

# Low-Cost Community-Driven 3D Digitization as a Climate Resilience Strategy for Tunisian Heritage

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## Abstract

Climate change, erosion, and resource constraints are placing increasing pressure on Tunisia's cultural heritage, much of which remains under-documented and vulnerable to loss. This paper examines how digital documentation, extended reality (XR), and citizen science can be integrated to support scalable and sustainable heritage preservation in Tunisia and beyond. Drawing on existing efforts, including academic, institutional, and participatory initiatives, the study highlights both the progress made and the remaining gaps in documentation capacity and accessibility.

It introduces Tanit XR, a nonprofit initiative founded in 2025 and fiscally sponsored by Florida Community Innovation, as a case study of a community-driven approach to heritage preservation. Tanit XR combines low-cost technologies such as photogrammetry and mobile scanning with volunteer training, hackathon-based innovation, and immersive XR platforms to document and share heritage at scale. Since its launch, the initiative has digitized over seventy artifacts across eighteen Tunisian sites, including Carthage, Dougga, and El Jem, while engaging a global network of volunteers.

The paper argues that Tanit XR's model—centered on accessibility, participatory training, and grassroots engagement—enables the documentation of underrepresented sites and fosters both local stewardship and international appreciation. By demonstrating how community-driven digital tools can complement existing institutional efforts, this work contributes to broader discussions on climate resilience, cultural preservation, and the role of inclusive technologies in safeguarding global heritage.

**Keywords:** digital heritage preservation, community-based conservation, climate change adaptation, 3D documentation, Tunisia

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**Sub-axis**

2.1 – Digital tools and AI for sustainable conservation and interpretation of heritage

Secondary relevance: 2.3 – Education, cultural mediation and intergenerational transmission through digital tools

**Note:** AI-powered tools were used to find sources, proofread the paper, and translate it into multiple languages.

## I. Introduction

Located on the Mediterranean in North Africa, Tunisia, which became independent from France in 1956, also housed the ancient civilization of Carthage, which was founded in the 9th century BCE (Encyclopaedia Britannica, 2024). Tunisian's national heritage is globally noteworthy, with both Carthaginian and Roman ruins that provide insight into the ancient world's networks of trade, alliances, and daily life (UNESCO World Heritage Centre, 2024).

### *Heritage at Risk*

The cultural heritage of Tunisia is increasingly at risk due to a combination of environmental and economic pressures, alongside the growing complexity of managing and preserving heritage sites in a changing context (World Bank, 2024; UNESCO, 2025). Climate change is a major driver of this vulnerability, with rising sea levels, coastal erosion, flooding, and drought accelerating the deterioration of archaeological sites, particularly in coastal regions (UNESCO, 2025; World Bank, 2024). These environmental pressures are already impacting heritage locations, where erosion and extreme weather events can rapidly damage or destroy irreplaceable structures and artifacts (UNESCO, 2025).

At the same time, urban expansion and increased tourism activity place added strain on historic landscapes, requiring careful management to balance preservation and access (UNESCO World Heritage Centre, 2021, 2023). Resource constraints and the scale of Tunisia's rich archaeological landscape can make it challenging to provide comprehensive monitoring, documentation, and conservation across all sites (UNESCO World Heritage Centre, 2023, 2025). Ongoing efforts by national institutions and partners continue to address these challenges through improved planning, conservation strategies, and international collaboration (UNESCO World Heritage Centre, 2021, 2023, 2025).

### *Digital Documentation for Heritage Preservation*

Digital documentation plays a critical role in protecting cultural heritage by creating accurate records that support conservation, research, and long-term monitoring (ScienceDirect, n.d.). This process includes technologies such as photogrammetry, 3D scanning, and digital modeling, which together enable detailed digital representations of physical environments (ScienceDirect, n.d.; Salagean-Mohora et al., 2023). Photogrammetry is a technique that reconstructs three-dimensional models from overlapping photographs, allowing objects and environments to be recorded without physical contact (Salagean-Mohora et al., 2023).

3D scanning, including methods such as laser scanning and LiDAR, captures precise spatial data by measuring distances between a sensor and a surface, producing highly accurate geometric representations of heritage sites (Historic England, 2018). Digital modeling builds on these datasets by generating structured 3D environments that can be analyzed, visualized, and shared for conservation and educational purposes (ScienceDirect, n.d.).

Together, these tools enable the creation of high-fidelity digital replicas that can be used to monitor deterioration, support restoration planning, and preserve information that may otherwise be lost due to environmental or human-driven threats (Salagean-Mohora et al., 2023). In

resource-constrained contexts, these technologies are particularly valuable because photogrammetry can be implemented using widely available tools such as standard cameras, making it accessible and scalable for community-based documentation efforts (Salagean-Mohora et al., 2023).

Extended reality (XR) is an umbrella term that includes virtual reality (VR), augmented reality (AR), and mixed reality (MR), all of which blend physical and digital environments in different ways (Bekele et al., 2018). Virtual reality (VR) creates fully immersive digital environments that users can explore, often through head-mounted displays, enabling the reconstruction of heritage sites and historical settings that may no longer exist (Guttentag, 2010). Augmented reality (AR) overlays digital information such as images, text, or 3D models onto the physical world, allowing users to experience additional interpretive content while visiting real-world heritage sites (Yovcheva et al., 2012). Mixed reality (MR) combines elements of both VR and AR by allowing digital and physical objects to interact in real time, creating more dynamic and interactive user experiences (Bekele et al., 2018).

In cultural heritage contexts, these technologies are used to visualize and interact with 3D models of sites, supporting conservation planning and research without requiring direct physical access (Bekele et al., 2018). XR applications are also widely used for public engagement, enabling immersive storytelling, virtual tours, and on-site interpretation that enhance visitor understanding of historical environments (Yovcheva et al., 2012; Guttentag, 2010). Additionally, XR enables remote access to heritage sites, allowing global audiences to explore locations virtually while reducing physical pressure on fragile environments (Bekele et al., 2018). Together, these capabilities make XR a powerful tool for preservation, education, and sustainable heritage engagement (Bekele et al., 2018).

Citizen science, defined as the involvement of the public in scientific research and data collection, provides a powerful framework for scaling digital heritage documentation efforts (Bonney et al., 2016). In cultural heritage contexts, citizen science enables volunteers, students, and local communities to participate in documenting sites through accessible tools such as photogrammetry and mobile data collection, expanding the reach of preservation initiatives beyond institutional teams (Heiss & Matthes, 2017). When combined with digital documentation technologies, this approach allows non-experts to contribute meaningful data, including photographs and site observations, that can be used to generate 3D models and monitor changes over time (Bonney et al., 2016).

XR technologies further enhance this participatory model by providing intuitive and engaging interfaces through which contributors can explore, validate, and interact with digital heritage data (Bekele et al., 2018). For example, virtual and augmented reality environments can be used to train participants, visualize contributions, and share results, increasing both accessibility and motivation for continued engagement (Bekele et al., 2018). This integration of citizen science and XR supports not only data collection but also education, community ownership, and intergenerational knowledge transfer, particularly in regions where institutional resources may be limited (Heiss & Matthes, 2017). As a result, participatory approaches that combine low-cost

digital tools with community engagement offer a scalable and sustainable model for heritage preservation (Bonney et al., 2016).

### *Heritage Documentation in Tunisia*

Digital heritage documentation efforts in Tunisia have been led by a combination of academic researchers, international organizations, and cultural institutions, demonstrating the feasibility and impact of technology-enabled preservation. For example, a recent participatory project in the Medina of Tunis used low-cost photogrammetry to document the decaying Fondok El Henna, where locally trained teams captured photographic data that was processed into accurate 3D models for condition assessment and conservation planning (Cruz & Albuérne, 2025). This project showed that even with limited infrastructure, community-based documentation can produce usable datasets while also building local technical capacity and supporting advocacy for endangered sites .

Institutional efforts have also played a significant role. Through the “Dive into Heritage” initiative led by the UNESCO World Heritage Centre, digital documentation missions and training programs have been implemented across the region, including workshops in Tunisia that train site managers and students in photogrammetry, laser scanning, and data processing to improve monitoring and conservation of World Heritage sites. These initiatives have contributed to the creation of standardized digital workflows and increased regional expertise in heritage documentation.

At the project level, the digital documentation of Ksar Said Palace in Tunis used laser scanning, photography, and photogrammetry to create an interactive 3D model and virtual tour, making a historically significant but previously inaccessible site available to the public and educational institutions (Culture in Crisis, 2017). The resulting platform expanded access to heritage, supported education, and preserved detailed architectural and historical information that might otherwise be difficult to study due to limited physical access .

More broadly, digital platforms such as the Southern Tunisia Heritage Observatory, developed through international research collaborations, integrate participatory approaches and digital tools to document and share regional heritage data, promoting interdisciplinary research and community engagement (University of Sfax et al., 2020). Together, these examples demonstrate that Tunisia has already begun to adopt digital documentation, XR, and participatory approaches, with measurable impacts including improved site monitoring, increased accessibility, capacity building, and the creation of lasting digital records for at-risk heritage.

## **II. TanitXR**

Tanit XR, named for the ancient Carthaginian goddess Tanit, is a nonprofit initiative founded in 2025 by Ines Said, a Tunisian-born XR developer based in the United States, whose work bridges cultural, technical, and geographic networks to support heritage preservation through accessible technologies.

### *Organizational Rationale*

The project is fiscally sponsored by Florida Community Innovation (FCI), enabling it to operate as a community-driven initiative while building partnerships across academic, nonprofit, and local contexts. Developed in response to gaps in digital documentation and the need for scalable, inclusive preservation strategies, Tanit XR combines low-cost digitization tools with participatory approaches rooted in citizen science, in which members of the public actively contribute to data collection and research (Bonney et al., 2016).

### *Volunteer Communities*

A defining feature of Tanit XR is its emphasis on training and empowerment: volunteers—many of them student-aged, alongside educators, professionals, and community members—are taught to document heritage sites using accessible methods such as mobile photogrammetry and 3D modeling workflows. Through workshops and hackathon-style (weekends that are meant to be a high impact, short experience) events, participants gain technical skills while contributing meaningful data, expanding both documentation capacity and community ownership of heritage preservation efforts (Richterich, 2019; Bonney et al., 2016). This grassroots, participatory model distinguishes Tanit XR from many prior initiatives by enabling work at a broader scale and reaching smaller, underrepresented heritage sites that are often overlooked in large institutional projects.

### *Accomplishments*

Since its launch in 2025, Tanit XR has digitized over seventy outdoor and publicly accessible artifacts across eighteen Tunisian sites, including Carthage, Dougga, and El Djem Amphitheatre, using photogrammetry, mobile scanning, and emerging techniques such as Gaussian splatting for high-fidelity 3D reconstruction (Kerbl et al., 2023). Beyond documentation, Tanit XR leverages XR, including AR, VR, and web-based 3D viewers, to democratize access to Tunisian heritage and engage global audiences. These technologies enable remote exploration, support education, and create pathways for sustainable cultural tourism that reduce physical pressure on fragile sites while increasing international awareness and appreciation (Bekele et al., 2018). Together, Tanit XR demonstrates how combining accessible technology, participatory training, and immersive platforms can expand documentation efforts, strengthen local stewardship, and connect global communities to underrepresented and at-risk cultural heritage (Bonney et al., 2016; Bekele et al., 2018).

Tanit XR operates through a distributed, community-centered structure that combines in-person engagement, remote collaboration, and experiential learning. The project connects participants across geographic regions through regular coordination, including weekly stand-up meetings that support over 100 active volunteers, including university students. These volunteers include primarily student-aged participants as well as educators, professionals, and community members, reflecting a broad, interdisciplinary network. This structure enables continuous progress on digitization, training, and outreach efforts while maintaining a flexible and scalable model of participation aligned with citizen science principles (Bonney et al., 2016).

A central component of Tanit XR's workflow is its emphasis on training and skill development. The initiative offers structured learning opportunities, including a photogrammetry class and hands-on workshops, where participants are introduced to 3D documentation techniques and digital heritage workflows. These efforts are reinforced through participation in major immersive technology events such as the MIT Reality Hack and Georgia Tech Immerse in 2026, where team members collaborate, prototype, and refine XR-based heritage applications. Hackathon-style environments have been shown to accelerate learning, foster innovation, and expand technical communities, making them a valuable component of Tanit XR's capacity-building approach (Richterich, 2019).

In parallel with training and development, Tanit XR conducts on-the-ground documentation work in Tunisia, where contributors capture photographic and spatial data at heritage sites using mobile and low-cost tools. This hybrid model—combining local data collection with global collaboration—allows the project to maintain strong ties to place while benefiting from distributed technical expertise. Building on this model, Tanit XR is planning to expand its work to Nigeria in collaboration with organizations such as Unique Mappers, extending its participatory and technology-driven approach to new cultural and geographic contexts.

Looking ahead, Tanit XR aims to further strengthen its organizational capacity by securing grant funding to support and compensate volunteer contributors, ensuring the sustainability and equity of its model. In addition to documentation, the initiative is actively developing methods for sharing its outputs with broader audiences, including the distribution of immersive experiences such as virtual museums through public libraries and other community institutions worldwide. These efforts align with research demonstrating that XR-based cultural experiences can enhance education, broaden access, and foster cross-cultural understanding while reducing physical pressure on heritage sites (Bekele et al., 2018). Together, these structural and programmatic elements position Tanit XR as a scalable, globally connected model for community-driven digital heritage preservation

### **III. Discussion**

This paper demonstrates that the convergence of digital documentation, extended reality (XR), and citizen science offers a viable and scalable approach to addressing the growing risks facing Tunisia's cultural heritage. While existing efforts in Tunisia have established the value of digital tools and institutional capacity building, gaps remain in reaching smaller, underrepresented sites and in scaling documentation efforts across a wide and diverse heritage landscape. Tanit XR builds on these foundations by introducing a community-driven model that prioritizes accessibility, training, and global engagement, empowering volunteers—many of them students alongside broader community participants—to actively contribute to heritage preservation.

By combining low-cost technologies with participatory training and immersive platforms, Tanit XR demonstrates how grassroots approaches can expand documentation capacity, strengthen local stewardship, and foster international appreciation for Tunisian heritage. The project's distributed structure, integration of hackathon-based innovation, and emphasis on both local data collection

and global dissemination position it as a flexible and adaptable model for other regions facing similar challenges. As climate pressures and resource constraints continue to threaten cultural heritage worldwide, initiatives like Tanit XR suggest that sustainable preservation will increasingly depend on inclusive, technology-enabled, and community-centered approaches that connect people across borders while safeguarding the past for future generations.

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