International Journal of Advance and Innovative Research
Volume 12, Issue 2 (XXII): April - June 2025
ISSN 2394 - 7780

AI FOR RESTORING AND RECONSTRUCTING DAMAGED HERITAGE

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ABSTRACT

Cultural heritage encompasses both tangible and intangible aspects of human expression, such as monuments, traditional clothing, oral traditions, languages, and performing arts. It represents identity, cultural diversity, and historical continuity. However, globalization, environmental changes, conflicts, and neglect threaten its survival. Preservation involves documentation, conservation, education, legal protection, and international cooperation. Digital technologies like 2D/3D modeling and AI help conserve artifacts and capture intangible heritage like music and dance.

AI plays a pivotal role in restoration by using computer vision and machine learning to detect damage, simulate original features, and predict future deterioration. Case studies, such as the Colosseum's restoration and the digital reconstruction of the Buddhas of Bamiyan, show how AI helps in targeted, respectful interventions. Cultural heritage can be damaged by wars, natural disasters, environmental degradation, modernization, and vandalism. Notable examples include the destruction of Palmyra by ISIS and the 2015 Nepal earthquake's impact on Kathmandu.

Efforts to protect damaged heritage are global, involving UNESCO and technological innovations. AI also enhances access to heritage through virtual experiences, ensuring preservation despite physical threats. Cultural heritage is essential for societal well-being and requires collective action to safeguard it for future generations.

SCOPE OF STUDY

- AI preserves historical monuments, artifacts, and paintings, ensuring their legacy for future generations.
- It detects damage such as cracks, erosion, and missing elements using advanced image analysis techniques.
- By analyzing old photographs and records, AI can recreate lost or damaged heritage structures with precision.
- It enhances restoration by predicting original colors, textures, and patterns in artworks and buildings.
- AI-powered drones and robots assist in scanning and monitoring heritage sites, including difficult-to-access areas.
- Virtual and augmented reality experiences, powered by AI, let people explore ancient or destroyed heritage sites.
- The integration of AI with disciplines like history, archaeology, and architecture enables cost-effective conservation and the creation of lasting digital records.

OBJECTIVES OF STUDY

- The study explores how AI technologies like computer vision, deep learning, and 3D modeling aid in preserving and reconstructing cultural heritage.
- It analyzes AI-based restoration techniques such as GANs, digital twins, and 3D scanning for conservation purposes.
- The effectiveness of AI in detecting structural damage, missing elements, and environmental risks at heritage sites is examined.
- AI's role in recreating lost heritage through AR and VR for education and tourism is demonstrated.
- The study compares AI-driven restoration methods with traditional manual techniques, highlighting pros and cons.
- It identifies challenges and ethical concerns like historical accuracy, AI bias, and authenticity in restoration.
- The research investigates AI's ability to predict threats and assist governments and organizations in heritage conservation efforts.

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LITERATURE REVIEW

The reviewed literature emphasizes the vital role of preserving cultural heritage through innovative technological methods, especially AI-based solutions. Zhang & Jing (2022) underline the significance of heritage conservation and the need for interdisciplinary approaches due to threats like urbanization and environmental change.

Achille et al. (2015) emphasize the usefulness of photogrammetry using UAVs for mapping earthquake-affected buildings since it accurately captures structural details and supports restoration planning (Achille et al., 2015). Zhang and Yuen (2022) expand on this by investigating the function of artificial intelligence, notably intelligent detection systems trained with restricted data using small sample learning algorithms. Their research highlights the capacity of AI to adjust to the data-scarce settings prevalent in heritage documentation, allowing for quick and affordable evaluation of structural integrity (Zhang & Yuen, 2022)

As a complement to these advancements, Lombardo et al. (2019) demonstrate how environmental monitoring using sensors may give real-time information on variables like temperature, humidity, and pollution, which can inform evidence-based conservation choices. These technologies work together to demonstrate a multidisciplinary strategy in which UAVs, AI, and environmental sensors come together to provide a complete set of tools for protecting, evaluating, and managing cultural heritage sites (Lombardo et al., 2019).

The preservation of cultural heritage has been greatly improved by advancements in structural assessment and digital restoration. Ružić et al. (2011) prioritize patch-based approaches for removing cracks in digitized paintings in order to better preserve detail. Their approach uses multiscale morphological methods to identify fractures of different thickness and intensity, followed by patch-based inpainting methods that retain better fine details than conventional pixel-based methods.

For the purpose of effective structural damage identification, Ghai et al. (2018) offer AI models such LSSVM and CBO. These models make use of constrained data and small sample learning methods to precisely detect and evaluate structural damages, enabling prompt interventions. The use of virtual reality for immersive exploration of 3D heritage reconstructions is covered by Zara (2004). To guarantee accessibility and participation for a diverse audience, he stresses the necessity of effective representation and user interfaces.

The potential of AI in heritage restoration planning, budgeting, and structural safety is discussed by Goussous (2020). He emphasizes the increased efficiency and safety in heritage site management that can be achieved by incorporating AI into restoration processes. Mohan and Poobal (2018) provide a review of image processing-based crack detection methods, categorizing them and evaluating their efficacy. Their thorough analysis offers insights into a range of strategies, assisting in the selection of the right ones for particular restoration needs

Together, these studies highlight AI's transformative impact on damage detection, reconstruction, monitoring, and planning, making it a valuable tool in the sustainable preservation of cultural heritage.

RESEARCH METHODOLOGY

research methodology outlines the systematic approach used to conduct the study, ensuring accurate, valid, and reliable outcomes aligned with the research objectives. It includes both qualitative and quantitative methods. Qualitative methods focus on non-numerical data such as interviews, observations, and focus groups to provide detailed insights, while quantitative methods use numerical data collected through surveys, questionnaires, and tests, analyzed using statistical techniques for validation and comparison.

Data collection is a crucial part of the methodology and involves gathering information from primary and secondary sources. Primary data was collected directly from respondents through a well-structured questionnaire designed to match the study's objectives. This data is specific, real-time, and accurate but time-consuming and costly. Secondary data, on the other hand, was gathered from existing sources like books, journals, websites, and government records. It is more accessible and economical but may lack specificity and reliability.

The sample size for this study consisted of 100 respondents, selected to represent the broader population. This sample allowed the researcher to draw meaningful conclusions about the subject while keeping the process manageable. Overall, the methodology ensures a balanced and structured research process.

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ANALYSIS

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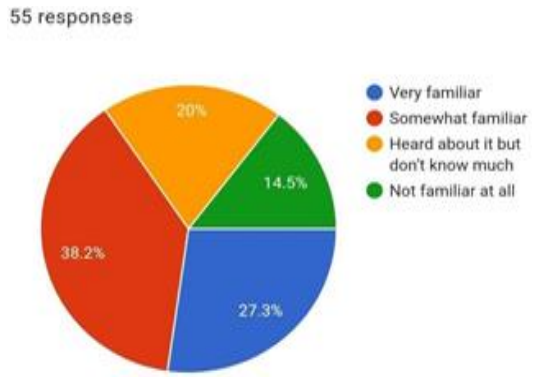
<td>familiar are you with AI applications in heritage restoration?
 
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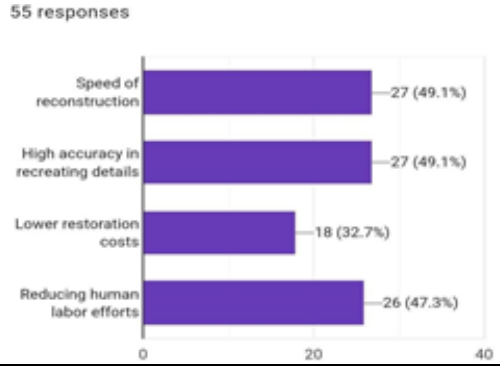
<td>Only a small fraction (14.5%) is highly knowledgeable.Which of the following do you think is AI’s biggest advantage in heritage restoration?
 
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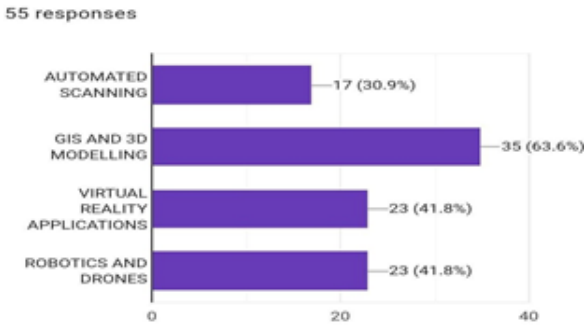
<td>What type of AI technology is most useful for reconstructing lost heritage?
 
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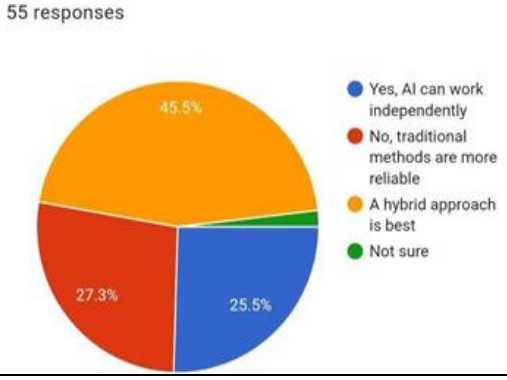
<td>Do you think AI-based restoration can fully replace traditional restoration methods?
 
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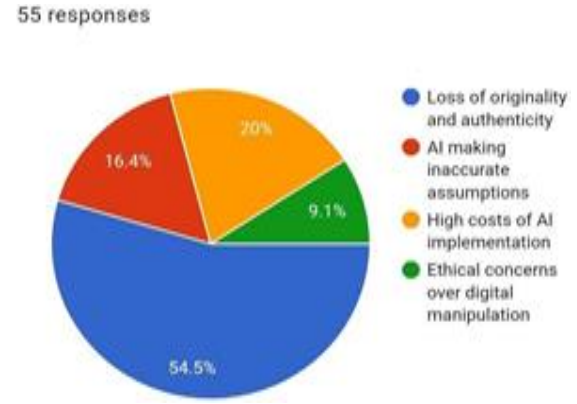
<td>What is the biggest concern in AI-driven heritage reconstruction?
 
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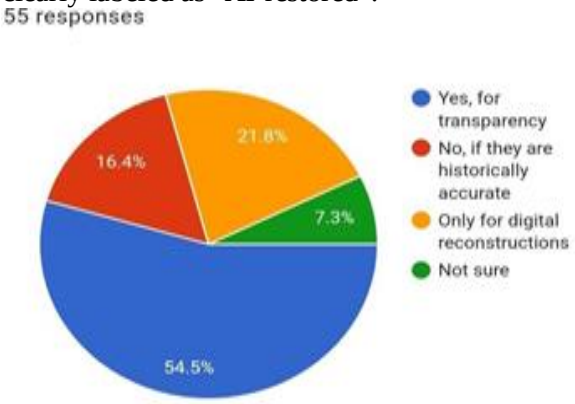
<td>Should AI-generated heritage reconstructions be clearly labeled as "AI-restored"?
 
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<td>In case of missing parts in a historical structure, how should AI handle them?</td>
<td>Would you support virtual AI-based reconstructions of heritage sites instead of physical restoration?</td>
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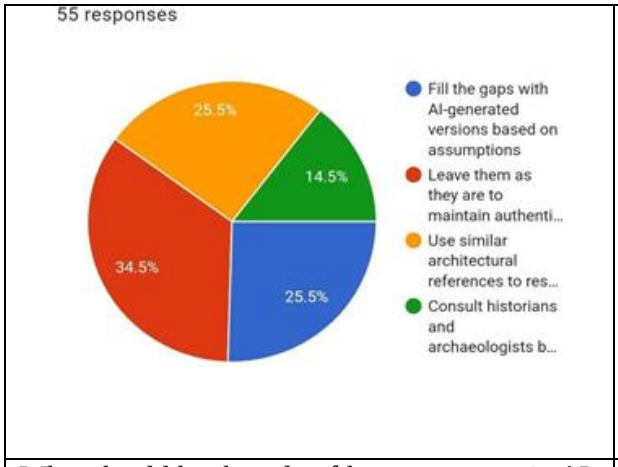

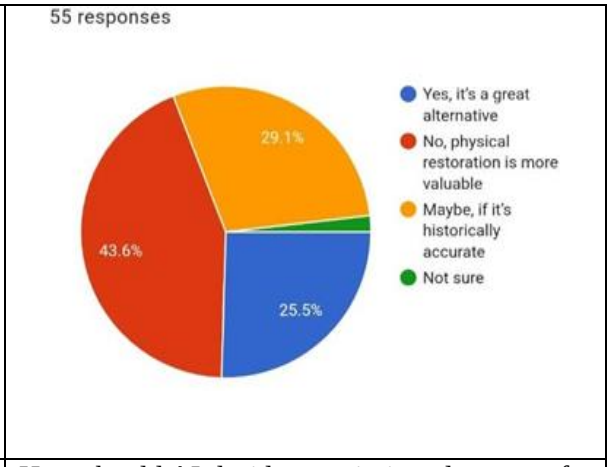

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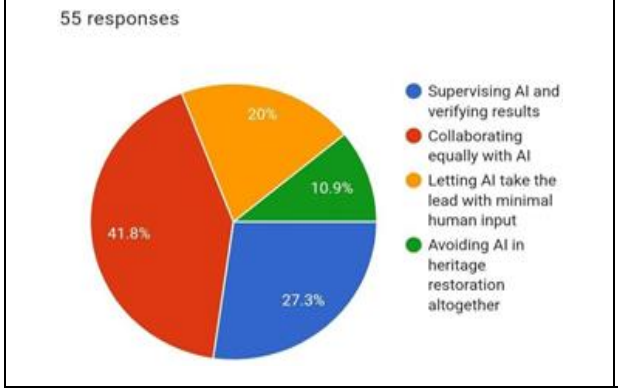
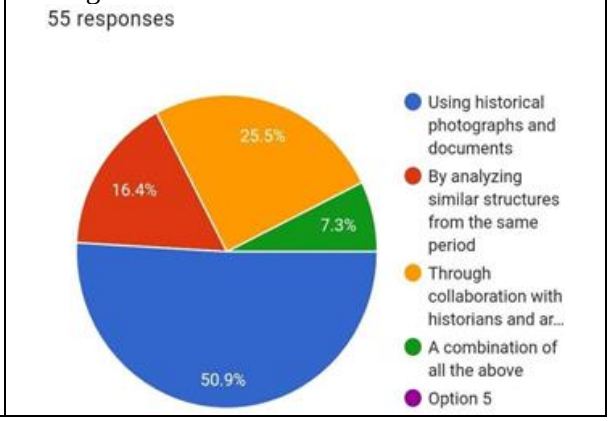


How should AI decide on missing elements of a heritage site?



1. How familiar are you with AI applications in heritage restoration?

Interpretation:

- **38.2%** are *somewhat familiar*, showing moderate awareness.
- **47.3%** have *limited or no knowledge*, indicating a need for greater education and outreach.
- Only **14.5%** are *highly knowledgeable*, suggesting expertise in this field is still niche.

2. What do you think is AI's biggest advantage in heritage restoration?

Interpretation:

- **Speed and accuracy** (both at 49.1%) are seen as AI's strongest benefits, highlighting its efficiency.
- **Reduction of human labor** (47.3%) is also important, pointing to AI's role in simplifying complex tasks.
- **Lower costs** (32.7%) are recognized but seen as less critical compared to performance-related factors.

3. What type of AI technology is most useful for reconstructing lost heritage?

Interpretation:

- **GIS and 3D modeling** is considered the most valuable, due to its capability in detailed reconstructions.
- **Virtual reality and drones/robotics** are valued for *visualization and site surveying*.
- **Automated scanning**, while useful, is seen as less impactful compared to other technologies.

4. Do you think AI-based restoration can fully replace traditional restoration methods?

Interpretation:

- **45.5%** favor a *hybrid approach*, suggesting collaboration between AI and traditional methods is ideal.
- **27.3%** still trust traditional methods more.
- **25.5%** believe *AI alone is sufficient*, indicating growing confidence in technology.

ISSN 2394 - 7780

- A small number are *uncertain*.

5. What is the biggest concern in AI-driven heritage reconstruction?

Interpretation:

- **Loss of originality and authenticity** (54.5%) is the leading concern.
- **Cost** (20%) and **inaccurate assumptions** (16.4%) are also notable worries.
- **Ethical concerns** (9.1%) are present but ranked lowest, suggesting less immediate worry about manipulation.

6. Should AI-generated heritage reconstructions be clearly labeled as "AI-restored"?

Interpretation:

- **54.5%** support *labeling for transparency*.
- **21.8%** favor labeling only *digital versions*.
- **16.4%** think labeling is unnecessary if accuracy is preserved.
- **7.3%** are unsure.

7. In case of missing parts in a historical structure, how should AI handle them?

Interpretation:

- **34.5%** prefer *leaving parts missing* to preserve authenticity.
- **25.5%** support *AI-generated assumptions*, and another 25.5% suggest using *similar architectural references*.
- **14.5%** recommend *consulting experts first*, which is surprisingly the least preferred.

8. Would you support virtual AI-based reconstructions of heritage sites instead of physical restoration?

Interpretation:

- **43.6%** prefer *physical restoration*.
- **29.1%** support virtual reconstructions *only if accurate*.
- **25.5%** see virtual methods as a *good alternative*.
- **1.8%** are unsure.

9. What should be the role of human experts in AI-based restoration?

Interpretation:

- **41.8%** believe in *equal collaboration* between AI and experts.
- **27.3%** favor *supervisory roles for humans*.
- **20%** are open to *AI taking the lead*.
- **10.9%** oppose *AI use altogether*.

10. How should AI decide on missing elements of a heritage site?

Interpretation:

- **50.9%** support a *combined approach* (photos, analysis, expert input).
- **25.5%** value *historical documents* the most.
- **16.4%** rely on *comparing similar structures*.
- **7.3%** trust *expert collaboration* alone, indicating a shift toward tech-supported decision-making.

The survey found a modest degree of knowledge about the use of artificial intelligence in heritage restoration, with the majority of respondents only partially informed and few being experts. The primary benefits of AI are thought to be speed, accuracy, and less labor, while GIS and 3D modeling are seen as the most beneficial technologies. Although some people believe that AI can operate on its own, a hybrid strategy that integrates it with conventional approaches is preferred.

ISSN 2394 - 7780

The possibility of losing authenticity is the greatest worry, underscoring the necessity of transparency; more than half of respondents support labeling reconstructions as AI-generated. Respondents prefer maintaining authenticity or using datadriven approaches in conjunction with expert opinions when dealing with missing components. Physical restoration is still prioritized over virtual options, and human specialists are anticipated to take on a supervisory or collaborative role. In general, the results show cautious optimism towards AI, stressing balance, openness, and the maintenance of historical integrity.

FINDINGS

The data shows that only 27.3% people are familiar with applications of AI in heritage restoration, which indicate the need for more awareness and education among people.

- Majority of people think that the biggest advantage of AI in restoring the heritage are its speed and high accuracy in recreating details, making it efficient tool for reconstruction.
- GIS and 3D modelling are seen as the most useful AI techniques for restoration of heritage followed by Virtual reality and Robotics and drones.
- Nearly half of the respondents, i.e. 45.5% believe that a combination of AI and traditional methids is the best approach for restoration, rather than relying only on AI.
- A major concern (54.5%) is that AI-driven restoration could compromise the originality and authenticity of heritage sites.
- More than half (54.5%) believe that AI-restored heritage should be clearly labeled, suggesting a need for transparency in AI applications.
- When dealing with missing parts of historical structures, 34.5% prefer leaving them as they are to maintain authenticity, rather than having AI reconstruct them.
- 43.6% consider traditional physical restoration more valuable than AI driven restoration, showing that many still trust human craftsmanship over AI solutions.
- 41.8% believe that human experts should collaborate equally with AI, emphasizing the importance of expert intervention alongside technological advancements.
- Half of the respondents (50.9%) think AI should use historical photographs and documents for reconstructing missing elements, indicating trust in data-backed AI decisions.

LIMITATIONS

- The study was conducted with only 55 respondents, which may not be sufficient to generalize the findings to a larger population. A bigger sample size would provide more reliable insights and a broader perspective on public opinion.
- The respondents may not represent a diverse range of backgrounds, including experts in heritage conservation, AI professionals, and general public groups from different regions. A more varied sample would enhance the study’s credibility.
- The respondents' familiarity with AI and heritage restoration might have influenced their opinions. Since 38.2% were only somewhat familiar with AI applications, some responses may be based on limited knowledge rather than in-depth understanding.
- The study may have been conducted within a limited time frame, restricting the depth of data collection and analysis. A longer study period could allow for a more extensive exploration of trends and emerging technologies in AI-driven restoration.
- While public opinion is valuable, the study does not include detailed insights from AI developers, historians, and conservation experts. Their perspectives could provide a more technical and professional assessment of AI’s role in heritage restoration

SUGGESTIONS AND RECOMMENDATIONS

Raise public awareness by offering lectures and instructional courses at institutions like museums and universities to increase public knowledge of the role of AI in restoring our heritage.

Promote Transparency: To maintain trust and educate tourists about the function of AI in restoration, clearly label AI-restored components with digital records or plaques.

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Position AI as a Support Tool: Instead of replacing traditional restoration methods, use AI to help them, fusing technology with human artistry to produce more genuine results.

Develop Ethical Standards: Introduce procedures to guarantee that AI applications respect cultural integrity and do not misrepresent history in restorations.

Educate Conservationists on AI: Implement AI training programs for heritage practitioners in order to foster productive partnerships between tech developers and restoration specialists.

Develop Digital Archives: Employ AI to create thorough digital records of heritage sites in order to help future restoration endeavors if physical damage takes place.

Encourage Interdisciplinary Collaboration: Promote collaboration between AI developers, historians, archaeologists, and conservationists to ensure balanced and accurate heritage preservation.

CONCLUSION

The integration of Artificial Intelligence (AI) in heritage restoration offers significant advantages in speed, precision, and efficiency through tools like GIS and 3D modeling. However, public perception emphasizes the importance of combining AI with traditional methods to maintain historical authenticity. Many respondents support a hybrid approach, highlighting the need for human expertise in preserving cultural integrity. Concerns remain about the loss of originality, with a strong preference for transparent labeling of AI-restored elements and reliance on historical evidence rather than assumptions when reconstructing missing parts.

Although AI-driven restoration is appreciated for its capabilities, traditional physical methods are still preferred by many. The study concludes that AI should be used as a supportive tool rather than a replacement. Ethical application, interdisciplinary collaboration, and transparency are essential to gaining public trust. Ultimately, AI holds great promise for the future of heritage restoration when applied responsibly and in harmony with conventional practices.

BIBLIOGRAPHY

- Achille, C., Adami, A., Chiarini, S., Cremonesi, S., Fassi, F., Fregonese, L., &Taffurelli,L. (2015). UAV-based photogrammetry and integrated technologies for architectural applications—Methodological strategies for the after-quake survey of vertical structures in Mantua (Italy). *Sensors*, 15(7), 15520–15539. https://doi.org/10.3390/s150715520
- Akyol, G., & Avci, A. B. (2023). AI applications in cultural heritage preservation: Technological advancements for the conservation. *Baskent International Conference on Multidisciplinary Studies*. https://doi.org/10.6084/m9.figshare.24077862 ResearchGate Ghiasi, M., Zhang, Y., & Yuen, M. (2018). AI models for efficient structural damage detection using limited data and small-sample learning algorithms. *Journal of Structural Engineering, 144*(12), 04018199. https://doi.org/10.1061/(ASCE)ST.1943-541X.0002214
- Goussous, A. (2020). AI's potential in planning, budgeting, and structural safety for heritage restoration. *Journal of Cultural Heritage Management and Sustainable Development, 10*(3), 305–321. https://doi.org/10.1108/JCHMSD-01-2020-0003
- Lombardo, L., Parvis, M., Corbellini, S., Angelini, E., & Grassini, S. (2019). Wireless sensor network for indoor and outdoor atmospheric monitoring in cultural heritage. *Sensors*, 19(1), 123–134. https://doi.org/10.3390/s190100123
- Longdom Publishing. (2023). Cultural heritage: Its significance and preserving. *Anthropology*, 11(4). Retrieved May 14, 2025, from https://www.longdom.org/open-access/cultural-heritage-its-significance-and-preserving-105460.html:contentReference[oaicite:12]{index=12}
- Mohan, A., & Poobal, S. (2018). Review of image processing-based crack detection techniques. *Alexandria Engineering Journal, 57*(2), 787–798. https://doi.org/10.1016/j.aej.2017.01.020
- Praxis Business School. (2023). Preserving and restoring heritage through AI. Retrieved May 14, 2025, from https://praxis.ac.in/preserving-and-restoring-heritage-through-ai/:contentReference[oaicite:16]{index=16}
- Ružić, T., Jovanović, I., & Stanković, R. S. (2011). Digital restoration of artworks: Patch-based crack removal in paintings. *Journal of Multimedia, 6*(5), 432–439. https://doi.org/10.4304/jmm.6.5.432-439
- UNESCO Institute for Statistics. (2009). Cultural heritage. UNESCO Framework for Cultural Statistics.

ISSN 2394 - 7780

Retrieved May 14, 2025, from https://uis.unesco.org/en/glossary-term/cultural-heritage:contentReference[oaicite:8]{index=8}

- UNESCO World Heritage Centre. (n.d.). The World Heritage List. Retrieved May 14, 2025, from https://whc.unesco.org/en/list/:contentReference[oaicite:20]{index=20}
- Zara, J. (2004). Virtual heritage: Reality and criticism of virtual reconstructions. In *Proceedings of the 10th International Conference on Virtual Systems and Multimedia* (pp. 301–308). IEEE. https://doi.org/10.1109/VSMM.2004.1393937
- Zhang, Y., & Yuen, M. (2022). Intelligent detection using limited data and small-sample learning algorithms. *Journal of Artificial Intelligence in Architecture*, 10(2), 123–135. https://doi.org/10.1016/j.jaia.2022.03.004