Beyond Digital Twins: Introducing the Memory Twin for Cultural Heritage

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ABSTRACT: The Memory Twin extends the Digital Twin concept by addressing the challenges of preserving digital cultural heritage holistically. Unlike traditional Digital Twins, which focus on physical attributes, the Memory Twin integrates paradata, metadata, and data to provide a compre-hensive representation of cultural assets. This layered approach ensures the preservation of historical significance, contextual narratives, and physical characteristics. By embedding contextual and struc-tural information, Memory Twins transform static digital copies into dynamic, interactive resources. This framework enhances accessibility, supports advanced archival practices, and fosters immersive user experiences. As an adaptable solution, the Memory Twin enriches both tangible and intangible heritage, offering innovative strategies for preservation and engagement in the digital age.

1. INTRODUCTION

The concept of Digital Twins has significantly impacted diverse fields, enabling detailed digital replicas of physical entities for analysis, simulation, and engagement ([3], [11]). Within the domain of cultural heritage, Digital Twins have transformed the way artifacts and sites are preserved, studied, and accessed ([9], [17]). By creating virtual models of cultural assets, this approach supports conservation, facilitates remote interaction, and enhances educational and interpretative experiences ([3]). However, the traditional Digital Twin model often focuses narrowly on replicating physical characteristics, leaving out the broader contextual and experiential dimensions critical to understanding cultural heritage fully ([19], [20]).

The Memory Twin addresses these limitations by integrating three essential layers: paradata, metadata, and data ([1], [10]). While metadata provides structured information describing attributes like provenance, content, and quality ([6]), and data constitutes the core digital representations (e.g., 3D models, photographs, and textual records) ([7]), paradata serves as a contextual layer that captures the processes, decisions, and methodologies involved in digitization ([1], [19]). This integration offers a holistic approach to preservation, emphasizing not only the physical attributes but also the narratives, workflows, and interpretative frameworks that give cultural assets their deeper significance ([5], [17]).

Since its adoption in 2006 through the London Charter, the concept of paradata has been a pivotal element in the digital documentation of the past ([19]). Initially introduced to address issues like expressing alternative interpretations, estimating probabilities, and supporting scholarly interrogation ([11]), paradata has grown to encompass workflows, data acquisition methods, and sustainability practices ([9]). It has become a cornerstone of high-quality digital cultural heritage (DCH) resources, working alongside metadata and geometric data to enrich 3D assets, foster knowledge creation, and promote reusability ([17]). Despite its importance, the DCH community continues to grapple with the definitive differentiation and articulation of paradata and metadata, as well as their specific benefits for stakeholders, owners, and the broader multidisciplinary community ([8]).

The urgency of establishing clearer definitions and frameworks for paradata is further underscored by the European Commission's Recommendation for the Collection of 3D-Digitized Cultural Heritage Assets ([6], [19]). Addressing these gaps was the focus of two pivotal webinars held under the auspices of the UNESCO Chair on Digital Cultural Heritage and the EU Eureka3D project in April and May 2024 ([1]). These sessions brought together international experts to review and establish definitions for paradata and explore its

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applicability throughout the digitization lifecycle ([3]).

The Memory Twin integrates these advancements, transforming traditional digital models into comprehensive, interactive, and contextually enriched resources ([1]). By embedding paradata and metadata alongside core data, it redefines how cultural heritage is preserved, accessed, and interpreted ([4]). This paper delves into the theoretical foundations of the Memory Twin and its practical applications, demonstrating its potential to advance cultural heritage management and engagement in the digital age ([8], [10]).

2. MEMORY TWIN CONCEPT

The Memory Twin framework (***Figure 1***) represents a transformative evolution from the traditional Digital Twin, introducing a holistic approach that integrates physical, historical, contextual, and experiential dimensions of cultural artifacts. This expanded concept moves beyond replicating physical attributes to capturing the narratives, workflows, and decisions that give cultural heritage its richness and depth. The implementation of this concept is guided by a structured workflow that ensures the accurate and meaningful preservation of cultural heritage, culminating in the dissemination of validated knowledge.

The workflow begins with a clear understanding and documentation of primary stakeholder requirements. These stakeholders, ranging from cultural institutions and researchers to local communities, provide insights into the desired outcomes and contextual significance of the artifacts or sites being documented. These requirements form the foundation for creating digital tangible objects, which act as the core components of further data processing and representation.

In the next phase, physical cultural objects are converted into digital formats using advanced digitization techniques such as 3D scanning, photogrammetry, and laser scanning. These methods capture high-fidelity details of the artifacts, ensuring that the physical attributes, textures, and spatial configurations are preserved. To enrich these digital representations, inputs from subject matter experts, historians, and practitioners are incorporated. Their contributions provide valuable historical context and practical insights, ensuring that the digital models are not only accurate but also meaningful.

The gathered information is then classified into three key layers: paradata, metadata, and data. Paradata captures the processes, methodologies, and decisions involved in the digitization workflow, offering transparency and supporting future research or replication efforts. Metadata provides structured information about the content, attributes, and context of the artifacts, facilitating efficient organization, retrieval, and management. The data layer includes the core digital representations, such as 3D models, high-resolution images, and textual documentation.

These three components are combined to create a comprehensive digital representation. This integrated information undergoes rigorous quality assurance checks to ensure its accuracy, relevance, and completeness. The quality assurance process includes evaluating hypotheses based on the collected data, formulating research questions, conducting experiments, and analyzing results. The aim is to validate the information and enhance its credibility as a scholarly and educational resource.

Additionally, the workflow involves creating narratives and storytelling elements to provide context and make the digital representations more engaging. This step ensures that the resulting digital models are not just static records but dynamic, interactive resources that can support educational initiatives and foster public engagement. The process also assesses the condition of the materials and monitors the structural integrity of the physical objects represented digitally, ensuring that both digital and physical preservation goals are met.

The final step involves the dissemination of the validated knowledge. The curated digital resources are published on platforms like Europeana and national aggregators, making them accessible to a wide audience. These platforms enhance the visibility of the cultural heritage assets, supporting research, education, and public engagement on a global scale.

This structured workflow, illustrated in the paper's accompanying chart, highlights the systematic approach required to address the complexity of cultural heritage digitization. By incorporating stakeholder requirements, leveraging advanced technologies, and ensuring rigorous quality control, the framework delivers high-quality digital resources that balance scholarly rigor with accessibility and engagement. This ensures that cultural heritage is not only preserved but also made relevant and meaningful for future generations.

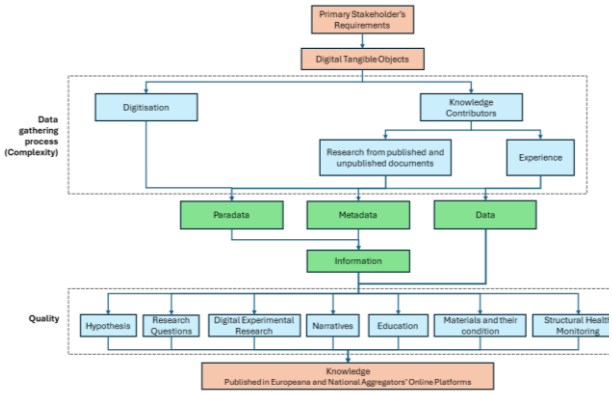

Figure 1: *Memory Twin concept*

CASE STUDIES

3.1 FIKARDOU VILLAGE

Fikardou village (***Figure 2***) provides a compelling case study in how a layered, integrated approach to cultural heritage preservation can address the challenges of both tangible and intangible heritage ([16], [21]). Situated in the Troodos Mountains of Cyprus, this traditional settlement embodies the architectural and cultural practices of rural Cyprus from the 18th and 19th centuries. The village faced significant threats due to urban migration and abandonment, which left many of its structures in a state of disrepair. Recognizing its value, the Department of Antiquities designated Fikardou as an "Ancient Monument" in 1978 ([21],[7]), initiating preservation efforts that included restoring key buildings and revitalizing its infrastructure. These efforts secured its listing on the UNESCO Tentative List of World Heritage Sites, underscoring its global cultural significance ([21]).

The documentation process began with an extensive data acquisition phase, employing advanced technologies such as terrestrial laser scanning, drone imaging, and 360-degree photography. These tools enabled the capture of high-fidelity details of the village's architecture, including its stone-built homes, cobbled streets, and historical landmarks. The use of drones proved particularly effective in documenting Fikardou's spatial layout, capturing aerial views that contextualize its setting within the surrounding natural landscape. The raw data gathered was processed into detailed 3D models, forming the foundation for digital representations that preserve the physical attributes of the village.

To enhance the value of these digital representations, the project integrated contextual information at multiple levels. Detailed records of the methodologies, tools, and decisions employed during the digitization process were documented as paradata([1],[2]). This layer of information provides insights into the workflows and techniques used, ensuring transparency and enabling future researchers to replicate or build upon the work. For example, decisions regarding scanning angles, environmental conditions, and the selection of specific technologies were meticulously recorded to create a comprehensive account of the digitization process.

Metadata played an equally crucial role, serving as the structural framework for organizing the digital archive. Each element of the village, from individual buildings to smaller architectural features, was annotated with attributes such as historical significance, construction materials, and architectural styles. This metadata not only facilitates efficient retrieval and management of the digital assets but also enhances their usability for various stakeholders, including researchers, educators, and policymakers.

Beyond its physical heritage, the project recognized the importance of Fikardou's intangible cultural elements. Oral histories and traditional practices were documented through interviews with residents, many of whom shared stories passed down through generations. These narratives provide a deeper understanding of the village's identity, shedding light on its role as a cultural hub in the region. For example, residents recounted communal activities, agricultural practices, and seasonal celebrations that shaped the social fabric of Fikardou. Incorporating these stories into the digital archive ensures that the cultural context of the village is preserved alongside its physical structures.

The outcomes of this effort were made accessible through an interactive digital platform, designed to engage both academic and public audiences. Users can explore the village through virtual tours, interact with high-resolution 3D models, and delve into multimedia resources that narrate Fikardou's history and traditions. The platform also includes educational tools, such as thematic modules and storytelling features, to make the heritage of Fikardou accessible to younger audiences and international visitors. This digital dissemination not only promotes cultural awareness but also supports sustainable tourism by reducing the physical impact of visitors on the fragile site.

The approach taken in Fikardou demonstrates the potential of integrating advanced digital technologies with community engagement and scholarly rigor. By combining tangible documentation with the preservation of intangible narratives, the project creates a comprehensive record that captures the full essence of the village. This methodology ensures that Fikardou's heritage is not only safeguarded for future generations but also presented in a way that fosters engagement, education, and appreciation on a global scale. The case study serves as a model for how cultural heritage preservation can evolve in the digital age, balancing the need for historical accuracy with accessibility and adaptability.

The development of the efikardou.eu platform (***Figure 3***) ([8]), exemplifies a holistic approach that embodies the principles of the Memory Twin framework, ensuring that both the memory and identity of Fikardou are preserved and celebrated. By integrating immersive virtual tours, interactive exhibits, and educational resources, the platform goes beyond merely replicating the physical attributes of the village. It captures the essence of Fikardou's cultural and historical narrative, offering users a comprehensive understanding of its heritage. This approach ensures that the tangible and intangible elements of the village—its architecture, traditions, and stories—are digitally preserved in a way that keeps its identity alive.

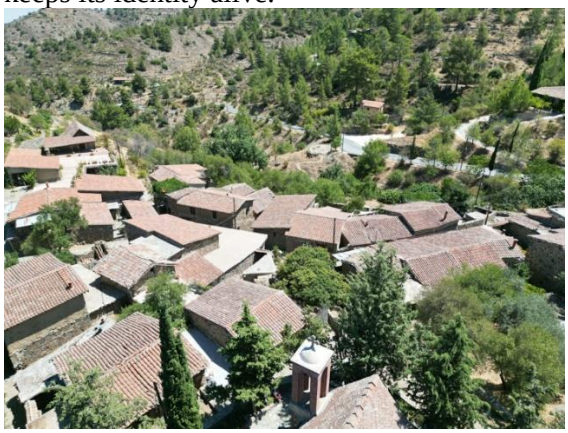

Figure 2: *Fikardou village, drone image*

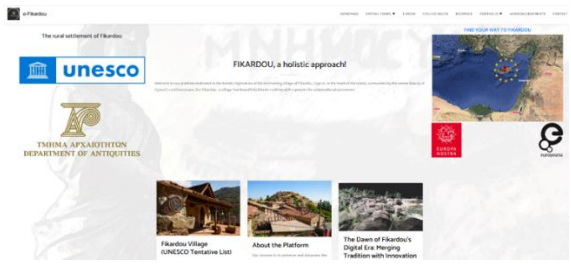

Figure 3: *Holistic documentation - efikardou.eu platform*

3.2 LAMBOUSA FISHING TRAWLER

The Lambousa fishing trawler (***Figure 3***) offers a rich and complex case study in the application of a comprehensive digital preservation framework ([14], [15]). As a historic vessel deeply tied to Cyprus's maritime history, Lambousa represents not just a piece of naval architecture but also a cultural artifact that encapsulates decades of Mediterranean fishing traditions, economic activities, and social resilience ([15],[23]). Built in 1955 by Dimitrios Zacharias in Perama, Piraeus, Greece, the vessel became a cornerstone of Cyprus's fishing industry upon its arrival in Famagusta in 1965 ([15]). Despite its prominence, Lambousa faced threats from aging, environmental changes, and regulatory pressures that required innovative preservation measures ([14], [15]).

The vessel's significance lies not only in its architectural and functional attributes but also in the stories it embodies. Measuring 25 meters in length with a gross tonnage of 48 tons, Lambousa was a marvel of mid-20th-century naval engineering, capable of reaching speeds of up to 10 knots. Its primary use for bottom trawling—a demanding and skill-intensive fishing method—underscored the expertise of its captains and crew. Over its operational life, the vessel became a symbol of resilience, navigating not only treacherous waters but also complex socio-political landscapes. For instance, in the summer before 1963, Lambousa's crew escaped Turkish port authorities under gunfire, showcasing their bravery and resourcefulness.

The Turkish invasion of Cyprus in 1974 marked a turning point for the vessel, as it was forced to relocate from its primary operating areas. Post-invasion, Lambousa continued its fishing operations in the free areas of the island, contributing to the revitalization of Cyprus's fishing industry despite mounting challenges such as overfishing and environmental degradation. Recognizing the trawler's unique cultural and historical value, the Municipality of Limassol undertook efforts to preserve it as a floating museum. This initiative, supported by the European Maritime and Fisheries Fund, involved extensive restoration work to maintain the vessel in its original condition while complying with regulations aimed at reducing fishing capacities to protect marine life.

The preservation efforts extended into the digital realm, spearheaded by the UNESCO Chair on Digital Cultural Heritage and EU-funded projects like Eureka3D and H2020 ERA CHAIR - MNEMOSYNE ([1]). The digital

documentation of Lambousa employed advanced techniques such as photogrammetry and terrestrial laser scanning to capture the vessel in both its decayed and restored states. A photogrammetric survey conducted in January 2023 documented the trawler's structure in detail during its decayed phase, while a subsequent laser scanning survey in October 2023 captured the geometry of its timber framework during restoration. These datasets were further processed to create a comprehensive CAD 3D model, incorporating all 440 distinct elements of the vessel.

Paradata played an essential role in documenting the methodologies, tools, and workflows employed during the digitization process. This contextual information not only supports transparency but also provides a valuable resource for future researchers and conservators. Metadata was meticulously compiled to describe the trawler's physical characteristics, historical significance, and restoration phases, creating a robust framework for organizing and accessing the digital assets.

To make the results widely accessible, the digital assets were integrated into the Europeana platform, enhancing the visibility and educational potential of Lambousa's story. The project also launched the elambousa.eu platform (***Figure 4***) ([9]), which offers interactive and educational tools such as virtual tours, 3D visualizations, and multimedia content. Users can explore the vessel's history through photos, videos, interviews, and detailed 3D models, gaining insights into both its functional and cultural dimensions. Features like educational games and e-books further engage younger audiences and promote maritime heritage.

The Lambousa project exemplifies how digital preservation frameworks can transcend traditional archiving methods by integrating physical, historical, and experiential dimensions. By capturing not only the vessel's structure but also the narratives that define its legacy, this initiative ensures that Lambousa's story continues to inspire and educate future generations. The approach demonstrates how the integration of advanced technologies with thoughtful storytelling can create a lasting and meaningful connection to cultural heritage, setting a precedent for the preservation of similar artifacts worldwide.

Figure 4:*The Lambousa Fishing Trawler*

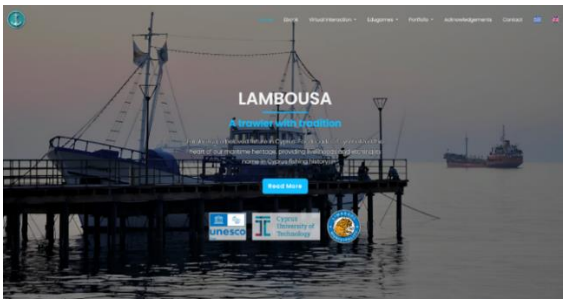

Figure 5: *The elambousa.eu platform*

4. CONCLUSION

The application of the Memory Twin framework represents a paradigm shift in the preservation and interpretation of cultural heritage, addressing both tangible and intangible dimensions ([1], [16]). By integrating paradata, metadata, and data, this methodology creates a comprehensive and dynamic representation of cultural artifacts and sites, offering new opportunities for understanding, accessibility, and engagement ([1], [3]). The case studies of Fikardou Village and the Lambousa fishing trawler illustrate how this approach can be effectively implemented to capture the historical, contextual, and experiential richness of heritage assets ([16], [23]).

Fikardou Village demonstrates the value of a holistic approach in preserving both physical structures and the cultural narratives that define a community's identity ([16], [21]). Through detailed digitization, contextual documentation, and community engagement, the initiative not only safeguarded the village's heritage but also made it accessible to global audiences via digital platforms ([8],[9]). Similarly, the documentation and dissemination of the Lambousa fishing trawler showcased the potential of integrating advanced technologies

with thoughtful storytelling to preserve maritime heritage ([14], [23]).

The workflow underlying the Memory Twin framework ensures that the digitization process is methodical, transparent, and adaptable ([1], [19]). By systematically capturing stakeholder requirements, employing advanced data acquisition techniques, and rigorously validating the resulting digital representations, the framework ensures the creation of high-quality, reusable digital resources ([1], [17]). This approach enhances not only the preservation but also the interpretability and usability of cultural heritage for diverse stakeholders, including researchers, educators, and the general public ([3], [8],[9])).

As digital technologies continue to evolve, the Memory Twin concept provides a forward-looking strategy for addressing the challenges of cultural heritage preservation in the 21st century ([19], [20]). Its emphasis on holistic documentation, contextual enrichment, and global accessibility ensures that cultural heritage remains relevant and meaningful ([16], [20]). By bridging the gap between tradition and innovation, the Memory Twin framework paves the way for more impactful and sustainable practices in the stewardship of cultural heritage, ensuring its legacy for future generations ([10], [15]).

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