Integrating Paradata, Metadata, and Data for an Effective Memory Twin in the Field of Digital Cultural Heritage

Marinos Ioannides(✉) , Elena Karittevli , Panayiotis Panayiotou ,
and Drew Baker

Department of Electrical Engineering, Computer Engineering and Informatics, UNESCO Chair on Digital Cultural Heritage, Cyprus University of Technology, Arch. Kyprianou 31, 3036 Limassol, CY, Cyprus
{marinos.ioannides,elena.karittevli,p.panayiotou,
drew.baker}@cut.ac.cy

Abstract. The extension of the concept of Digital Twin to Memory Twin offers an innovative approach to preserving and interacting in the field of Digital Cultural Heritage. This paper explores the integration of paradata, metadata and data to construct an effective Memory twin, providing a representation of cultural heritage. Paradata, together with metadata and data, greatly enriches the digital representation of cultural assets. By integrating these layers of information, we aim to develop a framework that enhances the preservation, accessibility and interpretability of digital cultural heritage. This approach enables advanced archival practices, personalised user experiences and improved data authenticity. Through case studies, we demonstrate the potential of this methodology to transform the management and dissemination of cultural heritage in the digital future.

Keywords: Memory Twin · Digital Cultural Heritage · Paradata · Cultural Heritage Preservation

1 Introduction

A Digital twin is a concept that has been applied widely in various sectors inclusive of digital cultural heritage. This means that digital twins are virtual replicas of cultural objects, which allow for tracking, analysis and simulation of such things within digital environments. They provide dynamic and interactive representations, thus advancing the preservation and dissemination of cultural heritage. For instance, through the creation of detailed 3D models for historical sites and artefacts, they have made virtual tours possible thus improving learning. The Memory twin on the other hand is not just an artefact performing this function but one which also considers factors such as contextuality, temporality and experience of archaeological sites and cultures. The main intention behind this technique is not only to replicate the material characteristics of cultural artefacts but also consider their use and historical settings. However, the Memory twin approach maintains attributes pertaining to their physical nature as well as historical backgrounds associated with them (Ioannides et al., 2021).

The Memory twin approach preserves the physical characteristics of cultural objects and incorporates their historical significance and the stories associated with them. This layered integration ensures more holistic preservation, facilitating advanced archival practices, personalized user experiences, and improved data authenticity. Through Memory twins, cultural institutions can change the way cultural heritage is managed and shared in the digital environment. This paper aims to discuss this concept and the corresponding theoretical background and practical examples of their use and possibilities. By incorporating paradata, metadata, and data in the creation of Memory Twins, the future of archival practices and engaging cultural history experiences are opened, thus enhancing the learning and appreciation of history.

2   Theoretical Background

The concept of a digital twin has been a transformative development in various industries, creating virtual replicas of physical objects or systems that allow for real-time monitoring, simulation, and optimization. Originally pioneered in the fields of manufacturing and engineering, digital twins have found applications in smart cities, healthcare, and beyond, providing dynamic, data-driven representations that enhance efficiency and decision-making (Grieves, 2014; Tao et al., 2018).

In the realm of digital cultural heritage, the digital twin paradigm has enabled the creation of virtual models of artefacts, sites, and monuments. These models facilitate preservation by allowing detailed study and interaction without the need to physically handle or be present at the actual sites. For instance, detailed 3D models of historical buildings and artefacts have been created, allowing for virtual tours and educational experiences that bring cultural heritage to a global audience (Bruno et al., 2016; Bekele et al., 2018).

3   Memory Twin Concept

Human history, art and achievements become a rich tapestry of cultural heritage. It is necessary to preserve and document these invaluable assets for our collective memory. Memory Twin is not just an idea but the digital copy of our culture enabling us to keep our past alive and make it accessible worldwide. This innovative approach goes beyond the possibilities of digital twins by introducing paradata, metadata, and data thereby giving a more comprehensive and enhanced view of what constitutes cultural heritage. Paradata involves contextual information that surrounds data creation as well as its application thus provides insights into the reasons why cultural items were made in such way. Metadata indicates the content, quality, condition, among other characteristics of data thus allowing better organization and retrieval. Data involves actual digital representations of cultural objects like 3D scans, photographs and textual records.

By integrating these three layers of information, the Memory Twin approach not only replicates the physical attributes of cultural artefacts but also preserves their historical significance and usage contexts. This multi-dimensional representation enriches the digital artefacts with narratives that are crucial for understanding their full value.

The combination of paradata and metadata ensures that users can access comprehensive information about how and why the artefacts were created, their journey through history, and their current digital state. This holistic integration transforms static digital copies into dynamic, informative, and interactive resources, making cultural heritage more engaging and accessible to a global audience. This methodology not only supports advanced archival practices but also fosters personalized user experiences and enhances the authenticity and interpretability of digital cultural heritage.

While digital twins have significantly advanced the preservation and accessibility of cultural heritage, they primarily focus on replicating the physical attributes and operational behaviours of artefacts. This approach, while valuable, often overlooks the deeper, more nuanced aspects of cultural heritage—its historical significance, usage contexts, and the experiential dimensions that are integral to understanding its full value.

The Memory Twin concept emerges as an evolution of the digital twin, addressing these gaps by creating a more comprehensive and enriched digital representation of cultural heritage. A Memory Twin goes beyond the mere replication of physical characteristics to incorporate the historical, contextual, and experiential information associated with cultural artefacts. This evolution reflects a shift from a focus on physical accuracy to a broader, more holistic understanding of cultural heritage.

The workflow chart (Fig. 1) included in this paper illustrates the comprehensive process of converting primary stakeholder requirements into publishable knowledge on platforms like Europeana and national aggregators. This process is systematically structured to address both the complexity of data gathering and the quality assurance necessary for preserving and disseminating digital cultural heritage.

The process begins by understanding and documenting the requirements of primary stakeholders. These requirements form the basis for developing digital tangible objects that accurately represent cultural heritage. The stakeholder requirements are transformed into digital tangible objects, which act as the foundational elements for further data processing and digitization.

The data gathering process involves converting physical cultural objects into digital formats using techniques like 3D scanning, photogrammetry, and other digitization methods. Contributions from experts and practitioners are integrated, encompassing comprehensive research utilizing both published and unpublished sources to enrich the digital representation. Practical insights and historical context are provided by individuals with relevant expertise.

The gathered information is classified into three primary components: paradata, metadata, and data. Paradata includes data about the processes and methodologies used to create the digital objects, offering insights into the digitization and decision-making processes. Metadata is structured information that describes the content, context, and attributes of the data, facilitating easier retrieval and management. Data refers to the actual digital content, such as 3D models, photographs, and textual records.

Paradata, metadata, and data are combined to create comprehensive information that serves multiple purposes, enhancing the overall understanding and utility of the digital objects. This information is evaluated and refined through several quality parameters to ensure its accuracy, relevance, and completeness. This includes developing and testing hypotheses based on the information, formulating research questions to guide further

investigation, conducting experiments and analyses to validate the information, creating narratives to provide context and storytelling elements, ensuring the information is suitable for educational purposes, assessing the condition of the materials involved, and monitoring the structural integrity of the physical objects represented digitally.

The final product is validated knowledge, ready for dissemination and publication. The validated knowledge is published on online platforms like Europeana and national aggregators to ensure broad accessibility and engagement.
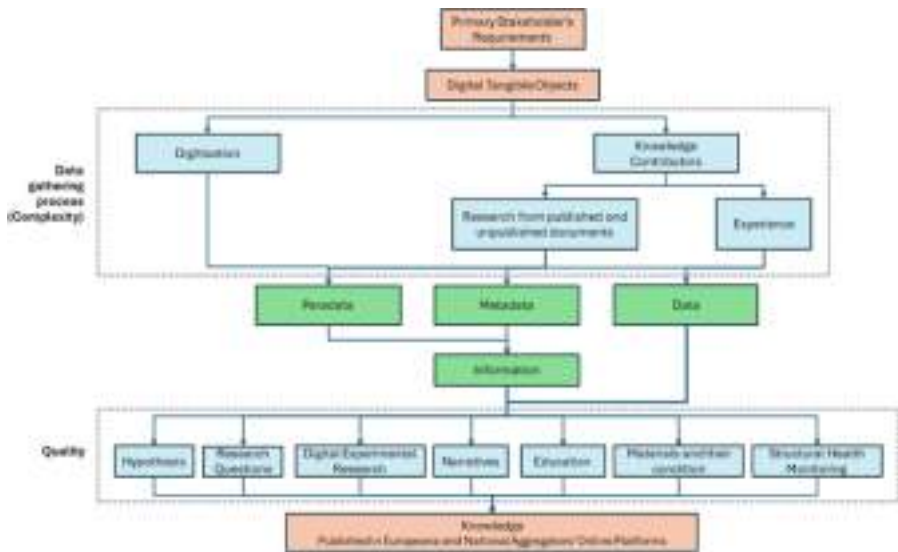
Fig. 1. The Memory Twin approach

4   Holistic Preservation

The Memory Twin approach integrates paradata, metadata, and data to ensure a holistic preservation of cultural heritage. Paradata provides more information than merely preserving data as it documents the way information was developed; hence, digital representations can capture methods employed, tools utilized and even circumstances under which the research was conducted. It is this kind of contextual information that helps us understand how decision making or other conditions shaped digitization processes, with such insights being very valuable for future investigation and conservation purposes.

Metadata on the other hand offers the necessary structural and descriptive details required to efficiently organize, retrieve and manage data. Metadata provides a way of describing different attributes of digital objects like their content, format, and where they came from thus ensuring that they are well organized and accessible. That is what makes browsing better by allowing advanced searching capabilities while ensuring effective retrieval to access interactive artefacts online.

This approach also adds to the experience of users by opening multiple avenues for engagement. The paradata can be used by researchers with a view to understand digitization methods, complexity and quality, metadata can be exploited by educators to come up with structured learning modules while at the same time the public can play around with high fidelity data for enhanced participation. Memory Twins is meant to serve different user requirements by offering a much more inclusive and engaging heritage experience. Memory Twins holistic preservation is not only about protecting the past but rather about aiding future research and conservation initiatives as well. Detailed paradata and metadata provide robust frameworks that will enable future scholars conducting digitization processes to understand how they have been done and may potentially reproduce or continue building on them. In terms of studying and conserving cultural heritage, this continuum is important because it allows digital representations to remain apposite and informative for future generations.

5 Enhanced Accessibility and Interpretability

The integration of paradata and metadata within the Memory Twin framework enhances the accessibility and interpretability of digital cultural heritage. Comprehensive metadata allows for sophisticated search and retrieval functionalities, making it easier for researchers, educators, and the public to access and engage with digital artefacts. Paradata enriches the narrative by providing the necessary context to understand the conditions and methods involved in the digitization process, facilitating a deeper and more informed interpretation.

This layered approach ensures that digital artefacts are not only preserved in a way that maintains their physical integrity but also captures the rich, contextual narratives that give them meaning. By providing a detailed account of the historical and cultural contexts in which these artefacts were created and used, the Memory Twin approach enables a more nuanced understanding and appreciation of cultural heritage. The evolution from digital twins to Memory Twins represents a significant advancement in digital cultural heritage. Memory Twins provide a richer, more nuanced representation of cultural artefacts, ensuring that both their physical properties and their historical and contextual significance are preserved. This comprehensive approach enhances the preservation, accessibility, and interpretability of digital cultural heritage, paving the way for more advanced archival practices and engaging cultural experiences.

The transformative potential of Memory Twins lies in their ability to create digital representations that are not only accurate and detailed but also rich in context and meaning. This allows for a deeper engagement with cultural heritage, fostering a greater understanding and appreciation of the past. Through theoretical exploration and practical application, Memory Twins offer new opportunities for cultural institutions to preserve and share their heritage in innovative and impactful ways, ensuring that the rich tapestry of human history is accessible to future generations.

6   Case Studies: Memory Twin of Lambousa Fishing Trawler and Fikardou Village

The Lambousa fishing trawler (Fig. 2), a significant piece of Cyprus's maritime history, serves as a prime example of how a Memory Twin can encapsulate both physical and historical dimensions of cultural heritage. Originally built in 1955 by Dimitrios Zacharias in Perama, Piraeus, Greece, and later named Lambousa upon its arrival in Famagusta in 1965, this 25-m vessel has been an integral part of the Mediterranean fishing narrative. The Lambousa was a marvel of naval architecture, measuring 25 m in length with a gross tonnage of 48 tons, and capable of reaching speeds of up to 10 knots.

The Lambousa was renowned for its use of bottom trawling, a fishing method involving a robust net designed to sink to the ocean floor. This method required a high degree of skill and knowledge from the captain and crew, who meticulously navigated the complex apparatus to avoid underwater hazards. The net could hoist up to four tons of catch, demonstrating the vessel's efficiency and the crew's expertise.

Throughout its operational life, the Lambousa witnessed numerous historical events and adventures. One such incident occurred in the summer before 1963 when the crew ventured into Turkish waters and encountered Turkish port authorities. The quick thinking and bravery of Captain Kyriakos Kastenis, who orchestrated a dramatic escape under gunfire, underscored the vessel's significance as a symbol of resilience and resourcefulness. The Turkish invasion of Cyprus in 1974 marked a turning point for the Lambousa. Prior to the invasion, the vessel operated across the entirety of Cyprus, but the conflict forced it to seek refuge in the Ormidia fishing harbour. Post-war, the Lambousa continued its fishing operations primarily from Limassol and Larnaca, contributing to the revival of the fishing industry in the free areas of the island. However, overfishing and environmental changes posed significant challenges to the sustainability of the marine ecosystem.

Recognizing the cultural and historical value of the Lambousa, the Municipality of Limassol undertook efforts to preserve the vessel as a floating museum. This initiative, funded by the European operational program 'Sea' for the period 2014–2020, included extensive restoration work to maintain the vessel in its original condition. The restoration not only preserved the physical structure of the Lambousa but also ensured its legacy would be accessible to future generations.

The preservation efforts for Lambousa are also driven by significant regulatory frameworks. According to Regulation (EU) No 508/2014 of the European Maritime and Fisheries Fund, certain fishing boats, including traditional vessels like the Lambousa, were required to be decommissioned to reduce fishing capacities and protect marine life. This regulation posed a threat to the existence of many historic vessels. However, recognizing the Lambousa's unique cultural and historical value, an exception was made to preserve it as part of Cyprus's maritime heritage. This legal framework highlights the importance of balancing conservation efforts with regulatory compliance, ensuring that significant cultural assets are not lost to stringent regulations.

The UNESCO Chair on Digital Cultural Heritage, with the support of the EU-funded project EUreka3D and MNEMOSYNE, has spearheaded the digitization and preservation of the Lambousa fishing boat. This initiative employs advanced 3D digitization techniques to create a detailed digital model of the vessel, ensuring its historical integrity and

accessibility for future generations. Specifically, a Photogrammetric survey was made in January 2023 when the Trawler was in a decayed condition. Moreover, in October 2023, while the boat was under restoration, a Terrestrial Laser Scanning survey was made to capture the geometry of its timber structure. The point cloud data from both surveys was further processed, for the creation of a CAD 3D model, which includes all the elements of the boat which are 440 in total. By integrating these digital assets into the Europeana platform, the project enhances the visibility and educational potential of the Lambousa, promoting a broader appreciation of Cyprus's maritime heritage and contributing to the preservation of European cultural history. Further details on the holistic documentation approach of the Lambousa can be found on elambousa.eu (Fig. 3). This platform allows the user to learn about the history of the vessel, through a 360 virtual interaction, educational games, eBook, and a portfolio with photos, videos, interviews and drawings.

Fig. 2. The Lambousa Fishing Trawler

Fikardou Village (Fig. 4), a UNESCO Tentative List World Heritage Site, exemplifies the Memory Twin approach in a different but equally compelling context. This traditional Cypriot mountain settlement, with its origins tracing back to the Byzantine era, offers a rich tapestry of cultural narratives. Fikardou Village stands as a prime example of a traditional rural settlement, meticulously conserving its 18th- and 19th-century architecture amidst its pristine natural environment. Named after its noble lineage during the Frankish rule in Cyprus, Fikardou embodies a rich cultural heritage that has endured through the ages.

Fig. 3. Holistic documentation – eLambousa.eu platform

The trend of urbanization and abandonment had left many houses deserted, threatening the village's unique architectural features and cultural practices. The Department of Antiquities took charge of the village in 1978, declaring it an "Ancient Monument" and establishing strict regulations through a "Controlled Area" designation. In 1984, a comprehensive revitalization effort was launched, focusing on the restoration of dilapidated structures and the enhancement of the village's infrastructure. These endeavours have garnered recognition, with Fikardou now proudly listed on the tentative UNESCO World Heritage Sites roster, underscoring its cultural significance and potential for global acclaim. Notably, the meticulous restoration of key residences, such as the "Residence of Katsinioros" and the "Residence of Achilleas Dimitri," earned international acclaim, affirming the village's status as a beacon of architectural heritage.

The Memory Twin of Fikardou involves extensive 3D scanning to capture the village's architectural intricacies and spatial layout. Paradata collected includes the methodologies employed in scanning the narrow, cobbled streets and traditional houses, the historical research on the village's founding and development, and the community's input on cultural practices and traditions. Metadata for Fikardou details the architectural styles, the historical significance of various buildings, and the socio-economic history of its inhabitants. This integration of paradata and metadata with high-fidelity digital models ensures that the Memory Twin provides a holistic and immersive experience, preserving both the physical and cultural essence of the village.

The digital documentation process employed by the UNESCO Chair on Digital Cultural Heritage team commenced with data acquisition, utilizing advanced technologies such as laser scanners, 360° photography, and drones to capture the intricate details of Fikardou's built environment. This initial phase was critical in creating a comprehensive digital representation of the village, facilitating subsequent data processing stages. Data preparation involved the meticulous cleaning and organization of acquired data, ensuring its suitability for analysis and interpretation.

The subsequent processing stages included registration, interpretation, and storage, culminating in the creation of structured digital assets that accurately represent Fikardou's architectural and cultural heritage. Data modelling played a pivotal role in structuring the digitized information, providing a robust framework for database management and application development. By establishing clear relationships between data entities and attributes, data models ensured the coherence and accessibility of the village's digital archives.

Central to the preservation efforts was the implementation of digital preservation strategies aimed at ensuring the longevity and accessibility of Fikardou's digital materials. Adhering to best practices, including metadata documentation, controlled storage environments, and proactive management, safeguarded the integrity and authenticity of the village's cultural heritage in the digital realm.

Additionally, the team engaged deeply with the community, conducting interviews with villagers spanning generations. These interviews were invaluable in capturing the intangible heritage of Fikardou, including stories, traditions, and cultural practices passed down through oral tradition. Each voice added depth to the digital archive, weaving together a rich tapestry of intangible heritage that defines the village's unique identity.

Furthermore, the development of the online platform efikardou.eu (Fig. 5) emerged as a strategic avenue for disseminating Fikardou's cultural legacy to a global audience. Through immersive virtual tours, interactive exhibits, and educational resources, the platform serves as a dynamic portal for engaging with the village's rich history and architectural splendour. By harnessing digital technologies, the team fosters cultural awareness, promotes sustainable tourism, and ensures the enduring legacy of the village for future generations.

Fig. 4. Drone Image, overview of the Fikardou village

Fig. 5. Holistic documentation - efikardou.eu platform

7 Conclusion

The integration of paradata, metadata, and data into the creation of Memory Twins presents a pioneering approach to preserving and interacting with digital cultural heritage. This paper introduces the concept of the Memory Twin as an evolution of the Digital Twin, offering an innovative methodology that enhances the representation of cultural assets by capturing both their physical and contextual aspects. This comprehensive approach ensures a more holistic preservation of cultural heritage.

Memory Twins not only replicate the physical attributes of cultural artefacts but also encompass their historical significance, usage contexts, and experiential dimensions. This richer and more nuanced representation enables cultural institutions to transform the management and dissemination of cultural heritage. By providing detailed accounts of the historical and cultural contexts, Memory Twin facilitates a deeper understanding and appreciation of cultural artefacts.

Through detailed case studies, such as the Lambousa fishing trawler and Fikardou village, the transformative potential of Memory Twins is demonstrated. These case studies highlight how Memory Twins provide enriched and accessible digital representations that support advanced archival practices, personalized user experiences, and improved data authenticity. The Lambousa fishing trawler Memory Twin preserves not only the vessel's physical structure but also its maritime history, while the Memory Twin of Fikardou village captures its architectural intricacies and cultural narratives.

The development of Memory Twins paves the way for innovative and impactful ways to preserve and share cultural heritage. This approach enhances the visibility and educational potential of cultural assets, promoting a broader appreciation of cultural history and contributing to the preservation of European cultural heritage. The advancements in digital documentation and preservation techniques embodied in Memory Twins ensure that the rich tapestry of human history is accessible to future generations. This evolution from Digital Twins to Memory Twins represents a paradigm shift towards a more holistic understanding of cultural heritage, providing new opportunities for cultural institutions to engage with and preserve their heritage in the digital age.

Disclosure of Interests.   The authors have no competing interests to declare that are relevant to the content of this article.

References

Bekele, M.K., Pierdicca, R., Frontoni, E., Malinverni, E.S., Gain, J.: A survey of augmented, virtual, and mixed reality for cultural heritage. J. Comput. Cult. Heritage (JOCCH) **11**(2), 1–36 (2018). https://doi.org/10.1145/3145534

Bruno, F., Bruno, S., De Sensi, G., Luchi, M.L., Mancuso, S., Muzzupappa, M.: From 3D reconstruction to virtual reality: a complete methodology for digital archaeological exhibition. J. Cult. Herit. **11**(1), 42–49 (2016). https://doi.org/10.1016/j.culher.2015.02.006

Charlotte, J.: Threats to Our Ocean Heritage: Bottom Trawling. Springer Briefs in Archaeology. Springer, Cham (2024). https://doi.org/10.1007/978-3-031-57953-0

Common fisheries policy (CFP) (2023). https://oceans-and-fisheries.ec.europa.eu/policy/common-fisheries-policy-cfp_en

Department of Antiquities – Museums. (n.d.) (2022). http://www.mcw.gov.cy/mcw/da/da.nsf/All/8865F898FAA8A275C22571990020EEAA?OpenDocument

European Maritime and Fisheries Fund (2014–2020). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM%3A0202_1

Fishing boats destruction (2021). https://woodenboats.gr/en/fishing-boats-destruction/

Grieves, M.: Digital twin: manufacturing excellence through virtual factory replication. White Paper **1**, 1–7 (2014). https://www.researchgate.net/publication/275211047_Digital_Twin_Manufacturing_Excellence_through_Virtual_Factory_Replication

Ioannides, M., Fink, E., Cantoni, L., Champion, E.: Digital heritage: progress in cultural heritage documentation, preservation, and protection. In: Proceedings of the 8th International Conference, EuroMed 2020, vol. 12719. Springer Nature (2021). https://doi.org/10.1007/978-3-030-73043-7

Ioannides, M.: Study on quality in 3D digitisation of tangible cultural heritage: mapping parameters, formats, standards, benchmarks, methodologies, and guidelines [VIGIE 2020/654], Final Study Report. Cyprus University of Technology, European Union (2022). https://doi.org/10.2759/471776

Tao, F., Zhang, H., Liu, A., Nee, A.Y.C.: Digital twin in industry: state-of-the-art. IEEE Trans. Industr. Inf. **15**(4), 2405–2415 (2018). https://doi.org/10.1109/TII.2018.2873186

UNESCO: The rural settlement of Fikardou – UNESCO World Heritage Centre. (n.d.) (2022). https://whc.unesco.org/en/tentativelists/1673/

Traditional Boats Destroyed According to European Directive, https://greekreporter.com/2011/08/10/traditional-boats-destroyed-according-to-european-directive/

Pavlou, L.: Traditional Earth Sheltered Buildings on Five Finger Mountain (Cyprus) Evaluation of the Energy Efficiency by Computer Simulating the Rectangular Plan Typology

Πλοιάριο, "Λάμπουσα." (n.d.) (2022). https://www.limassol.org.cy/en/ploiario-Lambousa