

RESEARCH ARTICLE

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Interactive 360° media for the dissemination of endangered world heritage sites: the ancient city of Palmyra in Syria

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Abstract

Since the onset of conflict in Syria in 2011, several heritage sites have suffered partial or complete destruction. The ancient city of Palmyra, a UNESCO World Heritage Site since 1980, was placed on the List of World Heritage in Danger in 2013, alongside five other Syrian heritage sites. Between 2015 and 2017, Palmyra experienced the loss of nearly 40% of its historic buildings and landmarks. The site's remote location and ongoing armed conflict pose additional challenges in accessing and preserving it.

This paper introduces an interactive online platform employing 360° media to document and disseminate information about the world heritage site of Palmyra. The platform contributes to the safeguarding process of Palmyra, facilitating public engagement and interaction with the site. It also has potential applications for other sites in Syria and beyond. The platform allows users to explore both archival and current information of damaged historical monuments and buildings, revealing their layered histories before and after demolition. Employing interactive 360° media, similar to applications like Google Street View, the platform offers a reality-based digital environment. Users can virtually move into different buildings or follow specific pathways within the site, accessing archival information and documentation about particular monuments and buildings along their journey.

This project serves as a unique informational resource for decision-makers and policy planners, aiding in the understanding of the site and the development of relevant strategies and recommendations. It also proves beneficial as an educational tool. The collective understanding fostered by this platform is expected to positively influence post-conflict restoration and reconstruction plans, making it an invaluable asset for research and educational purposes.

Keywords Palmyra, Web platform, 360° media tour, Cultural heritage, Archaeological preservation, Heritage in conflict zones

1 Introduction

Nestled within a verdant oasis in the heart of modern Syria, Palmyra—or Tadmor, as known in antiquity and as its Arabic name pronounced—emerges in the annals of history as a beacon of beauty. The name, aptly capturing

the city's grandeur, translates to 'wonder' (Al-Assad and Hansen 2010). Palmyra boasts a rich cultural context, woven with Greek and Semitic languages, reflecting its cosmopolitan nature at the pinnacle of the Roman era (Kaizer 2017). The city's lineage, stretching from ancient to Hellenistic times, is thoroughly documented, underscoring its continuous historical significance (Baird et al. 2023).

Palmyra was designated as a UNESCO World Heritage Site in 1980, meeting three of the ten selection criteria. This designation highlights Palmyra's status as a testament to the aesthetic heights achieved by a wealthy

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Roman-era oasis, as illustrated by its grand colonnade—a symbol of significant artistic evolution. Moreover, the site's ruins have been recognised for their influence on the resurgence of classical architectural styles and urban design in the West during the 17th and 18th centuries. Palmyra's comprehensive urban plan and its architectural marvels, notably the grand colonnade, encapsulate the apex of Roman influence and cultural exchanges in the East, characterised by unique artworks and sacred edifices. The site's integrity and authenticity were notably acknowledged in 2009, highlighting the well-preserved nature of Palmyra's structures¹.

Since the onset of the Syrian conflict in 2011, the focus on Palmyra's Roman-period heritage has intensified, with discussions often centring on the site's destruction and debates regarding its reconstruction, potentially overshadowing its extensive historical narrative. The control of the Islamic State of Iraq and Syria (ISIS) from 2015 to 2017 resulted in substantial damage to the site's ancient structures².

Current challenges include debates surrounding the reconstruction, repair, intervention, dissemination, and/or presentation of the remaining structures in Palmyra, along with a lack of adequate local heritage policies (issued in 1963) and suitable international heritage policies advising on appropriate reconstruction for Palmyra's unique context. Despite the site being under the control of the current government since 2017, ongoing conflict and the presence of ISIS in surrounding areas have led to the closure of Palmyra to the public.

As an alternative solution to such access issues, various digital technologies have been employed to represent specific structures or parts of site, with examples including Staatliche Museen zu Berlin (2019), Denker (2017), and Bond (2017). However, these approaches often fall short of capturing the authenticity, contextuality, and accuracy achievable through physical on-site recordings. This paper investigates the use of digital technologies in documenting cultural heritage damaged by conflict, particularly in Palmyra, where traditional access has been impeded since 2011 and further restrictions have been implemented since 2017.

Our study proposes the development of a 360° photographic platform to record and disseminate the current state of Palmyra as of 2021, following its different stages of demolition by ISIS. Despite the constraints of limited funding and a 6-month timeframe, our project aims to

establish a digitally preserved edition of a selected area of the site, serving both as a knowledge repository and a defence against war-induced physical destruction. Utilising archives from the Directorate General of Antiquities and Museums (DGAM) and leveraging access granted to the first author, this paper underscores the significance of technological advancements in the study of cultural heritage.

Our web-hosted platform, independent and politically neutral, seeks to provide an authentic digital archive of Palmyra's conditions at the time we were able to access the site in 2021. This aligns with the perspective that digital reconstructions should complement tangible heritage engagement, contributing to the concept of 'planetary heritage' (Stobiecka 2020). Developed by Yarmouk Private University in Syria and supported by the University of Liverpool in the UK, our project ensures an authentic representation of Palmyra, free from external political biases, and mindful of the contemporary cultural context of Syria.

Immersive media assists in developing the user's senses, making them feel as if they are part of the environment being depicted. This technology creates an environment that can simulate physical presence in places in the real world or imagined worlds and lets the user interact with this world (Interaction Design Foundation 2023). Moreover, 360-degree media, is a type of immersive content that allows the viewer to look in every direction from a single standing point. Created using a camera system that captures a full 360° panorama of a scene, this media type enables users to navigate and explore the environment in all directions. When viewed on compatible platforms or devices, such as VR headsets, mobile devices, or computers, the user can turn around, look up and down, and see the scene as if they were physically there (Yang 2023). Additionally, interactive hotspots refer to interactive elements overlaid on a panoramic or 360-degree view that users can interact with to learn more about the scene or navigate within it. These hotspots are strategically placed points of interest within the panorama that, when clicked or tapped, can display information, trigger multimedia content, link to other panoramas or external websites. The purpose is to enhance the user's engagement with the content by providing additional layers of information and interactivity. This approach is commonly used in virtual tours, educational content, online marketing, and interactive storytelling (InstaVR 2023).

Additionally, our platform emphasizes authenticity defined by the contextual and conceptual significance of heritage sites, aligning with the Nara Document on Authenticity (1994). This document advocates for a holistic understanding of authenticity in all aspects of heritage conservation, including digital dimensions.

¹ See 'Site of Palmyra' on UNESCO World Heritage Centre website (<https://whc.unesco.org/en/list/23/>).

² See state of conservation of Palmyra on UNESCO World Heritage Centre website (<https://whc.unesco.org/en/list/23/documents/>).

Our methodology incorporated a comprehensive literature review, extensive archival data collection from the DGAM, fieldwork including 360 documentation and video and photo capturing, and an information technology process for the creation of the online platform.

This paper is structured as follows: Section 2 provides the context of Palmyra to understand its significance, damage, and challenges. Section 3 explores Digital Heritage Preservation: International and Local Initiatives, along with the objectives and purpose of this study. Section 4 outlines the methodology, followed by Section 5 presenting the results and discussions. Section 6 concludes with recommendations.

2 Setting the context

2.1 Palmyra and its significance

Despite its remote location, Palmyra flourished as a commercial hub, attracting Arab tribes with its springs, Afqa spring, and becoming renowned for its extensive trade routes and cultural sway, epitomising wealth and power in the first century AD (Al-Assad and Hansen 2010). As a crucial Silk Road city, Palmyra facilitated significant East-West exchange. Its architecture, a seamless fusion of Greco-Roman, Persian, and Arabian influences, stands as a testament to the city's rich heritage and historical eminence (Munawar 2017). Palmyra transcends its role as an archaeological site, embodying the historical richness of Syrian heritage. Its legacy, having endured through various foreign dominions, symbolises the region's spirit and cultural tenacity and appeals to scholars and tourists alike as a vital part of global history (Sommer 2020).

The dissemination of Palmyrene knowledge in the West began with European exploration in the 17th century, culminating with Robert Wood's seminal 1753 publication (Wood 1753). These encounters profoundly influenced Western culture, spanning from art to literature (Sartre-Fauriat 2019). The French Mandate period in Syria witnessed significant archaeological undertakings that transformed Palmyra's landscape. The history of Palmyrene artefacts, from their excavation to their dispersion across 34 countries, reinforces the imperative of its preservation (Holtorf 2015). This history illustrates a complex interplay between colonial legacies and the shaping of Syrian antiquity (Meskell 2018). Recent scholarship has highlighted the need for a reassessment of archaeological practices and their impact on local communities (Almohamad 2022; Munawar 2022; Sabrine 2022), advocating for greater inclusion of local narratives in the field.

Palmyra not only embodies Syrian pride and cultural identity but also represents a vast, interconnected heritage. The valorisation of figures like Queen Zenobia casts Palmyra as a beacon of historical and feminist strength

(Munawar 2017). This emphasises its international importance and its influence on Western architecture and heritage.

The World Heritage site of Palmyra, as detailed in Fig. 1, includes the Temple of Bel, the largest temple on the site, situated to the east. It was constructed in the second century BC and inaugurated in 32 AD (1). Adjacent to it lies the Great Column Street, also known as the Long Street (2). The Tetrastylon, positioned near the center of the site, features a platform with four sets of four 18-m-high columns (3). The Triumphal Arch, distinguished by its three magnificent gates (4), is located near the Temple of Nabu (5), dedicated to the god of knowledge, light, craftsmanship, the arts, and writing. Nearby are the baths (6), noted for their enormous granite columns. In a more central location stands the theater (7), believed to have been completed during the reign of Emperor Caracalla in 212 AD. To the south, one can find governmental structures such as the market, the Senate, the people's Assembly, and the agora (8). At the western end of the Great Column Street (2) are the Temple of the Dead and an oval yard, featuring the three-entranced Damascus Gate (9), marking this street as a route for caravans and religious and funeral processions. In front of the Diocletian Camp (10) stands the Temple of the Arab Goddess Al-lat (11), the mother goddess of the Arabians and the sixth temple in Palmyra following the Temple of Bel (1), the Temple of Baalshamin (12), the Temple of Nabu (5), the Temple of Arsu (13), and the Imperial Temple (14). Unfortunately, the conflict in Syria has endangered this remarkable site, with significant damage already sustained (Fig. 2).

2.2 Damage and challenges

Palmyra's strategic location between Syria and Iraq, as well as its national and international significance, has made it a focal point in the conflict. The combat and subsequent military actions to regain control of Palmyra have posed significant risks to the site's integrity. Between 2015 and 2017, the dominion of ISIS over regions in Iraq and Syria led to significant destruction of historic structures, including the Temple of Bel and the Lion of Al-lat. The destruction extended to the Tetrastylon, the ancient theatre's stage, and other critical parts of the site, with the extent of the damage being closely documented by local authorities after regaining control of the site (Arkawi 2017; Ministry of Culture DGAM 2020) (Fig. 3)³.

The DGAM has been the custodian of the nation's heritage since its inception in 1946, facing significant challenges in safeguarding Syria's cultural sites and

³ See state of conservation of Palmyra on UNESCO World Heritage Centre website (<https://whc.unesco.org/en/list/23/documents/>).

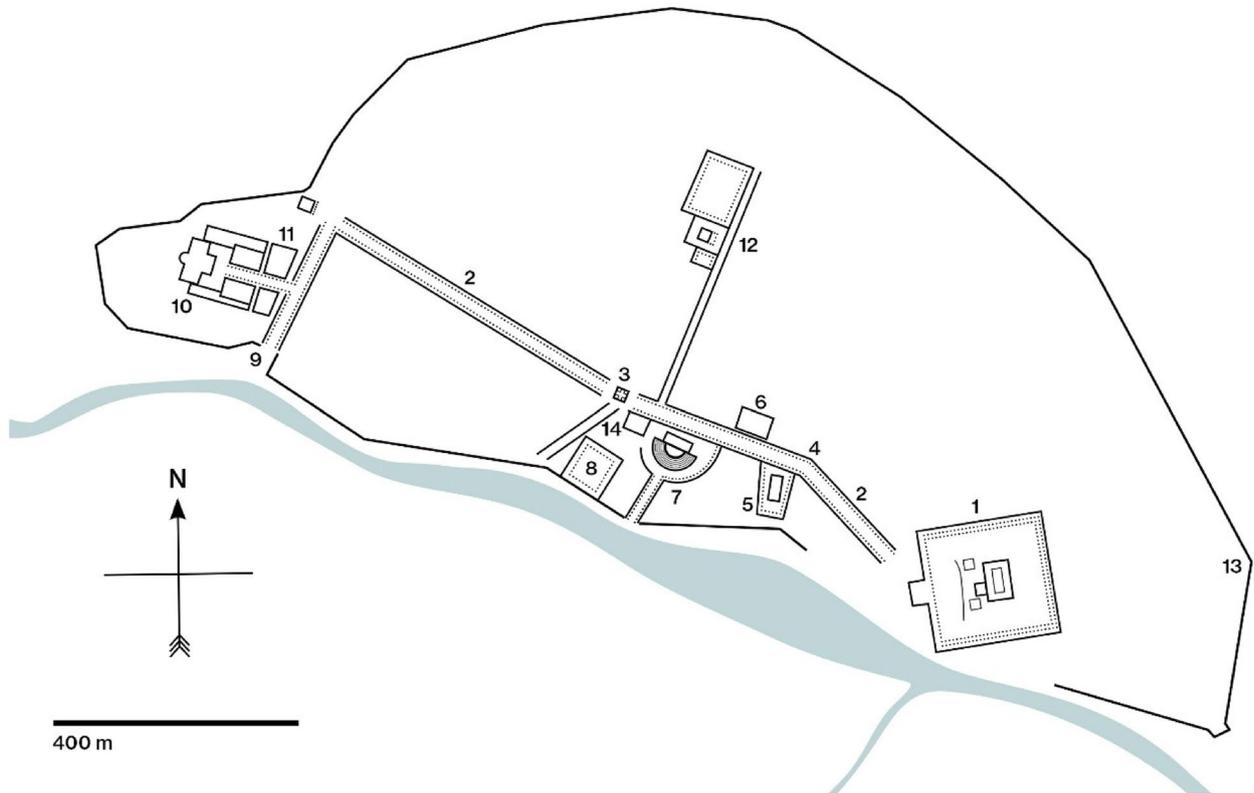


Fig. 1 Schematic map of Palmyra (Source: adapted from MLWatts, CC0, via Wikimedia Commons)

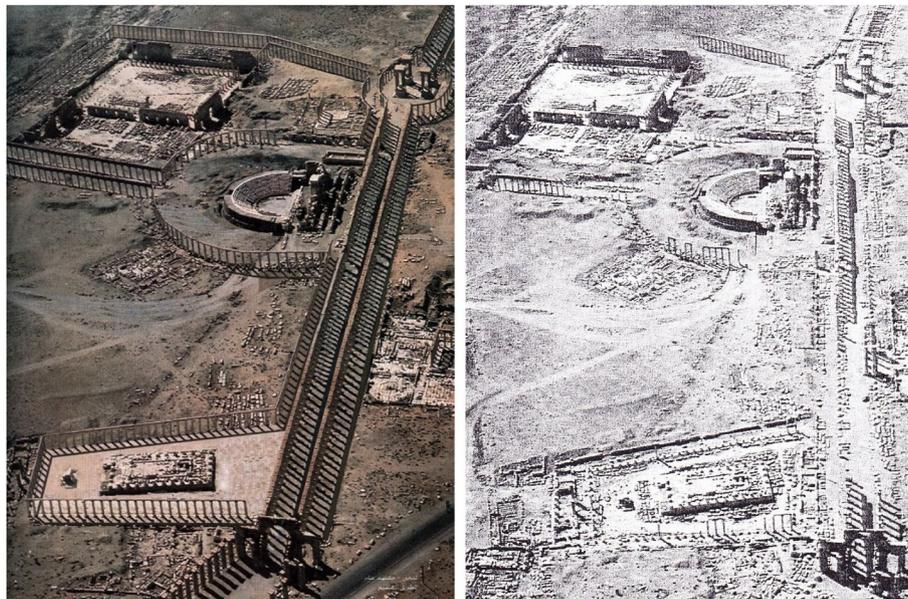


Fig. 2 Aerial photo of Palmyra in 1929 (left) and 1962 (right) (Source: the DGAM)

overseeing archaeological activities. This is largely due to the limitations of the Syrian Antiquities Law (No. 222) established in 1963, which, while defining

heritage within a specific temporal frame, fails to fully embrace the comprehensive spectrum of cultural heritage. Consequently, there is a pressing need



Fig. 3 Photographs before (top) and (after) the widespread destruction in 2017 of the triumphal arch (left), Temple of Bel (centre) and the Temple of Baalshamin (right) (Source: the DGAM)

for a revision of local heritage policies in Syria to encompass a broader understanding of heritage and to address the complexities of restoration and reconstruction (Munawar 2019).

Prior to the conflict, the existing management practices and legal frameworks were already found to be inadequate in effectively protecting the country's extensive array of heritage sites, thereby creating vulnerabilities in their preservation (Sabrine 2022). Compounding these challenges has been the constrained international involvement in these sites, a result of the intricate geopolitical landscape, which has further hindered efforts to protect and manage these cultural treasures (Al Quntar and Daniels 2016).

In the context of international reconstruction policies, the Warsaw Recommendations on the recovery and reconstruction of cultural heritage (2017) provide a structured approach to these complex undertakings. However, the specific nature of Syrian heritage, including the unique status and historical representation of Palmyra, demands a meticulous approach that honours both the tangible and intangible elements of heritage (Alsalloum and Brown 2019). This necessitates tailored strategies that respect the intricacies and unique character of Syria's cultural heritage, ensuring its preservation for future generations.

The complexity also lies in the fact that the conflict in Syria has established a challenging landscape for reconstruction, characterised by varying conditions across

regions. Some areas, like Aleppo, have stabilised enough to permit initiatives such as the Grand Mosque's reconstruction (UN Habitat 2021), while others remain embroiled in conflict, rendering them inaccessible. Palmyra exemplifies the severe impact of the conflict, suffering from extensive destruction of historical edifices and the theft of invaluable artefacts. Consequently, authorities have sealed the site for preservation (Ministry of Culture DGAM 2020), (Fig. 4).

As Syria edges towards peace, reconstruction provides an opportunity for improvement, aiming to serve both as a testament to Syria's rich cultural tapestry and as a repudiation of ISIS's cultural homogenisation efforts. Some scholars advocate for the reconstructed Palmyra to symbolise the nation's historical continuity and future aspirations (Harrowell 2016). However, there are concerns that reconstruction might introduce new power imbalances, potentially allowing dominant groups to imprint their narratives on Palmyra's renewed face (Azzouz 2022). The threat to Palmyra's standing in the World Heritage List underscores the urgency of preserving its Outstanding Universal Value (OUV), authenticity, and integrity. Without adequate funding, appropriate heritage policies, and secured protection, Palmyra risks further damage and potential exclusion from the prestigious World Heritage List.

Moreover, the loss of significant structures at Palmyra has sparked debate over the integrity of its heritage, with authenticity being a central concern. Integrity



Fig. 4 360° photo of the Tetrapylon in March 2021 (Source: the DGAM)

is associated with the physical aspects of the heritage assets, while authenticity transcends physical repair, encompassing the engagement of local communities in reconstruction efforts to foster a sense of belonging and contribute to social cohesion, and integrating intangible values (Alsalloum and Brown 2019; Soufan 2020). Therefore, the restoration of Palmyra transcends physical rebuilding; it is integral to restoring Syrian cultural unity and aiding societal healing in the aftermath of conflict.

In light of these challenges, there have been concerted efforts to digitally reconstruct parts of Palmyra's structures, a testament to the resilience and adaptability of cultural heritage preservation in conflict zones. The digital reconstruction of Palmyra has witnessed remarkable progress, marked by a range of innovative projects that have successfully brought to life parts of this ancient city, even in the face of adversity.

For example, the ancient Temple of Bel, demolished in 2015 by ISIS, was digitally reconstructed by the UC San Diego Library's Digital Media Lab in 2020 using advanced 3D methods and artificial intelligence (UC San Diego 2020). Similarly, the Institute of Digital Archaeology undertook the digital reconstruction of a portion of Palmyra's Roman triumphal arch, creating a model from pre-occupation photographs taken by archaeologists and tourists (Thompson 2018). The Baalshamin Temple, a blend of Syrian and Roman architecture destroyed in 2015, underwent diachronic 3D reconstruction in 2020, integrating scans of architectural elements with digitised archival materials (ALIPH Foundation 2020). Additionally, a collaborative effort produced a 360° film offering a historically accurate digital reconstruction of ancient Palmyra, providing an immersive virtual reality experience (Staatliche Museen zu Berlin 2019).

However, digital reconstructions, while invaluable, may not fully capture the authenticity and accuracy achievable

through physical on-site recordings (Stanco et al. 2011). The dynamic nature of historical sites like Palmyra, subject to changes from environmental factors and restoration efforts, calls for up-to-date documentation. Additionally, on-site recordings offer a comprehensive contextual understanding, including the site's surrounding landscape and spatial relationships, aspects that may be overlooked in digital reconstructions (Denker 2017). The limitations inherent in the technology used for digital reconstructions, which might not incorporate the latest archaeological findings or advancements, further underscore the importance of contemporary on-site recordings (Napolitano et al. 2019). Finally, on-site documentation of its current status complements digital efforts, adding a contemporary perspective to the collective narrative of heritage (Kansa 2022).

3 Digital heritage preservation: international and local initiatives

3.1 The role of DGAM and global partnerships

The DGAM in Syria has been proactively collaborating with the international heritage community to safeguard Palmyra, particularly during the peak of the conflict and its aftermath. This partnership entails active participation in a variety of conferences, seminars, and training sessions. Integral to these efforts are key organisations such as the United Nations Educational, Scientific and Cultural Organisation (UNESCO), the International Council on Monuments and Sites (ICOMOS), and the International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM) (Abdulkarim 2020). These collaborations have birthed multiple workshops and projects dedicated to preserving both the tangible and intangible heritage of Palmyra (UNESCO 2014; Lablaude and Russo 2017). Notable among these initiatives are a workshop in Damascus funded by the Flemish

Funds-in-Trust, and a series of workshops in Beirut, supported by a German grant, focusing on building capacity for the protection of Syrian cultural heritage. Furthermore, technical assistance and expert consultations at the UNESCO Headquarters have played pivotal roles in bolstering these activities (UNESCO World Heritage Centre 2016, 2019)⁴.

A significant outcome of these efforts includes the World Heritage Committee's resolution for Palmyra, advocating a careful approach to restoration by prioritising first aid over extensive reconstruction, pending comprehensive damage assessments and expert consultations. However, in spite of these recommendations and outcomes from meetings like the 2019 Palmyra recovery technical meeting, which emphasised museum artefact restoration and community-inclusive planning, implementation has been somewhat limited, reflecting a broader stagnation in heritage recovery efforts. Moreover, the commendable nature of these initiatives notwithstanding, their support pales in comparison to the more robust international involvement and substantial funding seen in contexts such as Yemen and Iraq, particularly in terms of direct on-the-ground assistance. Additionally, the political complexities involving access and financial sanctions imposed on Syria's government have further constrained UNESCO's actions and interventions (McCafferty 2023).

3.2 Digital heritage preservation

The restoration and visualisation of Palmyra through virtual heritage techniques, blending archaeological fidelity with digital technology, have led to the creation of highly accurate reconstructions of this historic site (Stobiecka 2020). Initiatives such as 'Revive Palmyra', 'The New Palmyra', 'Ghost of Palmyra', and 'The Virtual Palmyra' have emerged, utilising 3D computer graphics and virtual reality as means to mitigate the collective loss of this heritage (Denker 2017). These projects, including the 3D-printed Arch of Triumph by the Institute for Digital Archaeology and the first 3D model upload to Wikimedia Commons by the New Palmyra project, not only serve preservation purposes but also symbolise resistance against cultural vandalism (Mudie 2018; Al Quntar and Daniels 2016).

The Syrian Heritage Revival project in 2016, using a combination of reality-based digital surveys and source-based digital reconstructions, is another notable

initiative. It provides detailed records of individual monuments in their current state and models of their former appearance (ICONEM 2016). However, most models do not capture the overall value of the heritage site as a historical urban landscape, sometimes failing to communicate the full vitality and experiential movement through the site (Demetrescu 2018).

Physical reconstructions, like the restoration of the Lion of Al-lat by Polish and Syrian experts, can be seen as projecting a state-driven narrative of resilience, potentially compromising authentic restoration. These efforts, though significant, represent just a fragment of the broader reconstruction needs, which might include a combination of 3D virtual restoration and physical rebuilding with both old and new materials. This duality in restoration approaches highlights the complex motivations behind heritage reconstruction, where political objectives may clash with conservation principles and the prioritisation of community needs (Cuneo et al. 2015).

The challenge in reconstructing Palmyra lies in striking a balance between recognising its traumatic recent past and ensuring a restoration process that is culturally respectful and sustainable, aligning with the local community's journey toward healing (Cuneo et al. 2015; Mudie 2018). However, there is a risk that such efforts, potentially influenced by political powers, might overshadow the crucial need for community infrastructure in a conflict zone, which requires equal, if not greater, attention (McCafferty 2023).

Following the challenges of Palmyra's reconstruction, the politicisation of its cultural heritage has become increasingly evident. A notable example is the concert staged by the Russian government in Palmyra's Roman amphitheatre, which has been critiqued as an act of cultural diplomacy and a controversial display of 'civilized' posturing (Plets 2017; Eakin 2016). While such actions contrast with the aggressors' destructive behaviour, they can inadvertently contribute to the ongoing conflict dynamics and overshadow the efforts to preserve Syria's heritage (Eakin 2016). Additionally, exhibitions like France's 'Eternal Sites: From Bamiyan to Palmyra' and the Getty Research Institute's (GRI) 'The Legacy of Ancient Palmyra' online exhibition, featuring historical artworks and photographs, have played a significant role in raising global awareness about endangered heritage sites (Mudie 2018).

In November 2020, a new phase of restoration commenced with the DGAM and the Association of Stone Industry of Russia initiating the restoration of the Triumphal Arch. Natalia Solovyova, the project's director, shared insights from Russian restoration experiences at the University of Damascus's Faculty of Architecture in March 2023. This initiative followed a detailed

⁴ In the framework of the project funded by Germany entitled "Capacity Building, Technical and Media Support for the Protection of Syrian Cultural Heritage" (USD 200,000) implemented in collaboration with the German Archaeological Institute (DAI), between November and December 2017, three workshops were organized in Beirut and one was organized in Berlin to enhance the Syrian professionals capacities in recording, storing and analyzing cultural heritage research data.

plan outlined by the Russian Geographical Society in June 2022 for a 3-year restoration project. The project, situated in the relatively calm areas of the conflict zone, focuses on documenting the monument's current state, debris clearance, analysis of fallen blocks, and the creation of digital duplicates for virtual reconstruction in St. Petersburg before the actual on-site restoration begins (The Russian Geographical Society 2022).

The involvement of Russia in Palmyra's reconstruction is imbued with complex geopolitical and domestic political implications. By participating in the restoration of Syria's heritage, Russia asserts itself as a pivotal influence in shaping Syria's future, lending support to the current government and potentially using UNESCO's involvement to gain international legitimacy (Plets 2017; McCafferty 2023). This scenario underscores how the politicisation of heritage can intertwine cultural preservation with broader geopolitical strategies, raising critical questions about the true intentions and outcomes of such reconstructions.

In brief, while the 3D visualisation and reconstruction initiatives of Palmyra have been successful in enhancing awareness of the need to protect its world heritage, these digital tools, despite their importance, are limited in conveying the full context of the site or part of it. They particularly fall short in providing a serial vision through the site (Cullen 1961) and capturing the authentic quality and texture of the remaining structures, emphasising the need for a more comprehensive approach to heritage preservation.

3.3 Objectives and purpose of the study

Building on the initiative of utilising 360° photography for heritage preservation, this research seeks to develop a comprehensive web platform focused on Palmyra's heritage site. This platform, leveraging the capabilities of 360° media, will facilitate an interactive exploration of a selected area within the site. Users will have the opportunity to navigate along specific pathways, and simultaneously view juxtaposed documentation of the original monuments that have been lost and the current state of the surviving structures. This method offers a practical and current documentation of Palmyra, improving engagement with its heritage as it stands today. The specific objectives of the platform are as follows:

1. Presenting Reality-Based Views: The platform will offer high-resolution 360° media representations of the remaining structures and buildings, showcasing them within the broader urban landscape of Palmyra. This feature will allow users to gain an understanding of the site's current architectural and cultural context.
2. Navigable User Experience: Users will be able to virtually move along selected routes within the 360° media, effectively creating a journey through the selected area. This interactive experience offers a more immersive understanding of Palmyra's spatial dynamics.
3. Overlaying Archival Documentation: The platform will integrate archival and historical documentation of key buildings encountered along the selected routes. This content, sourced from reliable resources such as the DGAM archival library, will provide a comparative perspective, juxtaposing past and present states of significant structures and enhancing the platform's educational value.

4 Methodology

Our main approach involved conducting an in-depth review of literature on tours previously recommended at the site, gathering extensive archival data from the DGAM, undertaking fieldwork, and employing information technology processes to develop the online platform.

4.1 Digital pathways

Our study utilises a digital platform featuring 360° media for immersive exploration of Palmyra, presenting the site as of 2021 with enriched navigational and contextual data. This method builds on Silver et al. (2018)'s digital documentation, adding interactivity to the historical record.

In developing the virtual tour's pathway, understanding and integrating previously suggested tours were essential. Our research, therefore, examined the European Union Cultural Tourism Development Program of 2007, which financially supported Syria's Ministry of Culture (DGAM 2007). This initiative aimed to promote Syrian heritage sites, including Palmyra, as cultural tourism destinations, thereby fostering economic growth. A key component, the Arabic publication 'Palmyra: A Site Registered on the List of Cultural Heritage-Site Management Plan', outlined objectives such as collaborative stewardship of heritage sites.

From 2002 to 2007, a team of experts implemented this program, providing insights in their progress reports. They evaluated existing site management practices, proposed improvements, and designed visitor pathways. Our project is informed by these initiatives. Noteworthy contributions came from Christiane Delplace, Research Director at the French National Center for Scientific Research, who, in 2005, proposed eight walking routes to enhance visitor engagement with Palmyra's landscape (Delplace et al. 2005). These routes include:

1. A short tour starting at the visitor centre, proceeding to the Temple of Bel, traversing the Valley to the Agora, and continuing to the Temple of Baalshamin, the theatre, and the Arch of Triumph.
2. A route from the visitor centre to the Western Tombs Valley, showcasing the Western necropolis.
3. An exploration along the grand colonnade extending from the mortuary temple to the tetrapylon.
4. A direct path from the visitor centre to the Palmyra museum.
5. A scenic walk from the Dura Gate, along the city's north-eastern walls, cutting through the oasis.
6. A track designed for athletes.
7. A route encompassing the city's ancient cemeteries.
8. An extensive path covering Palmyra and its environs.

Delplace's insights, along with UNESCO's proposed management plan (UNESCO 1999), culminated in four distinct visitor circuits:

1. A brief loop from the visitor centre encompassing key sites like the Temple of Bel and Nabu, the agora, theatre, tetrapylon, and Baalshamin temple.
2. An intermediate circuit adding the basilica complex and the archaeological museum to the smaller loop.
3. An expansive loop including the Camp of Diocletian and the transverse hallway, offering a comprehensive exploration of Palmyra's historical landscape.
4. An extensive loop that adds a visit to the Valley of the Tombs before concluding at the agora and theatre.

The 1999 management plan, submitted to UNESCO, outlined a comprehensive visitor management strategy

for Palmyra. It focused on thematic presentation routes that would showcase the site's aesthetic beauty, historical evolution, ancient daily life, and its global significance. The plan proposed various exploration options, including self-guided tours, unrestricted tracking, and guided tours, to enhance visitor engagement. However, the onset of conflict in Syria led to an abrupt halt in the implementation of this management plan, and access to the site became severely restricted. Tragically, between 2015 and 2017, Palmyra suffered multiple attacks, leading to significant phases of demolition (Fig. 5).

In the context of our project, we selected a route within the first pathway. This choice was influenced by its alignment with the typical short, spontaneous visits by local visitors, who traditionally gravitated towards the site's most renowned monuments. Furthermore, this route was strategically chosen for its feasibility in testing our methods effectively while encompassing areas with varying degrees of damage and historical interest. Figure 6 displays the entire site of Palmyra, while Fig. 7 presents our proposed route for the project as a proof of concept.

4.2 Data collection

Prior to undertaking fieldwork, this study obtained the necessary permissions from the DGAM to adhere to the strict security protocols at the Palmyra heritage site. The DGAM's support extended beyond providing site access; they showed a keen interest in using the outcomes of our research for their archival enrichment and potential site management strategies. This cooperation granted us comprehensive access to their archival resources, which was instrumental in incorporating extensive historical data into the web platform.



Fig. 5 Part of the vandalism in the Arc de Triomphe and the Straight Street (Source: the DGAM)

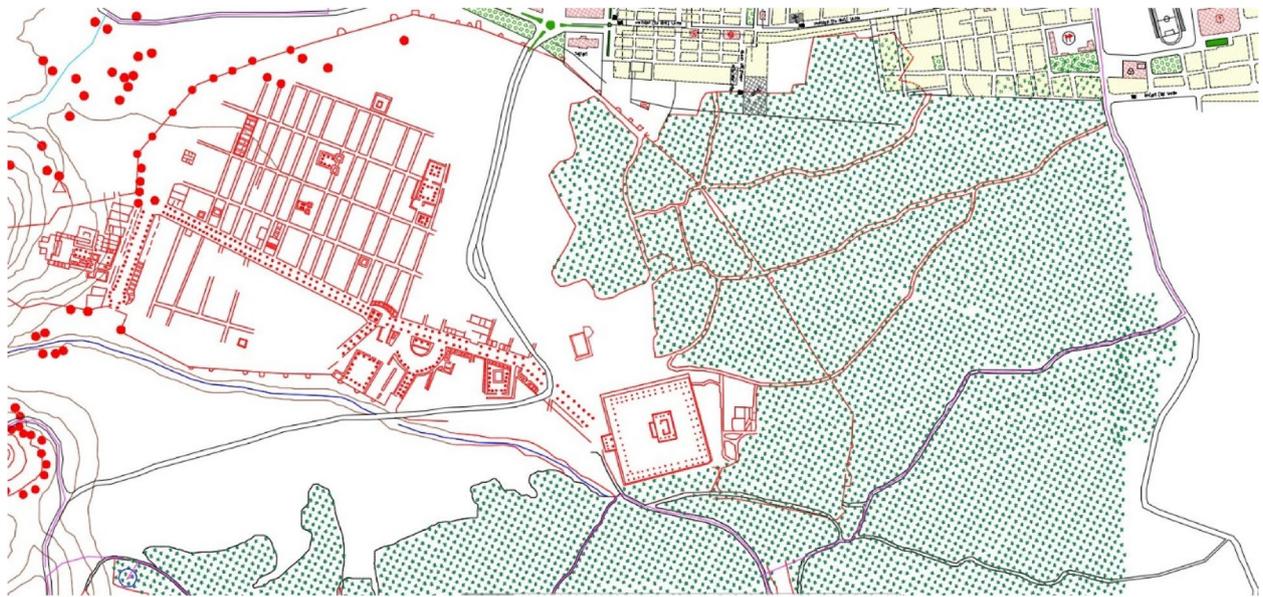


Fig. 6 The site of the archaeological area of Palmyra AutoCAD drawing (Source: the DGAM)



Fig. 7 The selected area: the research pilot project (Source: the DGAM)

However, the process of acquiring data from the DGAM archives presented some challenges. The absence of a systematic cataloguing system at both the DGAM library and the Palmyra site necessitated a rigorous and meticulous review and selection of materials. The disorganised state of the archival resources underscored the importance of our study's contribution in establishing a more refined archival system and informed our proposal

for the development of a comprehensive heritage site management plan.

For the purpose of delineating the visitor route within Palmyra, we curated a total of 71 images. Due to the well-preserved integrity of the original photographs, we determined that no further processing or optimisation was necessary. This approach was taken to preserve the authenticity of the visual data, ensuring that the images

used in our study accurately reflected the current state of the site.

4.3 Fieldwork

In March 2021, a collaborative team consisting of academics from Yarmouk University, conservation practitioners from the DGAM, and a professional photographer undertook the fieldwork in Palmyra. This multidisciplinary team navigated both emotional and physical challenges during their work at the site. The emotional toll stemmed from witnessing the extensive vandalism of this historically and culturally significant site first-hand. These challenges were further intensified by the demanding conditions of the desert environment. This experience not only highlighted the resilience required in such activities but also underscored the profound emotional impact that the preservation of cultural heritage can have on those directly involved in its conservation.

Over a period of four days, approximately 1,000 high-resolution photos and video clips were captured to document the expansive area of the site, utilising state-of-the-art 360-degree cameras. The equipment, set to operate at intervals of one second, maintained a consistent distance of approximately 40 to 60 cm—about one step—between each instance a group of photos was taken to ensure consistency in the imagery. This collection process was guided by a detailed methodology designed to cover every angle, providing a comprehensive digital

representation of the selected site. The collected photographic and videographic data will undergo advanced processing techniques to stitch images together seamlessly, creating an immersive 360-degree virtual environment. Given the vastness of Palmyra, the data collection was divided into two primary methods:

1. 360° Photographic Documentation: Utilising an Insta360 ONE X camera, spatially sequenced images were captured in INSP file format. The sequential photography began at the Temple of Bel, continued through the Arch of Triumph, spanned the grand colonnade and the Tetrapylon, and concluded at the theatre. This method ensured a comprehensive visual record of these key areas, capturing their current state in high detail.
2. 360° Videographic Survey: To enhance the documentation, a DJI Mavic drone was deployed, producing an immersive panoramic video that simulated the perspective of a pedestrian. The video was recorded at a standard elevation of 1.5 m to mimic the viewpoint of a visitor walking through the site. Additional aerial footage was captured from an elevation of 5 m, providing a broader contextual view of the site's layout and its present condition. This aerial survey was instrumental in capturing the overall spatial arrangement and the interconnections between different parts of Palmyra, offering a unique perspective that complements the ground-level imagery.



Fig. 8 An aerial view of the selected route (Source: <http://lms.ypu.edu.sy/palmyra/vtour/>)



Fig. 9 Exploration of the Theatre (Source: <http://lms.ypu.edu.sy/palmyra/vtour/>)



Fig. 10 Exploration of the Theatre (Source: <http://lms.ypu.edu.sy/palmyra/vtour/>)

This comprehensive approach to data collection, combining both ground-level and aerial perspectives, was crucial in developing a detailed and authentic representation of Palmyra for the proposed digital platform.

5 Results and discussions

The curated images from DGAM enable an archival enhancement of our proposed virtual tour, enhanced with interactive hotspots for a seamless panoramic user experience. For example, Fig. 8 presents an aerial view of the site's trajectory, while Figs. 9 and 10 offer immersive

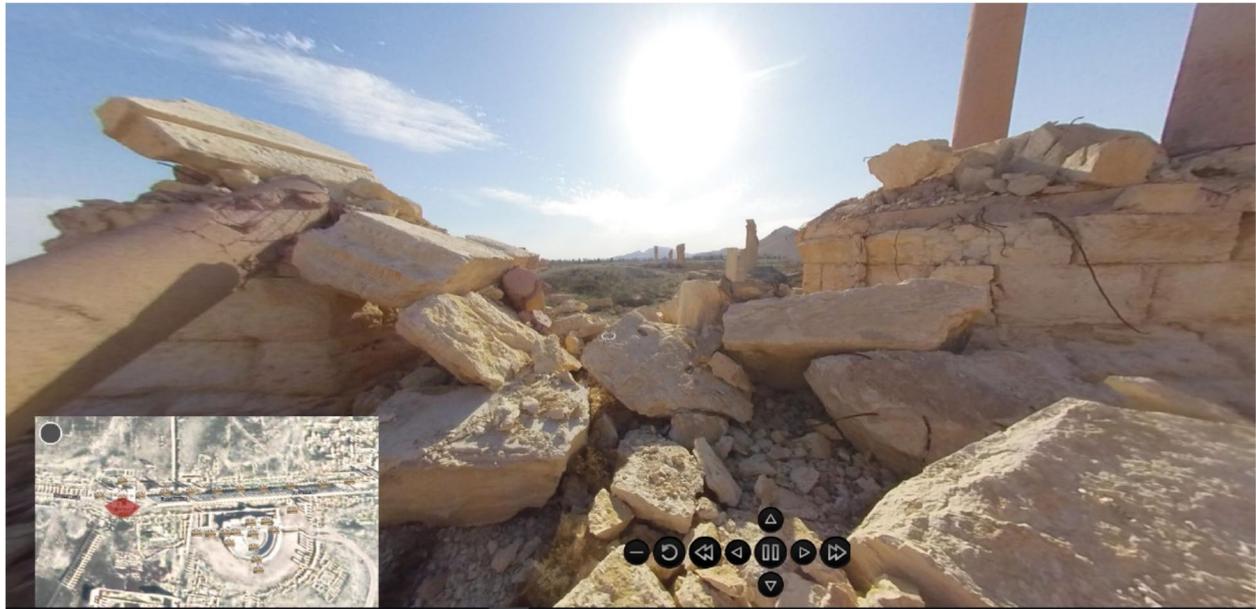


Fig. 11 The level of detail achieved (Source: <http://lms.ypu.edu.sy/palmyra/vtour/>)

explorations of the Theatre's interior and exterior, highlighting its architectural nuances. Figure 11 provides an intricate view of the monument's condition, vividly displaying weathering effects like cracks and erosion on its surface.

Complementing these images, an extensive collection of drone-captured videos, filmed from eye-level and aerial viewpoints, serve as a dynamic digital record of the site's current state. These videos provide detailed vistas that could aid scholarly analysis, thereby enhancing the understanding and dissemination of Palmyra's heritage. The web platform is available for access at <http://lms.ypu.edu.sy/palmyra/>. Our digital project stands out for three key perspectives, offering a thorough examination of the selected area of the site.

1. **Aerial Overview:** Unlike previous efforts that focused mainly on ground-level reconstructions, such as the one by Silver et al. (2018), our platform incorporates an aerial perspective, providing users with a comprehensive bird's eye view. This feature allows for a striking visual comparison between the current state and historical documentation, enhancing the understanding of the extent of the damage (Malik et al. 2021).
2. **Ground-Level Exploration:** While initiatives like the New Palmyra project concentrated on individual monument reconstructions (Mudie 2018), our platform goes further by offering a 'street view' for more detailed exploration. By integrating 360° photographic and videographic captures at both eye-level

and a 5-m elevated perspective, users can enjoy a richer, more immersive experience. While previous attempts, like the one by Iconem DGAM in collaboration with Google Arts & Culture Palmyra, produced captivating 360-degree videos, our platform surpasses this by providing a comprehensive website with scholarly documentation, ensuring an updated and thorough understanding of Palmyra's remaining structures (Stobiecka 2020).

3. **Guided Route Progression:** In contrast to static displays seen in earlier digital reconstructions, our platform offers guided navigation with site plans that enable virtual movement along documented routes.

Studies have highlighted the potential of 360 imagery to provide immersive learning experiences, yet they also note challenges such as accessibility and user engagement (Lampropoulos et al. 2021; Kuhail et al. 2022). Research indicates that 360° panoramas offer a more pronounced sense of presence compared to traditional simulation techniques, and integrating these panoramas with head-mounted displays can significantly enhance immersion, surpassing other display methods (Shinde et al. 2023). However, challenges such as cybersickness and specific technical limitations associated with 360° panoramas warrant further discussion. Some literature reveals certain caveats regarding the efficacy of 360° platforms in conveying the intended experience to viewers. While these platforms offer an innovative means of engaging with heritage sites,

literature suggests that the digital representation may not fully replicate the impact of physical presence. Studies such as those by Newman et al. (2022) indicate that virtual platforms, while beneficial for broadening access, may lack the emotional and contextual depth experienced through direct interaction with cultural heritage sites. Furthermore, Ginzarly et al. (2018) point out that digital platforms may inadvertently prioritise certain narratives over others, potentially leading to a skewed perception of history.

Indeed, our 360 platform is in the developmental stage, serving as a proof of concept showcasing only one route and a selection of buildings. As we continue testing and refining the platform, we anticipate addressing several limitations and developing the platform further alongside digital innovation. The feasibility of scaling this project to encompass the entire site with multiple routes and additional interactive features remains untested. It is also important to recognise that while 3D technologies are powerful tools for cultural presentation, they should be seen as complementary to physical conservation efforts.

6 Conclusions and recommendations

The introduction of an interactive online platform utilising 360° media represents a significant advancement in the efforts to document and preserve the world heritage site of Palmyra amidst the challenges posed by the conflict in Syria. With nearly 40% of its historic structures lost between 2015 and 2017, Palmyra faces significant threats to its preservation, compounded by its remote location and ongoing restrictive access. The platform presented in this paper not only contributes to the safeguarding process of Palmyra but also holds potential applications for other heritage sites in Syria and beyond.

By offering users access to both archival and current information, including detailed documentation of damaged historical monuments, the platform provides a comprehensive understanding of a particular area of the site's layered histories before and after demolition. Through its interactive features, users can virtually navigate different buildings and pathways within this selected area, accessing relevant archival information along their journey. Moreover, the platform serves as an informational resource for decision-makers, policy planners, researchers, and educators. Overall, this project offers hope for the continued protection and dissemination of Palmyra and other heritage sites facing similar challenges.

Our collaboration with academic and governmental entities has been instrumental in overcoming challenges associated with managing Palmyra's extensive archival data. Our initiative has brought to light the critical state of digital archival practices, characterized by

disorganised data management and insufficient meta-data, posing significant obstacles to preservation efforts.

However, it is essential to acknowledge our project's limitations. Firstly, the platform's reliance on digital technology may exclude individuals who lack access to the internet or advanced computing devices, potentially limiting its reach and impact. Additionally, the accuracy and completeness of the archival and current information provided on the platform may be subject to constraints such as the availability of data and the reliability of sources. Furthermore, while the platform offers a virtual experience of a selected area in Palmyra, it cannot fully replicate the sensory and emotional engagement of physically visiting the site. Finally, the scalability of the project to encompass other heritage sites in Syria and beyond may be hindered by logistical challenges and resource constraints.

Looking forward, the platform holds great potential for expansion in terms of routes and features to provide a more comprehensive portrayal of Palmyra and other at-risk heritage sites. This proof of concept sets a standard for wider applications in heritage site research, education, and virtual tourism. Recommendations for enhancing the platform include:

- Expanding the digital archive with a more extensive collection of images and information.
- Integrating interactive educational modules for enhanced user engagement and learning.
- Refining the user interface for more intuitive navigation and exploration.
- Complementing the 360° media with advanced 3D modeling to enrich the immersive experience.
- Implementing user feedback mechanisms for platform development attuned to audience needs.

Efforts to boost user engagement should prioritize interactive learning, broad public outreach, and the incorporation of the platform into educational curricula, which is currently under development by Yarmouk Private University in Syria.

Abbreviations

DGAM	Directorate General of Antiquities and Museums in Syria
ICCROM	International Centre for the Study of the Preservation and Restoration of Cultural Property
ICOM	International Council of Museums
ICOMOS	International Council on Monuments and Sites
ISIS	Islamic State of Iraq and Syria
SAC	Sharjah Antiquities Center
UNESCO	United Nations Educational, Scientific and Cultural Organization

Acknowledgements

We express our gratitude to the University of Liverpool's Virtual Fellowship Scheme for the invaluable training and evaluation they provided. We extend our thanks to Yarmouk Private University for generously hosting the web platform. Our appreciation goes to DGAM for facilitating access to the site and granting us permission to access the Palmyra archives. Special thanks to Shadi

Martk, the talented photographer involved in this project. We are also grateful to Billal Alshamaa and his dedicated team for their contributions. Lastly, we would like to thank Dr. Ahmad Deeb, Dr. Mayassa Deeb, and Maryam Hamoudeh for their invaluable sources and references.

Authors' contributions

The project was led by RD with all authors involved in the project's conception, design and interpretation of data. RD led on acquisition and dissemination of data at Palmyra and completion of the first draft manuscript. This was then edited and expanded by AA and NW, before final approval by all authors. The revision was led by AA and approved by all authors.

Funding

This work was supported by funding from the University of Liverpool's Virtual Fellowship Scheme <https://www.liverpool.ac.uk/humanities-and-social-sciences/research/training-and-support/virtual-fellowships/>.

Availability of data and materials

The web platform produced as part of this research project is available at <http://lms.ypu.edu.sy/palmyra/>.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Received: 26 July 2023 Accepted: 3 April 2024

Published online: 28 May 2024

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