From Digital Twin to Memory Twin: A Holistic Framework for Cultural Heritage Documentation, Interpretation, and Adaptive Reuse

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Abstract

Cultural heritage worldwide is increasingly at risk due to climate change, armed conflict, urbanisation, illicit trafficking, and the broader forces of globalisation. These natural and human-induced threats contribute to the irreversible loss of both tangible and intangible cultural assets. In response, heritage digitisation has advanced significantly - from basic 2D documentation to sophisticated 3D technologies - underscoring the urgent need for structured, ethically grounded methodologies in data acquisition.

This paper introduces the Memory Twin: an innovative framework that redefines digital heritage representation by integrating high-fidelity visuals with Paradata, Metadata, Data and intangible cultural values. Building on and extending the Holistic Historic Building Information Modelling (HHBIM) approach, the Memory Twin enriches digital heritage environments with narrative, emotional, and community-driven content, fostering inclusive access, transparency, and long-term cultural significance.

Developed within the framework of the EU-funded HERITALISE project, this paper explores both the theoretical foundations and practical application of the Memory Twin through a detailed case study of Villa Portelli in Malta. By integrating 3D scanning, archival research, oral histories, and participatory engagement, the project constructs a multi-dimensional digital portrayal of the site's material, historical, and social layers.

Aligned with the FAIR (Findable, Accessible, Interoperable, Reusable) and CARE (Collective Benefit, Authority to Control, Responsibility, Ethics) principles, the Memory Twin ensures semantic interoperability, ethical stewardship, and community empowerment. It marks a paradigm shift in heritage digitisation - from static documentation toward participatory, value-driven preservation - offering a scalable, sustainable model for safeguarding cultural heritage amid global challenges.

1. Introduction

Cultural heritage around the world faces continuous and escalating threats from a range of overlapping global crises. Climate change, armed conflict, urban overdevelopment, and illicit trafficking are accelerating the degradation and loss of both tangible and intangible heritage. Sites of profound historical and cultural significance are being irreversibly altered or destroyed in a matter of hours.

In 2018, a devastating fire engulfed the National Museum of Brazil, destroying over 90% of its 20-million-item collection. The loss marked an irreparable blow to Latin America's scientific and cultural heritage (Araujo, 2019). In Peru, increased rainfall and landslides driven by climate change are eroding the ancient citadel of Machu Picchu (Sassa et al., 2005). Armed conflict presents an even more immediate and violent threat. A stark precedent is the Taliban's 2001 destruction of the Bamiyan Buddhas, two monumental 6th-century statues, which sparked global outrage over the loss of cultural heritage (Margottini, 2014). Since 2022, Russia's invasion of Ukraine has resulted in the destruction of churches, museums, and historic urban centres (Alfatlawi, 2024). Similarly, in Gaza, the Great Omari Mosque, one of the oldest Islamic sites in the region, was reduced to rubble during the 2023–2024 conflict (Saeed, 2025).

Urbanisation and unchecked tourism also exert growing pressure (Francini and Rozochkina, 2024). Venice is one of the most trafficked harbours in Italy, with important emissions of all pollutants, and that this contributes to the corrosion of built heritage, foundation erosion, and environmental degradation (Seraphin et al., 2018). Moreover, looting and trafficking during armed conflict: conflicts in the Middle East, particularly in Syria and Iraq, have led to widespread looting of archaeological sites. These looted artefacts are then trafficked through international networks, often ending up in private collections or on the black market (Al-Azm, 2023).

A significant and evolving threat to cultural heritage lies in the absence of harmonised standards for 3D digitisation. Without commonly accepted benchmarks, the process of digitising a cultural heritage site or artefact in one country, such as Malta, may differ substantially from similar efforts elsewhere, resulting in inconsistencies in quality, interoperability, and long-term preservation. This fragmentation undermines the potential for shared access, comparative research, and sustainable digital heritage management. The VIGIE 2020/654 study, commissioned by the European Commission, addressed this gap by systematically mapping parameters, formats, standards, benchmarks, methodologies, and guidelines for the 3D digitisation of tangible cultural heritage (Ioannides et al., 2022).

A key innovation of the study was the introduction of a standardised approach to the recording of paradata for digital acquisition. This was a significant set forward in the state-of-the-art for the digitisation of cultural heritage resources, and the first practical attempt at the parameterisation of paradata - the record of the tools, decisions, and processes used during digitisation originally proposed by The London Charter for the

Computer-Based Visualisation of Cultural Heritage (2006) defined as "*Information about human processes of understanding and interpretation of data objects. .... It is closely related, but somewhat different in emphasis, to 'contextual metadata', which tend to communicate interpretations of an artefact or collection, rather than the process through which one or more artefacts were processed or interpreted.*". This paradata effectively functions as a certificate of quality about the Data Acquisition, offering insight into the reliability of the digitised results and enhancing intellectual transparency and trust in digital representations essential if the data recorded is to be available for reuse with confidence.

Building on these findings, cultural heritage owners and stakeholders are under increasing pressure to act swiftly and strategically to document, digitise, and safeguard their assets. This urgency is now widely recognised at the international level. The European Commission's 2021 Recommendation on a Common European Data Space for Cultural Heritage urges Member States to accelerate digitisation efforts, uphold high-quality standards, and promote open access to digital cultural content (European Commission, 2021). Similarly, UNESCO's Dive into Heritage[1] initiative provides a global platform for the digital preservation and presentation of heritage sites, integrating 3D technologies, storytelling, and immersive experiences. These frameworks not only highlight the scale of the challenge but also present an opportunity to reimagine how digital tools can protect at-risk heritage, enhance resilience, and foster broader, more equitable access to cultural knowledge.

This shift is part of a broader evolution in cultural heritage digitisation, which has progressed from early 2D imaging and documentation techniques to sophisticated 3D data acquisition systems. While 2D digitisation improved visual accessibility and archival stability, it offered limited spatial and contextual insight. The emergence of 3D technologies - such as LiDAR, photogrammetry, and structured light scanning - has enabled the capture of precise geometric detail and spatial relationships, marking a significant paradigm

2. The Evolution of Digitisation of Cultural Heritage

Latest advanced technologies in 3D digitisation, led to the development of Building Information Modelling (BIM) which originated within the fields of architecture, engineering, and construction, enabling precise digital representations of buildings through parametric objects and data-rich components (Eastman et al., 2018). BIM systems facilitate the lifecycle management of built environments, incorporating spatial geometry, structural systems, and material information. It fulfils only the needs of architects, engineers and the construction industry in general. However, BIM's conventional focus on standardised, contemporary architectural forms renders it insufficient for addressing the complex geometries and non-standard features often found in historic and ancient structures.

In response, the field of Heritage Building Information Modelling (HBIM) emerged, adapting BIM methodologies for cultural heritage applications. HBIM integrates irregular geometries, historical fabric, and conservation data into digital workflows, thus enhancing the capacity to model, assess, and manage historical sites (Murphy et al., 2013). Yet, HBIM still prioritises tangible aspects - structure, materiality, and physical

conservation - often overlooking the socio-cultural, narrative, and intangible dimensions intrinsic to heritage value.

To bridge this gap, the notion of Holistic Heritage BIM (HHBIM) has been proposed. HHBIM aims to expand beyond architectural and historical documentation by incorporating interdisciplinary data sources; archival research, oral histories, community engagement, and environmental context. This approach recognises that heritage is not merely a static remnant of the past but a living, layered narrative embedded in place, memory, and identity (Brumana et al., 2019). In this model, the digital representation of a site becomes a platform for inclusive interpretation, knowledge co-creation, and social engagement.

Building upon HHBIM, the Memory Twin represents the next conceptual evolution in heritage digitisation. While HHBIM enhances the richness and complexity of digital heritage models, the Memory Twin explicitly embeds paradata (documentation of the creation process), metadata, and intangible values such as affective responses, contested histories, and community narratives within a dynamic, interoperable framework (Giaccardi, 2012). It shifts the emphasis from preservation and representation to meaning-making and memory construction, fostering ongoing dialogue between past and present.

The Memory Twin is not merely a more detailed model; it is a living, evolving construct, capable of adapting to new inputs, narratives, and technologies. By aligning with FAIR data principles and integrating into broader infrastructures like GIS platforms and the European Common Data Space for Cultural Heritage, it ensures sustainable access, monitoring, public engagement, and long-term relevance in digital heritage practice (Wilkinson et al., 2016).

3. Authentic Identity and the Digitisation of Cultural Heritage

The concept of authentic identity within cultural heritage digitisation represents a shift from essentialist and object-centred frameworks toward more dynamic, context-driven understandings of heritage and its role in identity construction. Rooted in critical heritage discourse, this approach recognises that identity is not a fixed essence preserved through the material integrity of heritage assets, but a process that is continuously negotiated, performed, and lived through cultural memory, social practices, and affective engagement.

The *Nara Document on Authenticity* (1994) provides a foundational reorientation in this regard. In contrast to earlier conservation doctrines, such as the *Venice Charter* (1964), which largely privilege material integrity and formal consistency, the Nara Document advocates for a pluralist conception of authenticity, grounded in specific cultural contexts. It expands the criteria for evaluating authenticity to include not only form and material, but also use, function, traditions, techniques, setting, and, significantly, "spirit and feeling" (ICOMOS, 1994). Authenticity, under this model, is not inherent in the object but is a negotiated and culturally contingent value.

This redefinition has profound implications for the digitisation of cultural heritage. Digital heritage practices that aim merely to replicate physical form risk reproducing what Laurajane Smith (2006) terms the *Authorised Heritage Discourse* (AHD) - a dominant, expert-led narrative that marginalises alternative voices and lived experience. Such practices often reduce

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[1] UNESCO 'Dive into Heritage' initiative website https://whc.unesco.org/en/dive-into-heritage

heritage to static representations, overlooking the social and emotional dimensions through which people engage with and reinterpret the past. In contrast, approaches aligned with the Nara framework and critical heritage theory recognise the importance of community participation, memory work, and affective experience in shaping heritage's meaning.

Smith emphasises that heritage is a "cultural and social process" through which identities are created and negotiated, not passively inherited. Identity, in this view, is performative and situated - it. emerges through storytelling, ritual, and everyday engagement with heritage landscapes and objects. This relational and processual understanding requires digitisation practices to go beyond documentation and into the realm of meaning-making, allowing for plural, conflicting, and evolving interpretations of what heritage signifies.

Authentic identity in the context of digitised heritage cannot be confined to visual or structural fidelity. It must encompass the intangible, emotional, and narrative elements that constitute the lived realities of heritage communities. This broader, more inclusive conceptualisation forms the basis for future methodological frameworks that move beyond object-oriented digitisation toward digital ecosystems that reflect the complex ways in which identity is entangled with memory, place, and cultural continuity. This is what the Memory Twin concept aims to encompass.

4. Memory Twin Architecture and Enabling Technological Methodologies

The Memory Twin represents a conceptual and operational advancement in the digitisation of cultural heritage. It expands the scope of digital heritage practice by incorporating not only the visual and spatial fidelity of physical assets but also the interpretive, affective, and ethical dimensions of heritage representation. At its core, the Memory Twin integrates a range of technological enablers, certified documentation practices, and interdisciplinary methodologies, underpinned by the FAIR (Findable, Accessible, Interoperable and Reusable) and CARE (Collective benefit, Authority to control, Responsibility and Ethics) principles (Wilkinson 2016 and Carroll 2024 respectively). Together, these components provide a robust and sustainable framework capable of capturing the full socio-cultural and historical complexity of tangible and intangible heritage.

A foundational aspect of the Memory Twin is its dual reliance on metadata and paradata. Metadata provides essential descriptive, administrative, and structural information that identifies and contextualises digital cultural assets. Established standards facilitate semantic interoperability and long-term preservation. These metadata schemas allow cultural heritage institutions to organise, access, disseminate and share digital assets across platforms and communities.

Paradata, by contrast, documents the processes, decisions, and interpretive frameworks involved in the creation of digital surrogates. It records technical parameters such as equipment used, environmental conditions, resolution settings, post-processing workflows, and the rationale behind specific modelling choices. While metadata addresses the "what" of digitisation, paradata addresses the "how" and "why," offering critical transparency into the conditions and decisions that shaped the final output. The inclusion of paradata not only enhances scientific reproducibility and accountability but also mitigates the risk of misrepresentation, particularly in AI-

assisted reconstructions, where visually convincing outputs may obscure interpretive biases.

The Memory Twin framework further advocates for certified and standardised methodologies in data acquisition. Recognising the fragmentation and inconsistency across digitisation initiatives, it promotes internal protocols that document scanning pipelines in a structured and replicable manner. At Heritage Malta and through European projects such as HERITALISE [2] and STECCI [3], cross-departmental workflows are being piloted to integrate curatorial, conservation, and technological expertise into a unified data acquisition model. This holistic approach enables the development of certifiable standards that can be adopted across institutions and national contexts, ensuring consistency, interoperability, and long-term reusability of digital assets.

Figure 1. Aerial photogrammetry render of Villa Portelli and its surrounding gardens, captured as part of the HERITALISE project. The site serves as one of four demonstration locations within the project framework.
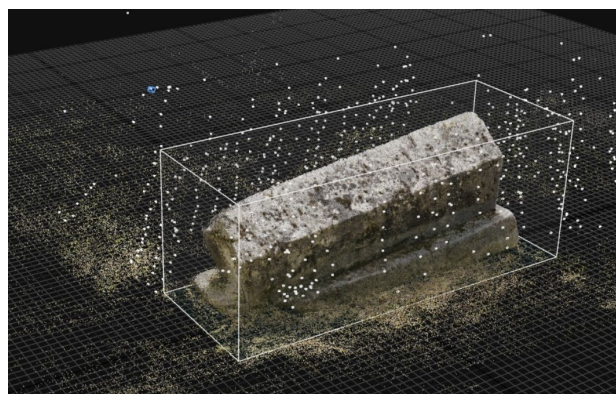

Figure 2. 3D render of a Stećak scanned by Heritage Malta as part of the STECCI project. This medieval tombstone, located in Bosnia, is one of several documented for the project's digital preservation efforts.

The ethical and technical integrity of the Memory Twin is reinforced through the adoption of the FAIR and CARE principles. The distinctive feature of the Memory Twin is its capacity to integrate multi-layered forms of knowledge such as structural, material, historical, conservation, curatorial, and architectural. This demands multidisciplinary input and

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[2] HERITALISE "Horizon Europe: Heritage buildings and objects' digitisation & visualisation within the cloud." Project information can be found online at https://heritalise-eccch.eu

[3] STECCI "Horizon Europe: Stone monument ensembles and the climate change impact" Project information can be found online at https://steccihorizoneu.com

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collaboration, ensuring a holistic digital representation that serves both internal operational needs and the diverse expectations of external stakeholders, including researchers, conservators, and the public, drawing from diverse disciplinary domains and community inputs. It moves beyond traditional, object-centred digital twins by incorporating oral histories, rituals, traditions, and intangible cultural expressions into the digital record. This integration is achieved through participatory practices such as co-curation, collaborative storytelling, and interactive annotation. The result is a living digital construct that not only documents physical form but also preserves the narratives, memories, and emotional resonances that endow heritage with meaning.

Figure 3. Diagram showing the various users and stakeholders of the cultural heritage site, who could contribute and use the memory twin.

Capturing intangible cultural heritage (ICH) presents a particular methodological challenge that the Memory Twin seeks to address. ICH elements, such as music, dance, oral traditions, and social practices, are often transmitted informally and vary across time and context. The UNESCO 2003 Convention offers a conceptual basis for safeguarding ICH, but its implementation in digital environments requires adaptable, culturally sensitive methodologies. The Memory Twin operationalises this by employing long-term community engagement strategies, ethical documentation protocols, and multimedia tools that reflect the dynamic nature of intangible heritage.

Furthermore, the Memory Twin supports semantic interoperability through the use of ontology-based metadata frameworks, enabling integration with wider cultural heritage infrastructures, such as national GIS platforms and the European Common Data Space for Cultural Heritage. CIDOC-CRM and Europeana Data Model (EDM) facilitate the semantic structuring necessary for aligning data across institutions, languages, and platforms, ensuring that digitised heritage assets are accessible and meaningful in diverse contexts.

Crucially, memory is positioned as a functional layer within the Memory Twin architecture. Rather than viewing memory as an ancillary or subjective component, the framework treats it as a central element of cultural heritage. It acknowledges the plurality, contestation, and evolving nature of memory, particularly in cases of dissonant or multi-vocal heritage. By embedding conflicting narratives and community perspectives into the digital model, the Memory Twin reflects the dialogic and negotiated nature of identity and authenticity, as articulated in the Nara Document on Authenticity (ICOMOS, 1994).

The Memory Twin thus exemplifies a holistic, ethical, and participatory model for cultural heritage digitisation. Its strength lies in the integration of certified documentation practices, ethical frameworks, semantic technologies, and multi-disciplinary collaboration. By preserving not only the form but also the meaning and memory of heritage, the Memory Twin offers a sustainable and inclusive approach to digital preservation that responds to both contemporary technological opportunities and the deeper human need to connect with the past.

5. Translating Memory Twin Theory into Practice

5.1 Bringing the Dockyard to Life: How the Memory Twin Was Used to Digitise Malta's Maritime Heritage

The digitisation of the Dockyard Collection at the Malta Maritime Museum represented a pioneering application of the Memory Twin framework, demonstrating a holistic, ethical, and participatory model for documenting both tangible and intangible cultural heritage. Led by Heritage Malta's Digitisation Unit, this multi-year project advanced beyond conventional digital twin methodologies to produce rich, multilayered representations of Malta's maritime industrial legacy - most notably that of the former Malta Drydocks.

At the core of the initiative was the systematic digitisation of over 8,000 artefacts, including archival photographs, ship models, tools, and ledgers, using 3D laser scanning, photogrammetry and high-resolution photography, together with structured metadata standards. The data acquisition of the physical artefacts was complemented by a large-scale oral history programme through which the team recorded more than 200 hours of testimonies from over 130 former dockyard workers. These narratives, rich in memory, emotion, and technical detail, were carefully indexed with metadata and paradata and integrated into Heritage Malta's collections management infrastructure and publish on Europeana.

Figure 4. Installation inspired by dockyard lockers, linking workers' portraits to their recorded oral histories via QR codes.

This integration of digital assets with personal testimony gave rise to the Malta Dockyard Memory Twin, a digital construct that embedded artefacts within its broader historical, social, and emotional contexts. The results of this digitisation efforts were publicly realised through "*An Island at the Crossroads*", an immersive exhibition that brought together digitised artefacts, oral histories, and interactive installations to explore Malta's evolving maritime identity. A central feature of the exhibition was a 4D digital installation within a former grain silo within

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the museum, where projection mapping, audio recordings, and animated 3D assets recreated the experiential environment of the dockyard, offering visitors an emotionally resonant and multisensory experience.
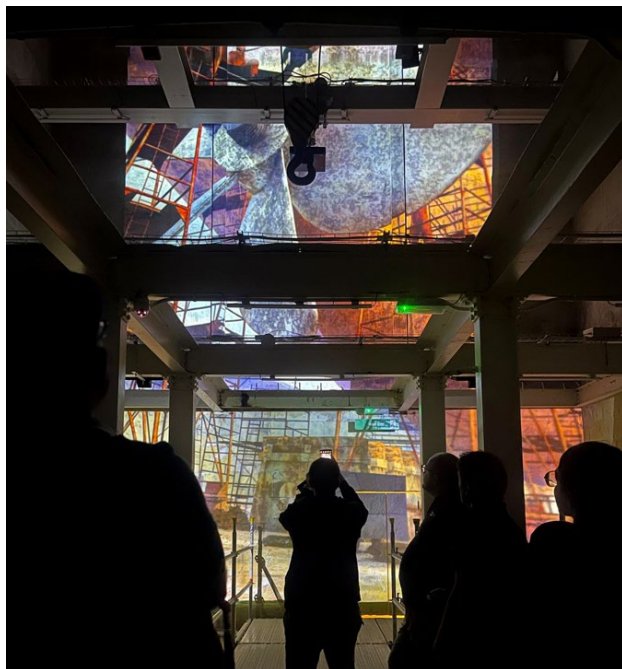

Figure 5. 4D dockyard experience inside the silo exhibition space.

In doing so, the Memory Twin approach transcended the traditional objective of preservation and became a dynamic act of cultural activation, connecting artefacts to people, stories to places, and heritage to identity. The project also culminated in the publication of a multimedia book - *Ilhna mit-Tarżna* (Voices from the Dockyard) that combined curated oral history excerpts, archival imagery, and QR-linked audio clips, making these memories accessible beyond the museum context. As a methodological model, the Dockyard Collection digitisation project demonstrated not only the viability but the transformative potential of the Memory Twin framework, reinforcing the idea that memory is not a supplementary feature of heritage digitisation, but its interpretive core.

A key strength of the project lay in its multidisciplinary and participatory approach. The digitisation effort brought together curators, technologists, oral historians, and designers, working collaboratively across departments. Most notably, former dockyard employees played an active role as volunteers, contributing not only to the physical digitisation of artefacts but also to their interpretation. Their lived experience provided invaluable context, enriching metadata, guiding thematic choices, and informing outreach activities. From co-curating exhibition content to leading public talks, these volunteers became co-creators of heritage, ensuring that the Memory Twin reflected authentic narratives rooted in personal memory and community identity.

5.2 Applying Memory Twin to a Cultural Heritage Building

The HERITALISE project (2025–2028), funded under Horizon Europe, advances the digitisation of cultural heritage through the integration of multi-sensor technologies - such as LiDAR,

photogrammetry, and Reflectance Transformation Imaging - combined with AI-driven processing and semantic knowledge graphs. The project seeks to benchmark and enhance digitisation standards while enabling cost-effective, scalable workflows that adhere to FAIR and CARE data principles. Within this framework, the *Villa Portelli case study*, one of four under investigation, explores the development of Memory Twins. Central to this concept is the commitment to preserving and accentuating authentic identity throughout all digital acquisition processes.

Figure 6. The main entrance and façade of Villa Portelli.

Figure 7. Interior view from Villa Portelli, overlooking Kalkara Creek and the Grand Harbour.

Villa Portelli was selected as a flagship case study for the Memory Twin framework due to its rich historical, architectural, and socio-cultural complexity. Overlooking Kalkara Creek and the Grand Harbour, the villa embodies Malta's stratified heritage, from its 18th-century origins as a rural retreat to its transformation into a British Admiralty residence and later a public institution. Its architectural evolution, which fuses Maltese baroque, neoclassical revival, and British colonial styles, reflects centuries of adaptation and layered identities. These features make Villa Portelli an ideal candidate for a holistic documentation approach that integrates both tangible and intangible heritage dimensions.

The Memory Twin framework, developed under the Horizon Europe-funded HERITALISE project, enables a multidimensional representation of heritage sites. At Villa Portelli, this includes advanced 3D scanning, archival research, oral history collection, and community engagement, culminating in a Holistic Heritage Building Information Model (HHBIM) linked to Malta's national GIS. This model captures not only the villa's architectural and material fabric but also its evolving social significance.

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Figure 8. LiDAR scanning of Villa Portelli during fieldwork for the HERITALISE project.

Importantly, the project foregrounds the villa's enduring role within the Kalkara community. While its use by British naval officers and dignitaries is well documented, the Memory Twin approach also highlights the lived experiences of local residents. Oral histories from former workers, neighbours, and long-time Kalkara inhabitants reveal how the villa's gardens, events, and presence shaped community identity. From serving as the residence of the Commander-in-Chief of the Mediterranean Fleet to housing a nautical school and later government offices, Villa Portelli has remained a landmark deeply embedded in the collective memory of Kalkara's people.

This participatory documentation process ensures that heritage is not merely preserved but reinterpreted through the voices of those who experienced it. By integrating community narratives into the digital model, the project fosters a more inclusive and democratic form of heritage stewardship. Villa Portelli thus becomes more than a monument - it is a living archive of shared memory, bridging past and present.

As a demonstrator site, Villa Portelli lays the methodological foundation for a new approach to cultural heritage digitisation. It offers a scalable model for other heritage sites in Malta and beyond, promoting holistic, community-driven documentation practices that honour both history and lived experience whilst ensuring authentic identity and maximise reuse and interoperability of digitised assets.

Figure 9. Processing and refinement of LiDAR data from Villa Portelli, supporting the creation of an extended HHBIM model.

However, implementing this framework presents significant challenges. Technically, integrating high-fidelity 3D data with metadata, paradata, and intangible content is resource-intensive and lacks standardised tools. Paradata, crucial for transparency and reproducibility, is often under-documented, leading to fragmented datasets. Additionally, incorporating narrative and sensory data introduces complexity in data modelling and storage. Addressing these challenges is essential to ensure the Memory Twin remains a robust, interoperable, and evolving tool for heritage preservation and engagement.

Institutionally, siloed practices and limited interdisciplinary collaboration hinder the holistic integration of tangible and intangible heritage. Digitisation efforts often prioritise technical output over contextual meaning, underscoring the need for cultural institutions to adopt participatory governance models, cross-sectoral training, and robust certification mechanisms.

6. Conclusion

The Memory Twin approach represents a paradigm shift in cultural heritage digitisation, moving beyond static, object-focused models to embrace a dynamic, participatory, and ethically grounded framework. By integrating certified documentation practices, paradata, and intangible cultural values, it ensures that digital surrogates reflect not only the physical form but also the lived meaning and memory of heritage sites.

The Villa Portelli case study demonstrates how this approach can be applied in practice, combining advanced 3D technologies with community engagement and interdisciplinary collaboration. Aligned with FAIR and CARE principles, the Memory Twin fosters transparency, inclusivity, and long-term relevance.

Rather than treating digitisation as an endpoint, the Memory Twin initiates an ongoing dialogue between heritage and its stewards - bridging past, present, and future. It offers a scalable, adaptable model for cultural institutions seeking to preserve heritage in ways that are both technologically robust and socially meaningful.

Acknowledgements

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