A New Methodology: The #MemoryTwin of a 20th Century Wooden Trawler

Marinos Ioannides[1](✉), Drew Baker[1], Panayiotis N. Panayiotou[1], Stelios Fotiou[1], Giorgos Neofytou[1], and Constantinos Nicolaou[2]

[1] UNESCO Chair on Digital Cultural Heritage at Cyprus University of Technology, Research Centre MNEMOSYNE, Limassol, Cyprus
{marinos.ioannides,drew.baker,p.panayiotou}@cut.ac.cy
[2] Independent Researcher, Limassol, Cyprus

Abstract. Memory Twin represents an expansion of the Digital Twin notion in terms that are not only limited to the physical attributes of the data but also include paradata and metadata, which are crucial for the improvement of data acquisition results in the cultural heritage sector. In a Memory Twin, the data refers to the digital content, such as the 3D model, whereas the paradata relates to the processes and tools used for creating high-quality data. Metadata relates to the information that explains the digital content and gives value to the "Memory of Data". This study applies the newly developed and ground-breaking Memory Twin methodology to ensure the highest standard of data-long preservation for the unique historic wooden fishing vessel Lambousa in Limassol, Cyprus.

Keywords: Memory-Twin · Paradata · Metadata Maritime Cultural Heritage · Holistic Documentation

1 Introduction

The first half of the 20th century was the last phase of the widespread use of wooden vessels in the Mediterranean, following a long evolution through the centuries. Common practices in Mediterranean countries, relating to the design and construction and to the typology and the use of wooden vessels, have been studied and published by numerous researchers. The Eastern Mediterranean has always been a very active nautical area, however shipbuilding activity has not been enough documented in the most of the near-coastal countries. Greek nautical activity, however, has been particularly active at least from the 18th century and up until the middle of the 20th century, where a rich infrastructure of wooden vessel construction and use has evolved. (Damianidis [1]).

Even though Cyprus is an island located in the centre of the Eastern Mediterranean, local nautical activity – at least from the 18th century to the mid-20th century – has been limited to a very basic level, and it follows that the same limitation applies to wooden shipbuilding as well. The establishment of the first organised shipyards occurred in the mid-20th century, with the majority of local mariners' needs for wooden vessels covered by imports from nearby areas, mainly the Aegean and Minor Asia, and later

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Syria, Lebanon and Egypt. However, a clear prevalence of Greek traditional shipbuilding locally can be confirmed during the first half of the 20th century, mainly based on the settlement of shipwrights – refugees from Asia Minor coastal areas and the Aegean – after the Asia Minor destruction and debacle and the Second World War. These craftsmen seem to have covered an existing gap in the craft on the island. Also, the common cultural background between Greek Cypriots and Greeks, the terminology preserved through the modern shipwrights, and the types of vessels built locally all corroborate and point towards this conclusion (Nicolaou 2021 [2]).

This Lambousa trawler was built in 1955 in Greece, and its construction design is of the liberty type classification, with a length of 25 m. It is a unique heritage object as the only remaining wooden trawler of this size in Cyprus. It was used as a fishing trawler until 2014, when it was withdrawn from service due to new EU regulations to prevent overfishing (Regulation (EU) No 508/2014 of the European Parliament and of the Council of 15 May 2014 on the European Maritime and Fisheries Fund). In 2020, a decision was made for its restoration, commencing in January 2023 with completion in May 2024. Digital documentation was undertaken of the vessel before, during and after its restoration to document it and preserve its lifelong memory for the generations to come. This digitisation, based on the results of the EU study VIGIE2020/654 [3], included the three phases of the restoration, which was achieved through geometrical surveying using photogrammetry and terrestrial laser scanning (TLS), creating a detailed and highly accurate point cloud data of the boat's exterior and interior structure and substructure. This data was further processed to produce a detailed naval architectural 3D model using non-uniform rational B-splines (NURBS) geometries, which make up the 440 individual elements of the boat. The overall result is a 3D CAD model which is available in a variety of formats such as 3DM, OBJ, STL, E57 and GLB and can be used in a range of sectors such as naval engineering, engineering, archaeology, 3D fabrication, web visualisation, and gaming.

While the digitisation was based on the paradata according to the VIGIE 2020/654 recommendations, the metadata are in line with the Europeana Data Model (EDM), allowing a successful aggregation to Europeana Heritage Library [4]. To ensure comprehensive knowledge documentation, an online platform was developed featuring an e-storybook, storytelling sessions with archaeologists and marine engineers involved in the restoration process, as well as educational games. This initiative resulted in a holistic form of digital documentation, accessible to the wider multidisciplinary community through the innovative Memory Twin approach.

1.1 Theoretical Background

The idea of a digital twin represents a ground-breaking advancement across numerous industries, generating virtual copies of physical items or systems that enable real-time monitoring, simulation, and enhancement. Originally conceived within the domains of manufacturing and engineering, digital twins have progressively extended their applications into smart cities, healthcare, and various other fields, providing dynamic, data-driven representations that enhance operational efficiency and facilitate informed decision-making [5, 6]. In the sphere of Digital Cultural Heritage (DCH), the digital twin concept has made it possible to produce virtual models of artefacts, sites, and monuments represented only in 2D/3D geometrical structures. These models support preservation efforts by allowing thorough examination and engagement without necessitating physical interaction or presence at the actual locations of the analogue represented. As an illustration, complex 3D models of historical buildings and artefacts have been constructed, delivering virtual tours and educational opportunities allowing a worldwide audience to engage with cultural heritage [7, 8]. Until now, our engagement with the monument had been largely limited to its physical and structural attributes. Despite its prominence, it was primarily regarded as a high-fidelity digital replica, rather than as a vessel of cultural significance and lived heritage.

Therefore, the concept of Memory Twin has emerged as an innovative extension of the Digital Twin paradigm, particularly within the realm of DCH. While digital twins primarily focus on the geometrical, technical and operational aspects of objects, memory twins integrate and embed a broader spectrum of information, including paradata, metadata, and data about the past story of the object [9]. Data encompasses the actual digital representations of cultural objects, including the holistic knowledge and story of the object, 3D models, images, and textual documents, which reflect the physical characteristics of these artefacts. Furthermore, metadata refers to the information that clarifies the digital content and enhances the significance of the "Memory of Data". Paradata expands this structure by recording the rationale, processes, methodologies, and tools employed in the data's creation, providing insights into the decision-making and circumstances that shaped the digitisation initiatives [10, 11].

Several case studies illustrate the application of memory twins in digitising and preserving cultural heritage. One notable example is the second most important cultural symbol of the city of Limassol: the Lambousa Fishing Trawler, which underwent a comprehensive digitisation process as part of a restoration initiative. The project utilised advanced digitisation techniques to create a detailed 3D CAD model that allowed the inclusion of both the vessel's physical structure and its historical narratives [11]. The integration of paradata and metadata in this project allowed for a representation of the trawler's significance, ensuring its accessibility to the public. Another case is the Memory Twin of Fikardou Village, a traditional Cypriot settlement which is included in the tentative list of UNESCO as a World Heritage Site (see Fig. 1). The village's memory twin was developed through extensive digitisation that included photogrammetric and laser scanning models. This data, along with virtual reality tours, e-books, educational games, and interviews with local residents, led to the creation of the eFikardou.eu platform for capturing not only the architectural features but also the intangible cultural heritage associated with the village's history [12]. This example underscores the importance of community involvement in the Memory Twin process, as local narratives and traditions contribute to a more comprehensive understanding of cultural heritage [13].

Despite the promising developments in the Memory Twin methodology, challenges remain in terms of data management, integration, and user engagement. The complexity of capturing paradata and metadata alongside high-fidelity digital models necessitates robust frameworks and tools that can facilitate this process [9]. This paper examines these challenges and the implementation of the methodology through the case study of the Lambousa Fishing Trawler, exemplified and tested in a real case scenario with a rich maritime history in Cyprus. Through the integration of the Memory Twin methodology,

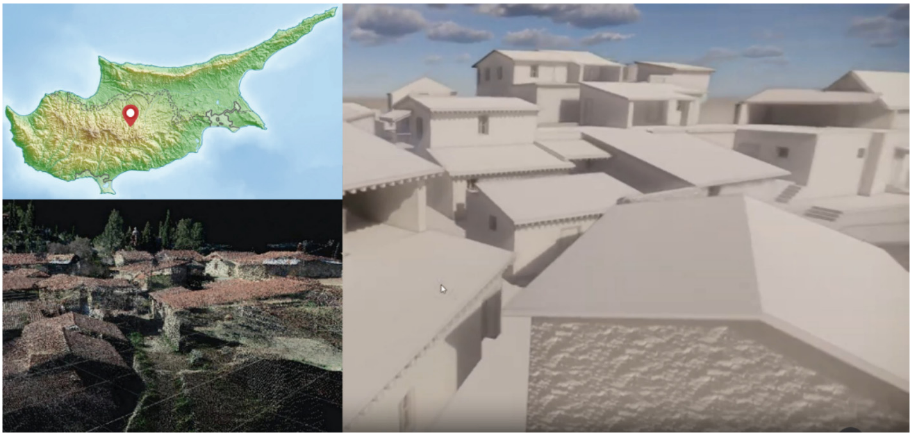


Fig. 1. Location of Fikardou in Cyprus (ISO 6709:2022: 34.958889, 33.171111), point cloud visualisation from UAV and final BIM model (LOD300)

a comprehensive representation arises that not only sustains the tangible features of this historical trawler but also embodies its intangible aspects, such as historical records, craftsmanship and maritime traditions. This is achieved through the aggregation of the Memory Twin data to Europeana as well as through the creation of the online platform in order to be available to the public.

1.2 Methodology

The Memory Twin methodology has been particularly influential in the field of DCH, where it enhances the preservation, accessibility, and interpretability of cultural assets [3]. By incorporating paradata and metadata, Memory Twins provide a holistic view that supports advanced archival practices and personalised user experiences. This approach is crucial for engaging diverse audiences within cultural heritage, as it allows for a deeper understanding of monuments and artefacts [9]. The following methodology diagram (Fig. 2) indicates the thorough procedure of publishing knowledge on platforms like Europeana and national aggregators through a memory twin by considering the primary stakeholder requirements.

The process is organised to manage data collection complexity and quality assurance for digitised cultural heritage objects. It starts with understanding and documenting stakeholder requirements, providing a guide for the creation of digital objects that represent the cultural heritage artefact or monument within a use case context. The data collection involves converting physical objects into digital formats using techniques like 3D scanning and photogrammetry. Contributions from experts and practitioners enhance the digital representation through comprehensive research. Relevant individuals provide practical insights and historical context. The collected information is categorised into paradata, metadata, and data. Paradata offers insights into the digitisation processes and methodologies used. Metadata describes the content and context of the data for easier management. Data consists of the actual digital content, like 3D models and

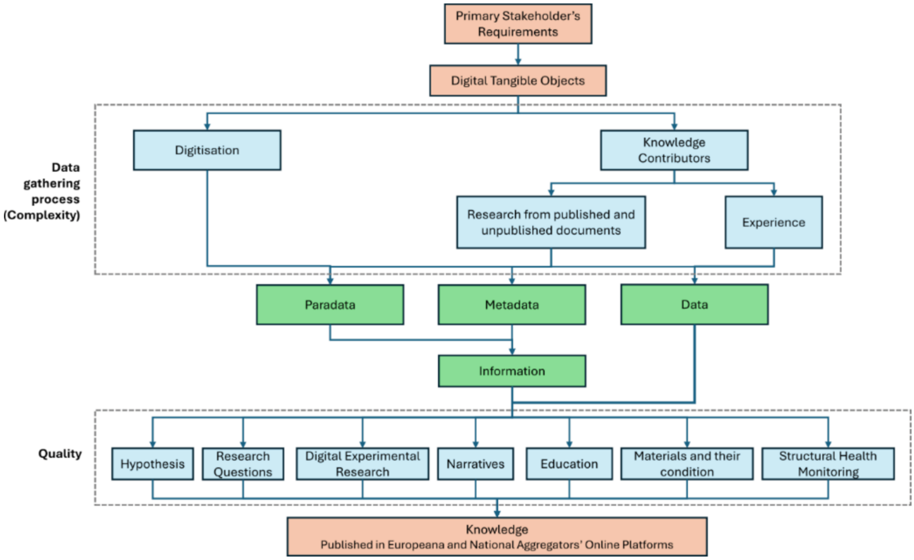


Fig. 2. The overview of Memory Twin methodology

photographs. Paradata, metadata, and data combine to create comprehensive information that improves understanding and utility. This information undergoes evaluation and refinement for accuracy, relevance, and completeness. This includes hypothesis testing, formulating research questions, conducting analyses, creating contextual narratives, and assessing material conditions. The result is validated knowledge, ready for dissemination. The validated knowledge is published on platforms like Europeana to ensure wide accessibility [11].

2 Case Study: Memory Twin of the Lambousa Fishing Trawler

The Lambousa is a traditional wooden boat of the liberty type with an ellipsoid stern, developed post-World War II [1]. Built in 1955 in Greece, it was registered in Cyprus a decade later. Its length is 25 m, and it features a diesel KELVIN TASC8 Marine 440 bhp diesel engine and two masts, originally used for sailing and later solely for fishing. Owned by fishermen from Ormidia, it served as a trawler in Cypriot and Egyptian waters. In 2004, it was withdawn under the EU Fishing Policy (EU Regulation 508/2014 of the EU Parliament and the Council of 15 May 2014) and preserved as a maritime heritage monument by Limassol Municipality. The boat underwent dry docking in 2020 for maintenance, funded by a European grant for its restoration. The restoration started in January 2023, led by local contractor Mr. Michalis Masouras, with oversight from municipal engineers and archaeologist-consultant Constantinos Nicolaou. Over 20 skilled craftsmen worked simultaneously, completing the restoration by March 2024 [14]. Following a special request from Limassol's Mayor Mr. N. Nikolaides, holistic digitisation with the latest advanced scanning and 3D modelling techniques and also intangible aspects such as historical records, construction craftsmanship techniques and maritime traditions. The total cost of the project reached around €1.3 million, making it the largest and most expensive of its kind in Cyprus. The primary aim of the Lambousa restoration project was to maintain its original shape and to retain as many details and features of the initial build as possible. The archaeological focus of the project was to protect and document all the historical and construction-related information about the boat, ensuring that the same traditional shipbuilding techniques and characteristics were adhered to throughout the restoration process. In June 2024, Lambousa was relaunched as a floating museum showcasing local maritime heritage.

The integration of the Memory Twin methodology with the holistic digitisation of the Lambousa Fishing Trawler represents a significant advancement in its preservation. The requirements of the Limassol Municipality, which is the stakeholder, were the digitisation of both the tangible and intangible data of this trawler. The process began with a geometrical survey and 3D modelling to create the tangible data, followed by extensive research into historical records and interviews with maritime experts to capture the intangible data. Specifically, through this innovative approach, the traditional craftsmanship was documented through a series of interviews with the archaeologists, craftsmen and engineers involved as well as through historical and photographic records. Moreover, the digitisation process involved UAV photogrammetric surveys and TLS to create a comprehensive point cloud data set that accurately reflects the trawler's structure and substructure. By processing this data with AutoCAD [15] and Rhinoceros [16] Computer-Aided Design (CAD) into a detailed 3D CAD model using NURBS geometries, all 440 components of the boat were reconstructed. The Memory Twin methodology enhances this process by integrating the contextual information surrounding the digitisation efforts, including the tools and techniques employed, the stakeholder requirements, and the historical significance of the Lambousa. This layered approach not only enriches the digital representation of the trawler but also facilitates its aggregation into Europeana as well as the creation of the e-Lambousa platform [17], ensuring broader accessibility and educational potential.

The holistic digitisation was made as part of the H2020 ERA Chair MNEMOSYNE [18] and Digital Europe EUreka3D [19] initiatives, aiming to safeguard its extensive history and to offer a comprehensive insight into the vessel's history. The data acquisition was based on the guidelines of the EU VIGIE 2020/654 study on quality standards in the 3D digitisation of tangible cultural heritage [3]. This process began in January 2023, before the restoration, involving a UAV photogrammetric survey executed with a DJI Mini 3 Pro [20] as the hardware and Reality Capture 1.2.2 [21] photogrammetry software to process the 1100 images collected. This effort resulted in a georeferenced textured mesh model consisting of 27,363,867 faces. To refine the data from the photogrammetric mesh, CloudCompare [22] was employed to extract the vertices and down sample them to 5,000,346 points.

Additionally, a further survey was conducted in October 2023 utilising the Z + F Imager 5016 Laser Scanner [23] during the restoration of the trawler. This was performed to capture the geometry of the timber structural elements, such as the frames, deck beams, keel, and stern, with a result of 14,164,403 points. The TLS point cloud was then aligned with the photogrammetric to create an overall dataset for further processing. This point cloud data was later processed using AutoCAD and Rhinoceros software, with the aim of generating the shipbuilding lines of the boat and the 3D model (Fig. 3). Initially, vertical cloud sections were created, and splines were developed based on these sections to construct a network of curves for the hull. Furthermore, the hull surface was developed, and its offset allowed the creation of a solid geometry. Using this hull geometry, the deck, frames, deck beams, cap rail, keel, and stern were all shaped.

Additionally, the remaining components, including the fish hold, cabin, and masts, were developed by tracing curves over the point cloud. The result is a closed 3D CAD model featuring NURBS geometry at a Level of Detail 400 (Fig. 4). A deviation analysis was also performed to evaluate the accuracy of the NURBS geometry in relation to the point cloud. The outcome of this analysis indicates a deviation ranging from -10 to 12 mm. After the vessel's restoration was finalised, it became essential to assess the deviation of the geometry compared to the boat before conservation. This deviation analysis is depicted in Fig. 5, which contrasts the point cloud of the restored vessel with the profile view before the restoration process.

Moreover, the developed raw model in Rhinoceros software was exported in OBJ to be used by engineers and archaeologists and in STL format for digital fabrication. The OBJ model, which included 10,078,258 polygons and was 1.5 GB in size, was further processed in Blender [24] for decimation and further usage in web visualisation and gaming. Specifically, the Limited Dissolve tool is used with a max angle of $1°$ and a delimit set to normal. This led to the reduction of polygons to 1,365,772 with a size of 162 MB, which allows for its efficient reuse.

3 Aggregation of Lambousa Fishing Trawler to Europeana

The aggregation to Europeana was achieved through the innovative infrastructure developed under the EUreka3D project, which emphasises the integration of advanced digital documentation and data management practices. After the detailed digitisation procedure, the assets were uploaded to the EGI DataHub, a cloud-based platform designed specifically for the storage and sharing of cultural heritage data [25]. This process involved registering with EGI Check-in and joining the EUreka3D Community, enabling initial tests and feedback loops to refine the platform's functionality. The 3D model, characterised by its complexity and high level of detail, was adapted for online visibility through a 3D viewer. Subsequently, the trawler was published as open data using the share and open data tool, which involved requesting a persistent identifier and adding metadata formatted according to the EDM [26]. This metadata was shared with Europeana through the harvesting of information via the OAI-PMH protocol, ensuring the model's visibility on the Europeana Portal [27]. This process is shown in Fig. 6

Additionally, the aggregation included the paradata reports generated according to EU-Study VIGIE2020/654, along with raw data accessible for download.

Figure 7 shows the EDM metadata, including the link that leads to raw data and paradata. The available formats to download are 3DM, OBJ, STL, and GLB, which refer to the 3D CAD model, and E57, which refers to the point cloud data. The 3DM, OBJ, and E57 files can be used by engineers and archaeologists due to the availability of creating, for example, further simulations. The STL is suitable for digital fabrication, while the GLB file, where the number of polygons is reduced and a wood texture is added, can be used for web visualisation and gaming.

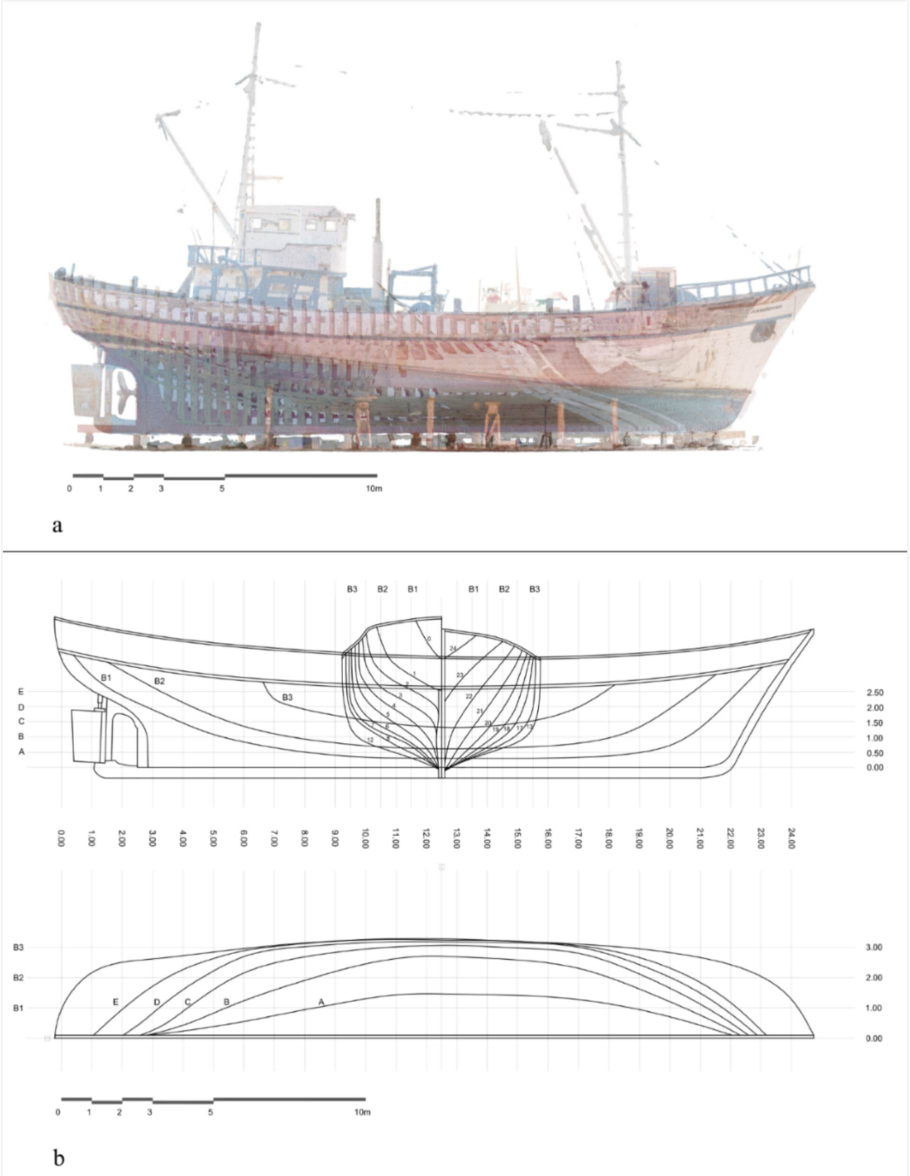


Fig. 3. a) Aligned TLS and Photogrammetry Point Cloud, b) Shipbuilding lines

In particular, the GLB model has been used for the aggregation to Europeana in order to allow its seamless visibility from the 3D Viewer. Through this initiative, the educational potential and visibility of Cyprus' maritime heritage are enhanced within the broader context of European cultural history. The result of the aggregation is shown in Fig. 8.

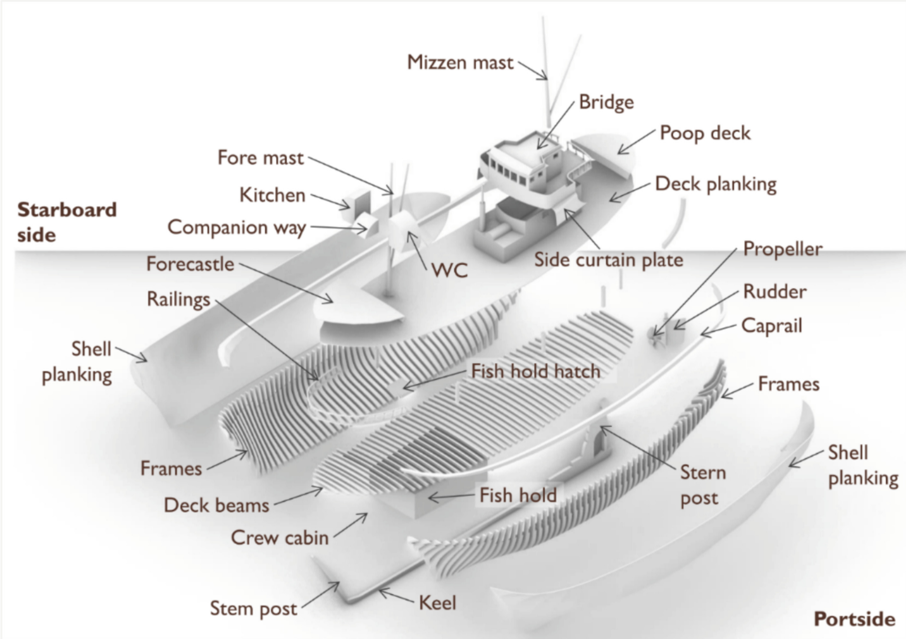
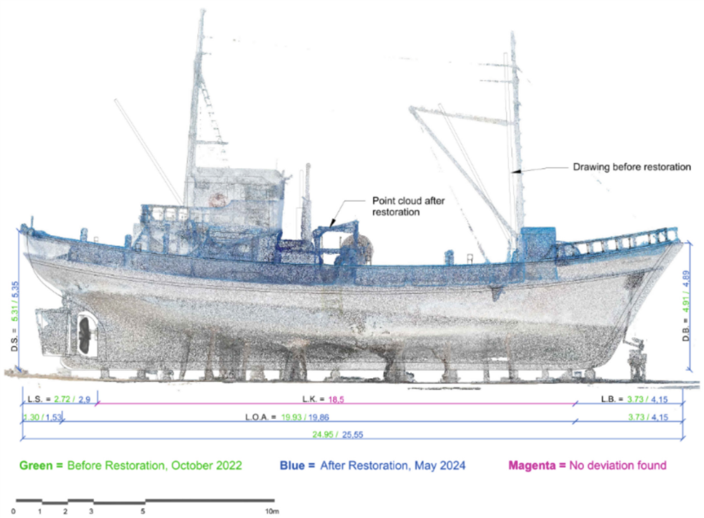


Fig. 4. Exploded Axonometric of the 3D CAD Model



Basic Dimensions	Before Restoration	After Restoration
Length Over All (L.O.A)	24,95m	25,55m
Maximum Breath (M.B.)	6,54m	6,54m
Length of the Keel (L.K.)	19,93m	19,86m
Length of Bow (L.B.)	3,73m	4,15m
Length of Stern (L.S.)	2,72m	2,90m
Depth of Bow (D.B.)	4,91m	4,89m
Depth of Stern (D.S.)	5,31m	5,35m
Height of the Mid-frame (M.D.)	4,02m	4,02m

Fig. 5. Deviation Analysis

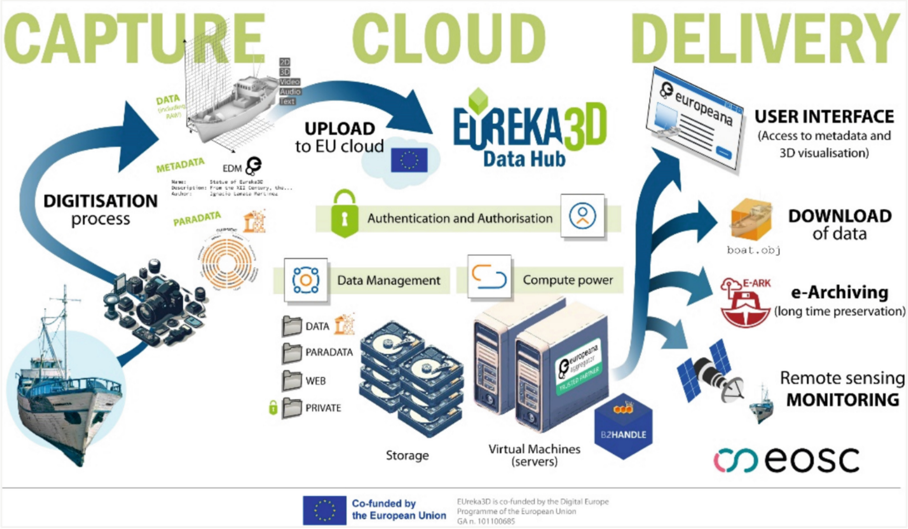


Fig. 6. Digitisation workflow from data acquisition to delivery through the Eureka3D DataHub

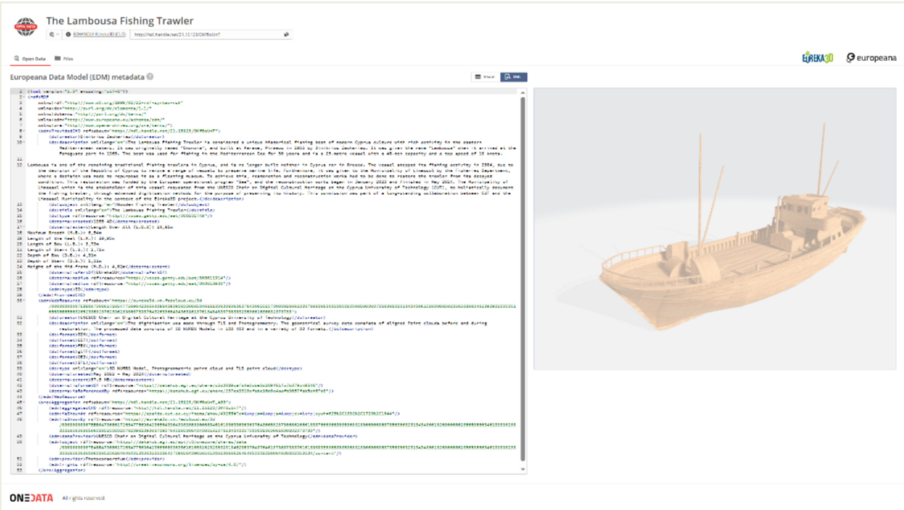


Fig. 7. Metadata, Paradata, and Data as it can be seen from Eureka3D Datahub

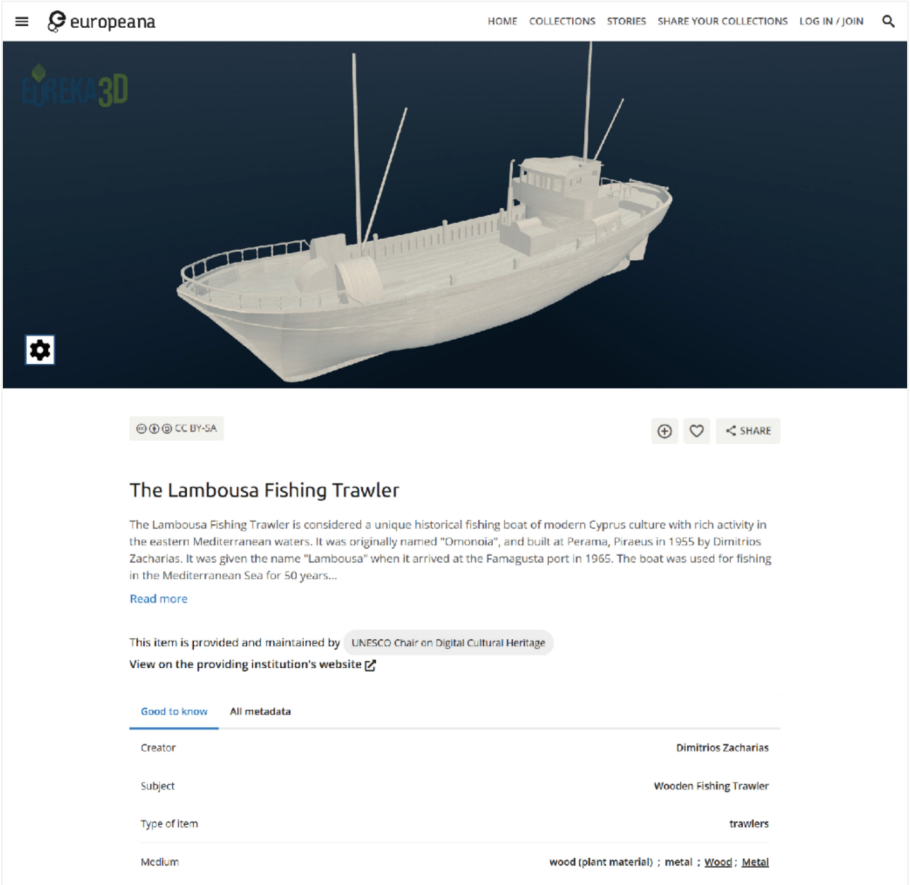


Fig. 8. Aggregation of the Lambousa Trawler in Europeana (https://www.europeana.eu/en/item/1268/21_15123_DKf8oUnT)

4 The e-Lambousa Online Platform

The e-Lambousa platform (Figs. 9, 10 and 11) stands as a dynamic digital repository dedicated to the preservation and celebration of the rich maritime heritage embodied by this significant vessel. This platform contributes to education by providing an accessible and interactive learning environment that fosters a deeper understanding of maritime heritage. Through its diverse range of educational resources, including 3D educational games, virtual tours, and a detailed e-storybook, users are encouraged to engage with the trawler's rich narrative and operational history in an immersive manner. Furthermore, visitors can explore a comprehensive portfolio filled with photographs, videos, and interviews with archaeologists and marine engineers who played pivotal roles in the trawler's restoration.

By offering insights into the craftsmanship and cultural significance of the Lambousa, as well as the collaborative restoration efforts, the platform serves as a valuable educational tool for students, researchers, and the public alike. It promotes interdisciplinary learning, bridging the fields of maritime history, engineering, and cultural heritage preservation, ultimately inspiring future generations to appreciate and engage with their cultural legacy [15].

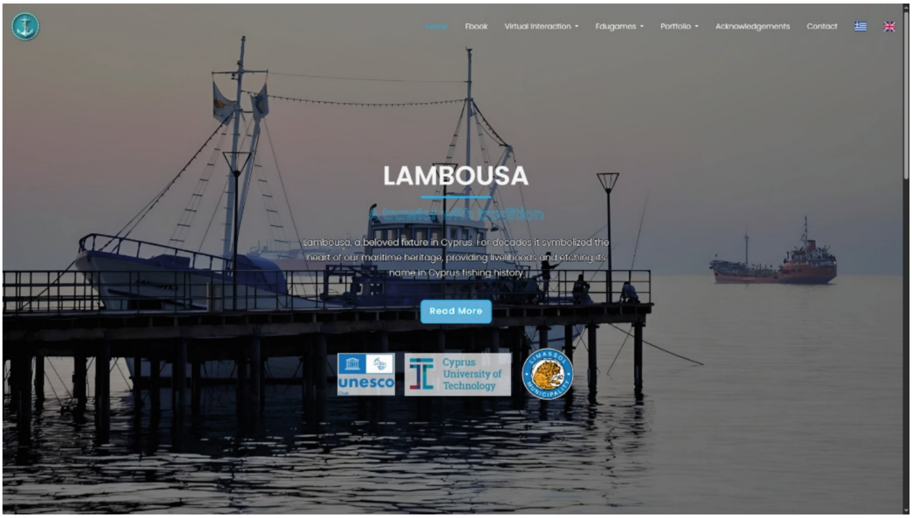


Fig. 9. Home page of the e-Lambousa platform (https://elambousa.eu/)

Fig. 10. E-Story book of the e-Lambousa platform (https://elambousa.eu/ebook.html)

(https://elambousa.eu/ebook.html)

Fig. 11. Educational games from the e-Lambousa platform (https://elambousa.eu/eduspace.html)

In addition, the eLambousa platform was able to utilize the 3D viewer of Kompakkt platform [28] embedding the 3D model into the online application as shown in Fig. 12 This enabled the inclusion of annotated metadata within the GLB model. In particular, the edit annotation tool was used, which allowed the inclusion of text and images to be visible in a variety of areas of the model. Figure 13 indicates the tools used and the result of this enhanced 3D visualisation of the model, allowing the inclusion of images before, during and after the restoration of the boat, which helped the viewer to further understand the history of this monument and navigate to each area of interest.

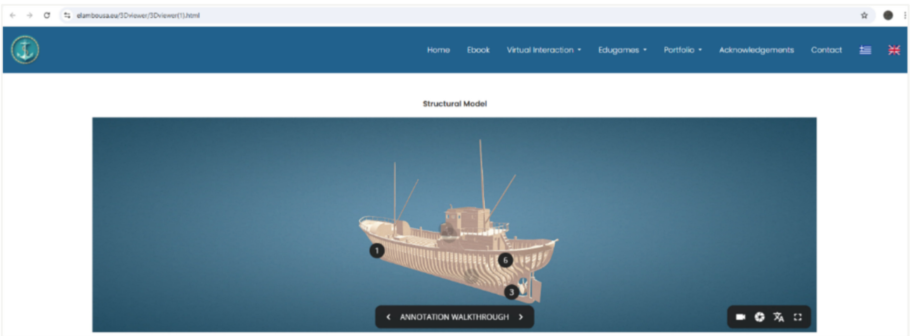


Fig. 12. Kompakkt 3D Viewer in e-Lambousa platform

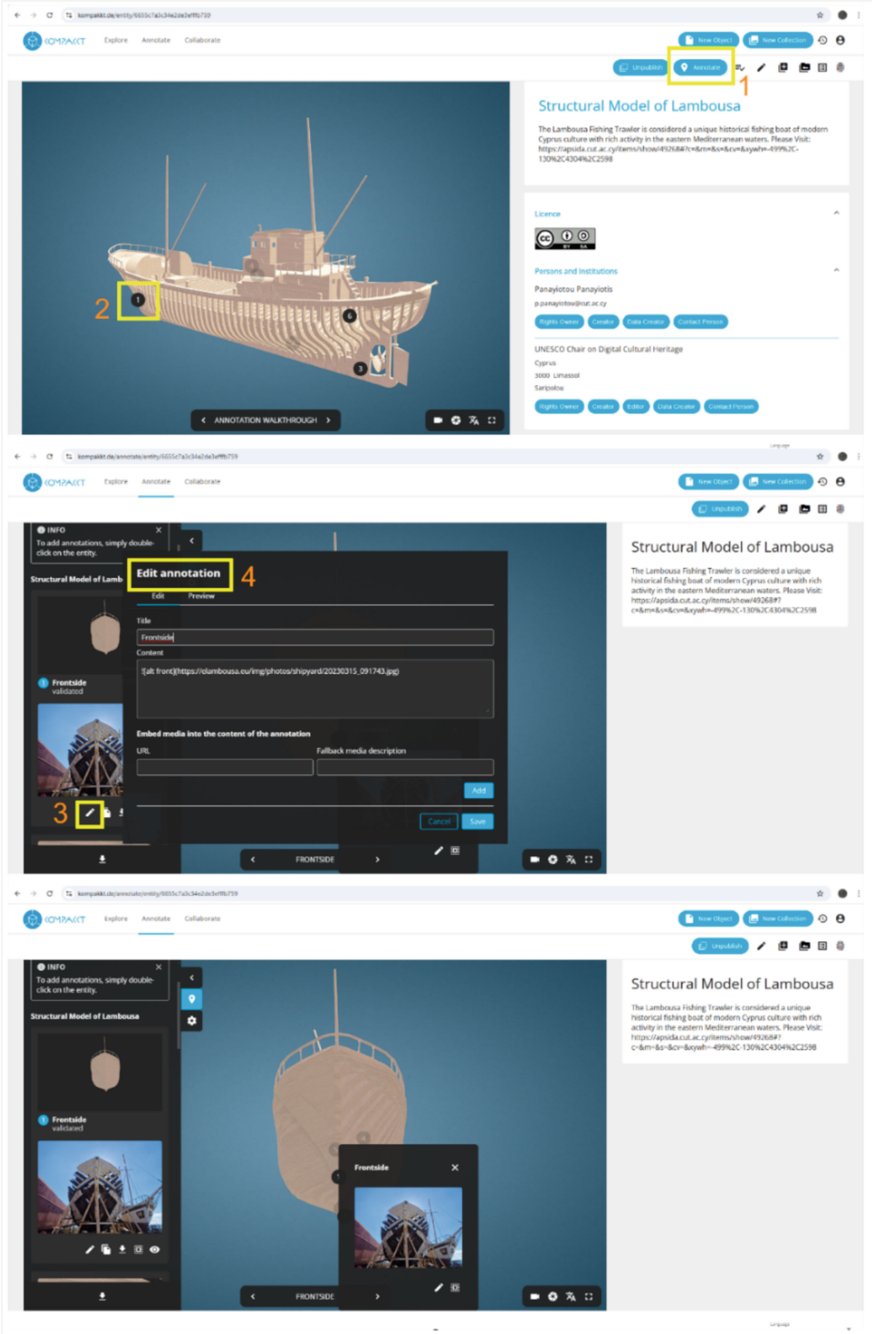


Fig. 13. Metadata annotations in the 3D Model using Kompakkt: 1) Annotate tool, 2) Position of the linked metadata, 3) Edit annotation tool, 4) Annotation information

5 Conclusion

In conclusion, the Memory Twin methodology presents a significant advancement in the field of DCH by integrating not only the physical attributes of cultural artefacts but also the critical layers of paradata and metadata. This comprehensive approach enhances the preservation and accessibility of cultural assets, as exemplified by the case study of the Lambousa Fishing Trawler. The detailed digitisation process, which included advanced techniques such as photogrammetry and terrestrial laser scanning, resulted in the creation of a detailed 3D CAD model for the tangible data, which further allowed the inclusion of intangible aspects of the vessel's heritage.

The Memory Twin methodology not only facilitates the documentation of the trawler's physical characteristics but also enriches its historical narrative through the inclusion of contextual information regarding its construction, craftsmanship, and maritime traditions. Moreover, the aggregation of this data -under open access- to platforms like Europeana ensures broader visibility and educational potential, fostering engagement with diverse audiences. The establishment of the e-Lambousa further enhances this initiative by providing an interactive learning environment that celebrates and preserves the rich maritime heritage of Lambousa. The platform is under official use by the Municipality and accessible for all visitors to the Lambousa museum and virtual users around the world.

Overall, the implementation of the Memory Twin methodology serves as a model for future projects in DCH, emphasising the importance of a multi-disciplinary approach in the documentation and preservation of cultural heritage. Future research should focus on developing standardised protocols for memory twin creation, enhancing interoperability between different platforms, and exploring innovative ways to engage users with DCH. As the field continues to evolve, ongoing research and collaboration among cultural heritage institutions and the rest of the multidisciplinary community will be essential for maximising the potential of memory twins in preserving our shared cultural history.

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