *ARTIFICIAL INTELLIGENCE, ARTIFACT PRESERVATION, DIGITAL CONSERVATION, VIRTUAL RESTORATION, PREDICTIVE MODELLING*

1. *Introduction*

Cultural heritage artefacts – whether paintings, manuscripts, sculptures or archaeological remains – represent irreplaceable sources of historical and artistic knowledge. The conservation of these objects has traditionally relied on expert craftsmanship, material science, and manual documentation. However, the growing volume of collections, environmental instability, and the increasing complexity of deterioration processes demand new scalable approaches to heritage management. In recent years, Artificial Intelligence (AI) has emerged not just as a tool but as a transformative force, enhancing the precision, efficiency, and scope of conservation science. Through automation, pattern recognition, and data modelling, AI introduces an unprecedented capacity to analyse, predict, and preserve the physical and digital integrity of cultural artefacts, inspiring a hopeful future for heritage conservation.

The use of Artificial Intelligence-based technologies in this field covers a broad spectrum of functions, from computer vision algorithms that detect micro-cracks or pigment fading to machine learning systems that forecast material degradation under different environmental conditions. High-fidelity digital surrogates and 3D reconstructions are now employed to document and virtually restore damaged or fragmented objects. Simultaneously, Natural Language Processing (NLP) enables the transcription and semantic linking of historical archives. In the fine-art sector, Artificial Intelligence further aids in authentication, forgery detection, and provenance verification, integrating advanced analytics with blockchain technologies.

This paper aims to examine the current landscape of Artificial Intelligence tools and their applications in artefact preservation and conservation. It explores both institutional and artistic settings, highlighting key technological trends, case studies, and challenges related to ethics, data quality, and long-term sustainability. By analysing these emerging practices, the study seeks to demonstrate how Artificial Intelligence can support the enduring protection, accessibility, and cultural significance of global heritage collections.

2. Results and Discussions

In the era of digital transformation, Artificial Intelligence is no longer just a technological novelty but a strategic partner for cultural institutions. To fully understand its potential, it is necessary to examine not only what Artificial Intelligence does but also how its role is evolving—from a tool for operational efficiency to a catalyst for scientific discovery and public engagement.

There are two main approaches to implementing Artificial Intelligence. The first explores its strategic aspects. Scholars and practitioners highlight AI's dual function: 1) as a technical enabler for large-scale digitisation, condition monitoring, and predictive maintenance, and 2) as a platform for improving accessibility, research, and public engagement through richer metadata, virtual exhibitions, and interactive services. While this dual role underscores the strategic importance of Artificial Intelligence, its true revolutionary potential lies in how these tools develop from passive assistants into active researchers. This transformative potential of Artificial Intelligence forms the core of the second approach, called "The Evolution of AI". These two methods are not mutually exclusive; instead, they complement each other. The "Dual Role" offers the strategic framework—guiding how cultural institutions can harness Artificial Intelligence. Meanwhile, the "Evolution" indicates the technological trajectory—towards a deeper, more intelligent, and more creative engagement with our heritage.

The convergence of tools and institutional need has been formalised in several sector initiatives and platforms that aim to lower the barrier for heritage organisations to adopt AI workflows. [1]

Digitisation and 3D documentation form a significant, well-established area of AI application. Research organisations employ photogrammetry, LiDAR, and high-resolution imaging pipelines enhanced with machine learning to produce accurate, archival-grade digital twins of sites and objects. These digital models serve both as research resources and as insurance against loss or damage, enabling reconstruction and remote study. CyArk's open 3D documentation projects and ICONEM's large-scale photogrammetry of damaged sites are notable practical examples of this approach, demonstrating how 3D capture combined with computational workflows support preservation and public dissemination. [2]

Artificial Intelligence also plays a key role in remote monitoring and threat detection: platforms that utilise satellite imagery, automated change-detection algorithms, and historical baselines can swiftly identify erosion, vegetation encroachment, illegal excavation, and damage related to conflicts across large areas. Recent initiatives (notably the HeritageWatch.AI collaboration) demonstrate how AI-powered alert systems can offer near-real-time situational awareness for heritage risk managers and help prioritise field responses. Such systems expand conservation efforts from individual objects to landscape-scale protection. [3]

Within archives and libraries, Natural Language Processing and Handwritten Text Recognition (HTR) tools are revolutionising access to textual heritage. Platforms like Transkribus and the AI4Culture ecosystem facilitate automated transcription, language recognition, and multilingual metadata enrichment, enabling full-text searches, cross-collection linking, and large-scale digital scholarship. These technologies lessen manual effort, support new forms of computational analysis (e.g., topic modelling, entity extraction), and enhance the discoverability of previously inaccessible primary sources. [4]

In the fine art sector, AI techniques have been used for authentication, stylistic analysis, and forgery detection. Commercial systems and academic research utilise convolutional neural networks and transformer-based architectures to analyse brushwork, pigment patterns, and microscopic textures to support attribution claims. Platforms like Art Recognition combine Convolutional Neural Networks and Vision Transformer models to generate analytical reports for experts. Although promising, these methods are debated in scholarly circles – authorities warn that AI should augment, not replace, traditional connoisseurship and scientific analysis. [5]

Beyond individual tools, numerous EU and research projects offer practical toolkits and deployment guidelines for institutions aiming to adopt AI responsibly. The ReInHerit toolkit and related EU resources compile open-source applications, computer vision prototypes, and ethical guidance for museums, demonstrating how AI can be integrated into visitor experience design, collection management, and preventive conservation workflows. These programmatic initiatives highlight co-design with curators, documentation of training data and evaluation metrics, and the importance of sustainability plans to preserve models and datasets over time. [6]

Table 1: Leading AI-based platforms and initiatives that apply artificial intelligence to the documentation, monitoring, authentication, and preservation of cultural heritage artefacts and sites.

Project/ Platform	Primary AI Technologies	Application Area	Example Use / Outcome
CyArk	Computer vision, photogrammetry, 3D reconstruction	Digital preservation of heritage sites	Creates detailed digital twins of endangered monuments (e.g., Angkor Wat) for research and reconstruction
ICONEM	Deep learning, image stitching, LiDAR integration	3D scanning and visualisation of archaeological sites	AI-optimised photogrammetry for war-damaged heritage in Mosul and Syria
AI4Culture	NLP, semantic web, metadata enrichment	Digital heritage collections	Enhances metadata accuracy, multilingual tagging, and searchability across European archives
Transkribus	Handwritten text recognition (HTR), machine learning	Archival preservation and digitisation	Automates transcription of manuscripts and archival documents
Art Recognition	Convolutional neural networks (CNN), vision transformers	Art authentication and forgery detection	Identifies stylistic patterns to assess artwork authenticity
HeritageWatch.AI	Computer vision, satellite image analysis	Damage monitoring and risk management	Detects looting, conflict damage, and environmental threats to heritage sites
ReInHerit Toolkit	ML-driven analytics, semantic integration, data fusion IoT	Preventive conservation and museum management	Offers AI toolkits for collection monitoring, metadata management, and visitor interaction

Despite technological advances, the literature highlights significant limitations: algorithmic bias, data scarcity for many object types, lack of interoperable standards for metadata and digital preservation, and unresolved ethical issues concerning representations and community consent. Consequently, recent reviews advocate for hybrid workflows involving domain experts interpreting AI outputs, thorough validation of models using provenance-verified datasets, and robust documentation practices—measures that will determine whether AI becomes a truly dependable tool for long-term heritage management. [7]

Artificial Intelligence is quickly evolving from a new technology into an essential partner in cultural heritage conservation. While its role in digitisation is well established, AI's real potential extends beyond simple digital copying. It now provides advanced features, including intelligent analysis, predictive conservation, and even virtual restoration – fundamentally changing how we safeguard and interact with our shared history. Here is a comprehensive overview of how AI technologies are being used throughout the preservation process, organised by their main functions.

1. Digital Documentation: Creating the "Digital Twin" The foundation of modern conservation begins with creating precise digital replicas of artefacts.

- Photogrammetry and AI-Assisted Modelling: AI algorithms automatically process thousands of photographs to create highly accurate 3D models, considerably speeding up what was once a labour-intensive manual task.
- 3D Scanning and Mesh Repair: From laser-generated point clouds, Artificial Intelligence produces accurate digital surfaces ready for 3D printing or virtual reality applications.
- Multi-Spectral and Hyperspectral Imaging: By analysing images captured beyond visible light, AI uncovers hidden features like underdrawings in paintings or faded texts in manuscripts, while also identifying materials and detecting early degradation invisible to the naked eye.

For example, the British Museum has used photogrammetry to create 3D models of the Rosetta Stone and other artefacts, enabling worldwide access and detailed research.

2. Condition Assessment: The Diagnostic Eye. AI serves as a Vigilant diagnostic tool, continuously monitoring artefact health.

- Automated Crack and Damage Detection: Computer Vision models (like Convolutional Neural Networks) are trained to identify and map the tiniest cracks, flaking surfaces, or structural weaknesses, establishing precise condition baselines.
- Change Detection: by comparing current states with reference models, Artificial Intelligence flags minute changes that signal active deterioration, enabling timely intervention.
- Degradation Prediction: Machine learning models analyse environmental conditions alongside artefact data to forecast future preservation needs, allowing conservators to move from reactive to proactive care.

It is often used to monitor frescoes in ancient caves or cathedrals, where AI can detect subtle moisture ingress or biological growth before they become significant problems.

3. Restoration and Virtual Reconstruction: The Digital Atelier. Artificial Intelligence facilitates both physical restoration assistance and non-invasive digital reconstruction.

- Virtual Inpainting: for damaged artworks. Artificial Intelligence reproduces missing elements in the artist's authentic style, offering valuable guidance for physical restoration or creating engaging digital exhibits.
- Fragment Reassembly: AI analyses break patterns and surface characteristics to solve what were once archaeological puzzles – from ancient pottery to fragmented tablets, which significantly speeds up reconstruction.
- Colour Restoration: by combining pigment analysis with historical data, Artificial Intelligence digitally revives the original vibrant colours of faded artefacts, bringing ancient sculptures and wall paintings back to life.

The "RePAIR" project has employed robotic arms and Artificial Intelligence to physically reassemble thousands of archaeological artefacts from the ancient Roman city of Pompeii, which were burned and buried by Mount Vesuvius. [9]

4. Analysis and Authentication: The Digital Art Historian. AI unlocks new dimensions of understanding about artefacts' origins and authenticity.

- Stylometric Analysis: by examining brushstrokes, the chisel marks on a sculpture, tool marks, or handwriting. Artificial Intelligence creates artistic "fingerprints" that can attribute works to specific creators or detect sophisticated forgeries.
- Material Analysis: AI swiftly interprets scientific data to determine material compositions, verifying authenticity and tracing origins through historical patterns by gathering and integrating data from techniques like X-ray Fluorescence (XRF) or Raman Spectroscopy. [14]
- Provenance Research: Natural Language Processing scans numerous digitised records to piece together ownership histories, aiding in resolving disputes and identifying looted cultural property.

The "Mona Lisa" has been analysed with Artificial Intelligence to study Leonardo da Vinci's sfumato technique in unprecedented detail. [10] Similarly, Artificial Intelligence has been used to question the attribution of certain paintings to Rembrandt. [11]

5. Access and Engagement: AI revolutionises how worldwide audiences engage with cultural heritage.

- AI Guides and Chatbots: Virtual assistants offer context-rich information and personalised storytelling, crafting engaging museum experiences for each visitor.
- Generative storytelling: AI constructs engaging narratives around artefacts, making historical content more accessible and relatable.
- Augmented Reality Reconstructions: Using smartphone cameras, visitors can view AI-powered reconstructions of artefacts or ruins in their original splendour.
- Personalised Journeys: AI curates bespoke museum tours and digital experiences based on individual visitor interests and behaviours.

The Smithsonian's "Skin and Bones" application employs Augmented Reality to project flesh and movement onto dinosaur skeletons. [12] The Google "Arts and Culture" app utilises Artificial Intelligence for features like "Art Selfie" and colour-based art discovery. [13]

Together, these applications show how Artificial Intelligence is not just preserving our past but actively reinventing how we understand, restore, and experience cultural heritage – ensuring that future generations can connect with human history in increasingly meaningful and personalised ways.

3. Conclusion

The integration of Artificial Intelligence into artefact preservation and conservation marks a fundamental shift in how we safeguard and interpret cultural heritage. This analysis shows that AI has developed from a basic digitisation tool into a highly advanced partner that improves every stage of the conservation process – from documentation and condition monitoring to restoration and public engagement.

Through technologies such as computer vision, machine learning, and generative AI, we can now create precise digital twins of artefacts, detect tiny signs of deterioration invisible to the human eye, predict future preservation needs, and even reconstruct missing elements with remarkable accuracy. These capabilities not only enhance the efficiency and accuracy of conservation work but also enable proactive rather than reactive preservation strategies. Artificial Intelligence also acts as a bridge between technical conservation and public accessibility, transforming static collections into dynamic, interactive experiences through virtual reconstructions, personalised tours, and augmented reality applications.

Although challenges persist regarding data quality, ethical implementation, and the necessity for human oversight, the evidence clearly shows that Artificial Intelligence is becoming an essential partner in preservation efforts. As technology continues to evolve, its potential to transform the way cultural heritage is understood, preserved, and experienced will only increase, ensuring that valuable artefacts endure and stay meaningful for future generations.

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