

# Advanced digitisation and AI-powered data processing for Cultural Heritage: the HERITALISE Project

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## Abstract

*The digitisation of cultural heritage assets ensures an accurate digital archive for future generations and serves as a powerful tool for conveying the knowledge and significance of material heritage to the broader public. This contribution presents the overall goals of the HERITALISE project and the foreseen activities, which will combine AI tools for data processing and metadata and paradata creation. NeRF, 3D Gaussian Splatting and LLMs will be involved in the project with different aims ensuring the advancement of digitisation methodologies and standardisation in the cultural heritage field.*

## CCS Concepts

· General and reference → Cross-computing tools and techniques → Evaluation; · Software and its engineering → Software organization and properties → Extra functional properties → Interoperability; · Computing methodologies → Machine learning.

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## 1. Introduction

Cultural Heritage (CH) objects encompass a wide range of tangible and intangible assets, including movable artefacts, architectural structures, archaeological contexts, and natural environments, all of which can be digitally represented. The documentation, study, and preservation of such diverse CH elements require complex and heterogeneous datasets. However, there is currently no internationally accepted framework, methodology or standard procedure to define the quality, level of detail, completeness, and accuracy of CH digitization processes. The HERITALISE project - 2025-2028 (funded by the HORIZON Europe Programme under the “European Collaborative Cloud for Cultural Heritage – Innovative tools for digitising cultural heritage objects” call) aims to research and develop advanced digitisation techniques and methods for accurately documenting and representing diverse CH assets, incorporating both visible and non-visible features for a full comprehension of the diverse CH parts. This contribution presents an overview of the HERITALISE project with a specific focus on the activities to be carried out with AI techniques for data pre- and post-processing, as well as for metadata and paradata creation. The final outcomes of this research will contribute to advancing CH digitisation methodologies by integrating AI-powered processing solutions, ensuring more accurate, efficient, and scalable digital preservation strategies.

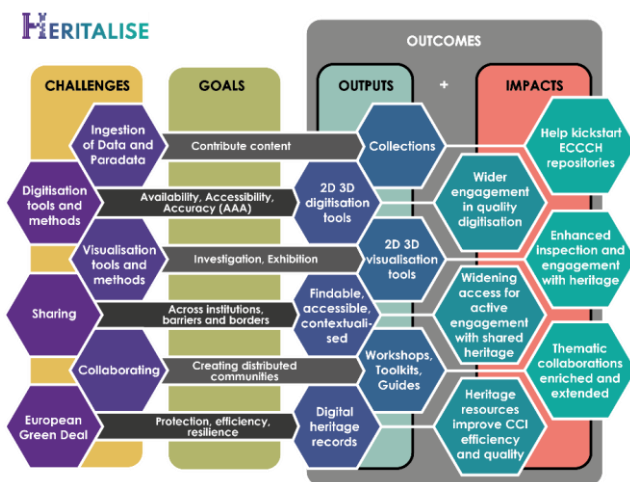
## 2. The HERITALISE project

Digitally recording CH is a vital step in preserving and understanding the values that embody the memory of the past. The

primary objective is to explore and appreciate the diverse values associated with CH objects - artistic, historical, scientific, aesthetic, social, and economic. However, currently, there is no globally recognised framework, methodology, or standardised procedure for defining the quality of detail, completeness, and accuracy in CH digitisation. Each documentation project is typically approached individually, utilising a variety of available methods and often demanding extensive collaboration across multiple disciplines. To determine the most suitable digitisation strategy for 2D/3D data acquisition, processing, visualisation, and application, a careful analysis of the object is essential.

For visible features, established 2D/3D digitisation technologies, such as laser scanning, structured light systems, and photogrammetry, are widely used. Meanwhile, the integration of AI and other advanced technologies is creating new opportunities. Additionally, the CH sector increasingly requires the inclusion of innovative data types, such as hyperspectral/multispectral imaging, panoramic capture, assessments of data uncertainty, and tomography for detecting inaccessible surfaces. Although these advanced methods hold promise, their effective use in CH still necessitates further research.

The HERITALISE project is thus dedicated to researching and developing advanced digitisation methods and solutions for documenting and representing a wide range of CH assets (Figure 1). It aims to enable a comprehensive understanding of both the visible and non-visible characteristics of CH. To enhance and streamline data post-processing and integration, the project will also develop AI-powered tools, including ML techniques, grounded in both standard and extended methodologies.



**Figure 1:** Main overview of the HERITALISE project, from challenges to key expected outcomes.

All information will be interconnected within a knowledge graph environment, allowing various aspects of a CH object to be linked and easily accessed. Much like navigating Wikipedia, users will be able to follow connections to explore detailed information about specific objects, the research conducted on them, and the insights gained.

In this framework, the project will contribute to the European Collaborative Cloud for Cultural Heritage (ECCCH) by providing:

- an interoperable, web-based ecosystem,
- enhanced digitalisation input methodologies,
- preservation-supporting tools,
- enabling wide-scale replicability and scalability across European cultural heritage institutions.

## 2.1 Main goals

HERITALISE will support the development of the forthcoming ECCCH by delivering an interoperable, web-based ecosystem. This ecosystem will integrate advanced input data derived from enhanced digitization methodologies, along with tools designed to support preservation efforts. These outcomes will be achieved by pursuing the following general objectives and by establishing the foundations for broad replicability and scalability across cultural heritage institutions and organizations throughout Europe:

- conduct a state-of-the-art review of current digitisation standards and methodologies; define data requirements for tangible and intangible CH objects.
- Improve 2D/3D data acquisition methods and technologies.
- Advance data post-processing methods with new AI-based digitisation approaches and multimodal data fusion techniques (e.g., multisensory, multiscale, multispectral).
- Develop hardware and software services for cultural heritage digitisation and management.

- Build ECCCH-compliant open interoperability components to connect and share data and services via a distributed, modular web-based architecture.
- Enhance the impact of current and emerging digitisation technologies across the CH sector.

## 2.2 New methods for data processing and integration supported by AI

In this framework, a specific work package will focus on developing advanced methods for 2D/3D data processing and post-processing, aimed at improving the efficiency of workflows involving the fusion of both visible and non-visible data. By adopting a multi-scale, multi-sensor, and multi-temporal approach, the objective is to enable seamless integration processes and cost-effective solutions. This integrated strategy enables the complete digital reconstruction of CH objects, both internally and externally, without the need for physical disassembly. The process will also include the integration of metadata (e.g., local measurement uncertainty) and paradata (e.g., digitisation conditions, environmental factors), as well as supplementary information.

In addition, AI-based generative algorithms will be explored to enrich data completeness, support data cleaning, classification and annotation tasks critical for conservation and restoration, including material identification, structural damage, and crack detection. Specifically, techniques like Neural Radiance Fields (NeRF) and 3D Gaussian Splatting (3DGS) will be applied to enhance the completeness of digital CH representations. These methods will be tested on 3D datasets acquired from a case study at the “Reggia di Venaria Reale”, an Italian UNESCO World Heritage site and part of the “Savoy Residences” system. This case study will allow to test the multiscale approach being constituted by both mobile objects (statues, paintings, furniture), and architecture, landscape and historical gardens.

As *technical objectives*, we thus intend to advance the state of the art in 2D/3D digitisation, by i) improving the data fusion of multisensor and multiscale data sets; ii) addressing measurement uncertainty and radiometric calibration; and iii) accelerating data processing through AI and algorithmic scripting.

In order to achieve these technical objectives, the following sub-activities have been foreseen:

- designing a comprehensive pipeline for the processing and post-processing of data. This will streamline processes such as the automatic registration of partial point clouds, referencing local objects within global point clouds, as well as object segmentation and categorization. The development of custom software solutions will also be a crucial component, aimed at improving data processing and analysis. These tools will be made available either as free libraries or standalone applications, ensuring compatibility with existing software packages, particularly those used within the ECCCH platform.
- Improving methods for multiscale and multispectral data fusion. We will explore how different digitization techniques, such as LiDAR, tomography, and X-ray, can be combined to

form a complete digital representation of CH objects, encompassing both their internal and external aspects, without requiring physical dismantling. A key aspect of this task will be the use of semi-automatic and automatic testing methods based on statistical tools like Bayesian approaches to evaluate the accuracy and completeness of the analyzed data. To ensure compatibility with the broader ECCCH platform, the task will make use of standardised formats for metadata, such as local measurement uncertainties, and paradata, which will include details about the digitisation conditions, environmental factors, and additional information like local chemical analyses.

- Advancing AI algorithms to improve the completeness of digitized objects. This task will explore the integration of NeRF and 3DGS to create more complete and detailed digital representations of CH objects. NeRF will enable the recreation of entire objects and environments, while 3DGS will enhance the preservation of fine details. These advancements will help integrate AI into the preventive conservation of CH, and museums, historians or other stakeholders will benefit from improved virtual exhibits, accurate documentation, and enhanced collaboration in restoration efforts.
- Development of a monitoring system that will provide real-time data on the conservation status of CH in various environments. This system will gather comprehensive data on geometrical, radiometric, thermal, and microclimatic conditions vital for understanding the factors affecting CH and will be used to generate multi-temporal digital models.

### 3. AI-powered approaches for CH

#### 3.1 Data acquisition, pre and post-processing

As mentioned in paragraph 2.2, different approaches to enhance both data acquisition and processing will be involved in the project. Among them, we can find Neural rendering methods (NeRF and 3DGS) and LLMs to be applied differently to the acquired data based on the purpose. The application of these methods to the CH domain is still in the initial stages, and the HERITALISE projects seeks to deepen their knowledge and make their appliance more aware especially from a technical point of view (e.g. accuracy evaluation or trustworthy usage).

**NeRF** have certainly emerged as a transformative technology in the digital documentation and preservation of architectural and cultural heritage, offering highly photorealistic 3D reconstructions from ordinary oriented 2D image inputs even in case of texture-less, reflective, and refractive surfaces [RKY\*23]. Unlike traditional photogrammetry or LiDAR, NeRF can effectively reconstruct complex geometries and occluded areas, which are often present in historical architecture maintaining an accurate point fidelity [MG23]. These advantages will be tested and deeply evaluated on the data acquired for the case study, not only to complete possible occlusions in point clouds, but also to define a set of possible guidelines for a wider involvement of this approach, even for non-expert users. Recent research has, in fact, demonstrated the effectiveness of NeRF in multiscale heritage applications, from small artefacts to large architectural

environments [CFB\*24]. However, limitations still exist in terms of generalizing across lighting conditions, partially managing reflective or cooperative textures [RKY\*23], requiring dense photographic coverage as well as image orientation, noisiness and density [MG23]; these elements present the ongoing challenges for practical deployment in heritage contexts that will be deepened in the HERITALISE project.

On the other hand, **3DGS** has rapidly emerged as a transformative technique, especially in the digital visualization of CH. This approach is particularly advantageous for the project activities since it allows for capturing intricate architectural details and complex lighting conditions inherent in heritage sites [JB25] that could be encountered while acquiring data.

The studies of [DCR\*24], which introduced a pipeline that leverages 3DGS for 3D digitisation of CH objects using only RGB images (facilitating efficient object segmentation without manual annotation) simplifies the digitisation process, making it accessible for widespread use in museums and heritage conservation. Moreover, [CNAC24] conducted a comparative analysis of 3DGS, NeRF, and Structure-from-Motion Multi-View Stereo (SfM-MVS) techniques for 3D representation of architectural heritage using low-cost sensors. Their findings highlighted 3DGS's potential in producing high-quality reconstructions with reduced computational resources.

In addition, **LLMs** are increasingly being leveraged in the domain of cultural and architectural heritage, where they support tasks such as archival data access, interpretation of historical materials, and cross-cultural engagement. For example, the Greek National Theatre has implemented an LLM-based system that translates natural language queries into SQL, allowing users to interact with structured archival content more intuitively and accessibly [TPK23]. LLMs are also being applied to enrich and interpret historic building datasets. [ZKKX\*24] used LLMs to support semantic annotation of architectural features in historical Chinese buildings, enhancing their accessibility and interpretive value for broader audiences. Or more, they can be applied for the 3D reconstruction and to create parametric models for HBIM purposes. Starting from the archaeological plan, the parametric modeling of a text-to-BIM workflow based on OpenAI and open source tools can be conducted to automate and streamline the modeling process facilitating even non-expert users [Dia25], as it could be the case of the HERITALISE project. [PADLV23], still, introduced the Multimodal Enhancement Fusion Index (MEFI), a method for evaluating and improving multimodal 3D reconstruction of built CH. MEFI allows analyzing and visualizing the density and quality of information from different acquisition modalities, such as photogrammetry and laser scanning, facilitating the identification of areas requiring additional data or attention. A similar approach can be integrated into HERITALISE workflows to improve the efficiency and quality of multimodal data fusion, supporting the goal of creating complete and accurate digital representations of cultural heritage.

However, it has to be taken into account that the use of LLMs in the field of CH still raises concerns about cultural misrepresentation and value alignment. [BWWJ24] have shown that current models can unintentionally mischaracterize cultural

narratives, highlighting the importance of developing culturally sensitive AI systems. In response, initiatives like CultureLLM aim to fine-tune LLMs to account for diverse cultural norms and expressions, improving their contextual awareness and ethical grounding [LCW\*24].

### 3.2 Meta-paradata automatic definition

Finally, the project will take advantage of AI algorithms also for the automatic explanation and generation of metadata and paradata. There are already some existing works in the state-of-the-art dealing with this possibility and, even if applied to other CH sectors, they could be adapted and further investigated also for museum collections or architectural heritage. An example is constituted by the research of [RMD\*24] where they present a multimodal classifier for the CH domain using a late fusion approach. The three modalities considered are images, text and tabular data. The results show that the multimodal approach provides the best performance in predicting missing properties in digitized silk artefacts. This work demonstrates the effectiveness of AI-supported multimodal fusion in improving the annotation and classification of cultural artifacts, a key goal of HERITALISE.

### 4. Conclusions

In this contribution, the main objectives and future outcomes of the just-started HERITALISE project have been presented. Data acquisition on the case study and state-of-the-art phases are ongoing. In addition to what is described, consideration will also be given to the computational demands of the proposed methods and techniques. This research will enhance CH digitisation methodologies by incorporating AI-driven solutions, leading to more accurate, efficient, and scalable strategies for inner-outer 3D representation of CH assets, as well as for their data processing.

### Acknowledgments

This study was carried out within the Horizon HERITALISE project. This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

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