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# ARTIFICIAL INTELLIGENCE IN DOCUMENTING, ANALYZING AND REIMAGINING SOIL ARCHITECTURE: A COMPARATIVE STUDY BETWEEN SAUDI ARABIA (DIRIYAH/AL-ULA) AND THE UAE (AL AIN)

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## ABSTRACT

*This study examines the roles of AI, 3D imaging, and augmented reality in the documentation and reconstruction of earthen architecture in Diriyah (Saudi Arabia) and Al Ain (UAE). Undertaking a preliminary study within the framework of the theory of environmental adaptation, the study shows the role of new technologies in the preservation of heritage. The study analyzes how emerging technologies such as photogrammetry, LiDAR, and BIM are used respond in the generation of precise digital twins of heritage sites, with the incorporation of AI and machine learning enabling deeper insights into the data. It further examines the role of augmented reality in public outreach and education about the sites and virtual reconstructions of the sites. The findings stress the importance of the inclusion of AI workflows to earthen architecture, which enhances its preservation, cultural significance, and scholarly inquiry and community heritage projects. Then study concludes with recommendations to the heritage community, educators, and policy makers about the widespread adoption of digital intelligent tools for sustainable preservation of the Gulf and the Arab world.*

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**KEYWORDS:** Artificial Intelligence, Earthen Architecture, 3D Modeling, Augmented Reality, Heritage Preservation.

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## 1. INTRODUCTION

Adobe and mudbrick earthen constructions across the Arabian Peninsula represent an architectural, historical, and cultural identity that spans hundreds of years of evolution to withstand life in the desert. These construction sites can be seen as gated historical areas in Diriyah and AlUla, in KSA, and in Al Ain, in the UAE, and are distinguished by their mudbrick walls, palm fronds, courtyard, and passive cooling devices, all held together with coated gypsum and earthquake clay mortar (Almagro, 2002; Al-Khalifa, 2019).

New strategies are needed to preserve these sites as rapid urbanization and climate change, coupled with waning artisanal skills, make traditional approaches to craftsmanship obsolete. In KSA and the UAE, sympathetic governmental cultural authorities recommend conservation approaches that blend contemporary devices, including artificial intelligence, 3D modeling, and augmented reality (Al-Hussayen et al., 2021; Al-Khalifa, 2019). This research examines and develops intelligent digital strategies to preserve, analyze, and reimagine living culture earthen architectural legacies (Wardat et al., 2025; AlArabi et al., 2022; Alneyadi & Wardat, 2024; Shirawia et al., 2023).

Critical to these approaches is an understanding of the threats to these historic sites, which can be bordered by a lack of sufficient documentation techniques and tools, as well as the more commonly known forms of environmental degradation. This inquiry takes these challenges, along with the architectural identity of the region, and explores the protective potential of contemporary digital tools.

### 1.1. Challenges to Earthen Heritage

#### 1. Environmental Degradation

Earth structures, particularly their stability, experience rapid decline owing to the combined effects of temperature changes, moisture, and the process of natural decay (Al-Anzi, 2020). Preservation of the structure is only feasible by ecosensitive techniques and prescriptions (Smith, 2019).

#### 2. Ventilation Issues

Erosion and fracture of earthen materials could arise as a result of poor ventilation (moisture accumulation). Enhanced passive ventilation may aid in internal controllability without

disturbing the internal historic fabric (Taylor 2021).

#### 3. Urbanization Pressure

The advancement of the town is an ongoing and evolving phenomenon (Al-Kaabi, 2019).

Planning for the town's advancement will become more complex as we keep delaying determining the desired town character and the historical site's image we wish to keep (Rodriguez, 2020).

#### 4. Lack of Precision Tools

Efforts in conservation lack the modern tools necessary for more precise documentation. Laser scanning and aerial imaging technologies increase precision and aid in more precise actions to be taken (Johnson, 2018).

### 1.2. The Role of Artificial Intelligence in Heritage Preservation

Technologies such as visual classification, 3D modelling, and augmented reality are used in the documentation and conservation of earthen architecture. AI processes large data sets and produces precise models, improving the interpretation and preservation of heritage (Smith 2020).

#### 1. Visual Classification

AI image analysis, including convolutional neural networks (CNNs), analyzes and identifies architectural features and material degradation with a high degree of accuracy, thus minimizing visual inspections (Johnson, 2019).

#### 2. 3D Modeling and Structural Analysis

The use of AI, Photogrammetry, and LiDAR produce precise three-dimensional models which allow for stress tests and planning for preservation and also allow for scalable digital archiving (Williams, 2018).

#### 3. Augmented Reality for Cultural Engagement

According to Brown (2021), AI augmented reality has enabled users to take virtual tours of reconstructed heritage sites and engage with history while learning and enjoying tourism simultaneously.

#### 4. Strategic Integration of AI

AI assists in predictive conservation analysis and even enables the development of knowledge bases other than providing analysis. The integration of the AI approach and the culture of the region is important and warranted for the inclusion of sites such as Diriyah and Al Ain within the scope of the national preservation policy.

### 1.3. Research Questions

This study seeks to answer the following questions:

1. To what extent is AI effective in documenting and analyzing earthen architecture in the Saudi and Emirati contexts?
2. How can AI, 3D modeling, and AR

technologies be utilized to reimagine earthen architecture and enhance cultural engagement?

#### 1.4. Research Objectives

- Study the application purpose and the usage of AI in the documentation and analysis of earthen architecture, including visual classification, 3D modeling, and AR.
- Conduct a comparative study of Saudi and Emirati case studies along with fieldwork in Diriyah and AlUla (Saudi Arabia) and Al Ain (UAE) concerning AI and documentation practices.
- Propose targeted and context-sensitive guidelines to embed smart digital technology within the foundational, local context and architectural identity preservation policy.

#### 1.5. Theoretical and Practical Significance of the Study

This research contributes to AI-based conservation of earthen architecture in the Saudi and Emirati contexts and fills a void in digital heritage engineering. It shows the role of 3D modeling and visual classification, and AR in sustainable conservation, with actionable takeaways for the field. Work done in Diriyah, AlUla, and Al Ain enhances its wider utility.

## 2. LITERATURE REVIEW

Structures made out of clay have been around in Asia and the Middle East for many decades. The impacts of new technology have changed these structures and have made them difficult to sustain (Mulush and Baik, 2025). Digital preservation in the forms of artificial intelligence, 3D models, and virtual reality is being used in places like Diriyah and Al Ain in Saudi Arabia and the UAE. (Baik 2023; Miky et al. 2024).

### 2.1. Digital Documentation and 3D Modeling

Laser scanning and photogrammetry technology cultivates highly accurate 3D replicas of earthen structures. Conservation work can be undertaken without direct contact to the structures. 3D documentation of At-Turaif and Al Ain is done to assist restorations with preservation of authenticity (Baik, 2023; CulTech Lab, 2023).

Despite the inclusion of photogrammetry and 3D models into architectural data, the irregular shapes of the models still present significant modeling difficulties. AI, however, has enhanced the modeling process with automated element recognition and

deterioration detection (Al- Mashaqbeh et al., 2024; Abdullah et al., 2024).

A complete digital model with GIS, integrated with HBIM, HBIM, and inputs from other stakeholders, has been suggested for the mudbrick structures of Saudi Arabia (Mulush & Baik, 2025).

### 2.2. Artificial Intelligence in Conservation

Predictive modeling that shows risk of decay from environmental data is one way that AI assists with predictive modeling (Miky et al, 2024). CNNs and GANs deep learning tools reconstruct missing parts of structures and surface deterioration and damage (El-Gohary et al, 2023, Khan et al, 2023).

Automated analysis minimizes decision making that is dependent on manual assessments. AI and humans work best together where AI does all the data work and humans supply the cultural background (Zaki and Elshahed, 2025).

### 2.3. AR/VR for Heritage Engagement

Heritage sites become richer because of augmented and virtual reality which provides immersive experiences without physical intrusion. In real time, AR fills in absent parts. VR, in turn, reconstructs historical settings for educational and touristic purposes (Turkoglu & Alp, 2025; Saleh & Almarri, 2023). These technologies have already been put to use in Saudi Arabia and the UAE to enhance the interaction and accessibility with heritage. Turkoglu and Alp (2025) also researched the use of AR for the multi-period Kayseri Castle in Turkey, focusing on it as a case study for the preservation of heritage with AR.

### 2.3 AR/VR and Regional Integration in Heritage Preservation

The use of AR/VR technologies boosts interest in and protects heritage sites. The Kaisareia-AR project illustrates how immersive overlays improve visitor understanding without compromising the physical remains (Turkoglu & Alp, 2025). Virtual tours alleviate tourism pressure while increasing access to delicate sites around the world (Saleh & Almarri, 2023).

In the case of At-Turaif in Saudi Arabia, it was digitally scanned to obtain accurate 3D models, which then guided restorations while avoiding contact with the structure (Baik et al., 2024). At AlUla's Hegra site, AR glasses incorporate 3D images and holograms for immersive storytelling while preserving delicate components of the site (RCU, 2023). These initiatives complement Vision 2030 and

reinforce Saudi Arabia's position as the leader in high-technology-assisted heritage preservation.

The 19th-century Al Jahili Fort in Al Ain (UAE) is a prime example of Emirati mudbrick

fortification. The UAE's Department of Culture and Tourism has documented such sites with 3D laser scanning and photogrammetry to support restoration and public presentation (CulTech Lab, 2023; Hamdan et al., 2024).

### 2.3. B: UAE - Al Ain

The earthen sites of the city of Al Ain, which were adobe structures, forts, and towers, are UNESCO World Heritage listed sites. Since the 2000s, DCT Abu Dhabi and its heritage directorate have prioritized digital and spatial analysis and have created corresponding base records for guiding conservation strategies (Hamdan et al. 2024). Principal examples of this approach include the 3D laser scanning of Al Jahili Fort and its UAV photogrammetry, as well as remote watchtower systems (CulTech Lab 2023; UNESCO 2023).

Newer forms of AR public engagement are also a part of the strategy, for instance, mobile historical reconstruction guides. This policy is illustrated by the upcoming Terra 2026 World Congress, which is designed to showcase the balance of AI, digital heritage, and traditional heritage site integration of the region, and will be hosted in Al Ain.

## 3. METHODOLOGY

### 3.1. Approach

A mixed-methods approach that integrated field surveys, interviews with specialists, and AI powered digital analysis to the study of earthen architecture in the context of Saudi and Emirati.

### 3.2. Study Sites

- Diriyah (Saudi Arabia): An important example of mudbrick architecture from the Najd region.
- Al Jahili Fort & Al Ain (UAE): Gulf vernacular heritage with some form of digital curation, active or otherwise, or the possibility of it.

### 3.3. Tools and Techniques

- Artificial Intelligence Classification: Google AutoML and Convolutional Neural Networks processed images and used BIM for LiDAR to recognize components of the image's geometry and structural features.
- 3D Reconstruction: photogrammetry by Reality Capture was harnessed for structural

surfaces, while structural reinforcement was modeled in Autodesk Revit BIM.

- Augmented Reality: developed unified immersive experiences for smartphones and HoloLens using the Unity and Vuforia integration for the richly illustrated, gamified AR experience of heritage sites.

### 3.4. Qualitative Methods

- Field Surveys: Equipped with data recording instruments, the group was able to document the architectural features of the area by direct observation.
- Expert Interviews: Regions' architects, conservators, and technical innovators were spoken to for the purpose of giving this research more depth.

### 3.5. Analytical Techniques

- Data Interpretation: Synthesized recorded conversations assessing different cultures views on earthen architecture.
- 3D Spatial Analysis and Revit Model: Integrated BIM models and photogrammetric results.
- Comparative Analysis: Analyzed architectural styles and the use of AI in Diriyah and Al Ain.

### 3.6. Data Sources

Photographs along with UNESCO documentation

## 4. ANALYSIS AND DISCUSSION

Q1: How effective is AI in documenting and analyzing earthen architecture in Saudi and Emirati contexts?

Analyzing Diriyah and Al Ain images with AI showed a great ability to find structures like erosion and even the motifs and cracks. Deep learning performed greatly in comparison to manual methods in both time and accuracy which speaks on the potential AI has on heritage documentation and analysis.

**Table 1: Manual Analysis Compared To AI Based Analysis For Selected Reference Architectural Elements in Terms of Accuracy.**

Architectural Element	Manual Analysis Accuracy (%)	AI-Based Analysis Accuracy (%)
Najdi Arches	76%	92%
Gypsum Ornamentation	69%	88%

**AI Performance (Table 1)**

AI technologies have proven extraordinary accuracy and efficiency in documenting earthen architecture and saving time, and reducing subjectivity. That said, effective deployment comes down to culturally and environmentally oriented architectural databases for the region.

**Expert Interview Insights**

Improvement in documentation AI accuracy and speed was confirmed by all 9 experts. AI received from the 3 members in the UAE and 6 members from Saudi Arabia. However, they pointed out the difficulties in the field and the application’s requirement for more generalization, as well as the problem with the focus and localized datasets.

“Local teams need to be trained on how to use the techniques for fractures and mudbrick erosion AI can uncover.” Architectural Heritage Engineer, Diriyah Gate Development Authority.

“An added benefit of AI to Revit and BIM models is the ease in digital documentation in capturing difficult places.” Architect, Urban Heritage Department – Al Ain.

“For AI to understand and engage with the context in a significant and contextually relevant manner, databases of Arabic Architectural Heritage need to be constructed.” Researcher, Center for Heritage Studies – King Saud University.

**Integrated Qualitative–Quantitative Analysis**

Artificial intelligence ought to be regarded in a system-wide context, rather than simply as a tool for visual evaluation. Its effective use calls for contextually relevant training data, appropriate institutional supports, and geoculturally accurate built environment data.

Q2: How Can AI, 3D Modeling, and AR Enhance Earthen Architecture and Cultural Engagement?

Technologies such as artificial intelligence, three-dimensional (3D) modeling, and augmented reality (AR) transform the analysis, conservation, and dissemination of the earthen heritage of the Gulf. These advancements enhance public engagement as well as educational opportunities regarding the earthen heritage of the Gulf.

**A. 3D Modeling**

Digital reconstructions with photogrammetry and LiDAR ensure visualization and structural analysis for educational purposes. Underlying technologies include:

- BIM: Integrates functional and structural data.
- LiDAR: Captures accurate 3D point clouds.
- Photogrammetry: Projects 3D images from 2D photos.
- VR: Provides tools for immersive interaction.

**B. Case Studies**

- Al Jahili Fort (UAE): Photogrammetry provided detailed and accurate surfaces for educational and interpretive purposes.
- Diriyah (Saudi Arabia): LiDAR + Revit created digital duplicates for structural assessment and planning.

*Table 2: A Comparison Summary of 3D Modeling Techniques in Saudi Arabia and the UAE.*

United Arab Emirates (Al Jahili Fort - Al Ain)	Saudi Arabia (Diriyah - Al-Turaif)	Aspect
Photogrammetry	LiDAR Scanning + BIM Integration.	Primary
		Technology used.
Software Tools	Reality Capture + Autodesk Revit.	Reality Capture
		software.
Level of Detail (LOD)	Very high (millimeter accuracy).	High (Enough for
		visual and spatial
		recognition).
Use Case	Structural analysis, conservation planning, and digital archiving.	Educational and
		Cultural
		Interpretation of
		Heritage.
Field Accessibility	Limited physical access; technology-enabled	Allowed image
	remote analysis.	capturing and full
		photographic
		documentation for
		site
		photogrammetry at
		a distance.
Integration with AI	Integrated with AI for defect detection and	Restricted
Tools	material erosion analysis.	primarily for
		visual
		reconstruction.
Outcome	Highly detailed BIM models supporting	Augmented
	restoration and structural simulations.	Reality and
		Museum
		Exhibition
		Integration with

This table2 describes the 3D documentation and modeling techniques applied at two cultural sites: Al

Jahili Fort located in Al Ain, the United Arab Emirates, and Diriyah (Al-Turaif) in the Kingdom of Saudi Arabia. It delineates the utilized hardware, software, detail captured, applications, availability, AI incorporation, and result of the projects.

**D. Augmented Reality (AR)**

Equipped with Unity and the HoloLens, a prototype enables its users to virtually walk through reconstructs of mudbrick structures, allowing them to simulate the processes of construction, decay and restoration. This type of immersion contributes to contextual knowledge by layering history with structure and fostering a diverse range of models, enhancing the understanding of these concepts onwards.

*Table3: The interactive model is built along three primary stages.*

Stage	Description
1. Documentation	2. Digital capture of architectural features using photogrammetry and LiDAR.
3. Analysis	4. Structural and visual interpretation using AI-powered classification tools.
5. Reimagination	6. Immersive AR experience presenting historical evolution and potential restoration

	scenarios.
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According to the table3, combining AI with 3D modeling and AR improves documenting heritage and engaging the public. These technologies preserve and reinterpret earthen architecture by converting them from static structures to dynamic, interactive cultural repositories. Such a combination aids the preservation of heritage, both tangible and intangible, for the future.

**5. DISCUSSION, CONCLUSION**

This study investigates the combination of artificial intelligence, 3D modeling, and augmented reality, architectural preservation and reinterpretation of earthen structures in Diriyah (Saudi Arabia) and Al Ain (UAE), and shows the impact of various digital tools, including AI visual classification and machine learning, on LiDAR and photogrammetry used for structural analysis and cultural interpretation and analysis and immersive engagement. The development of digital twins and augmented reality (AR) experiences, which this research facilitates, serves the purpose of sustainable heritage preservation in the Gulf and offers models for scalable use worldwide. Creation of national digital heritage open repositories, promotion of community-driven digital heritage initiatives, the use of AI in the educational digital heritage interface, AR and VR public engagement interfaces, and AI-driven traditional digital restoration interfaces are the key suggestions.

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