Heritage Buildings and Objects' Digitisation and Visualisation Within the Cloud (HERITALISE)

Alan Miller[1(✉)], Catherine Anne Cassidy[1], Sharon Pisani[1], Mikel Borras[2], Drew Baker[3], and Jacquie Aitken[4]

[1] Computer Science, University of St Andrews, St Andrews KY8 4QH, Scotland
{ahr1,cc274,cc259}@st-andrews.ac.uk
[2] Innovation, Ingeniería Medio ambiente y Arquitectura, Barcelona, Spain
mborras@idp.es
[3] Heritage, Cyprus University of Technology, Limassol, Cyprus
drew.baker@cut.ac.cy
[4] Museum, Timespan Museum, Helmsdale, Scotland
jacquie@timespan.org.uk

Abstract. HERITALISE mission is to research and develop advanced digitisation techniques and solutions for documenting and representing diverse Cultural Heritage assets, giving a full comprehension of the diverse Cultural Heritage features, visible and non-visible. In addition, AI-powered tools including Machine Learning (ML) will be developed for improved and optimised data post-processing and integration based on standard and expanded methodologies. All this will be connected through a knowledge graph environment that allows the individual aspects known about the CH object to be related and retrievable. As with Wikipedia, by following links it will be possible to learn more about a particular object, what research has been done, and what results have been derived from it. HERITALISE will provide the upcoming European Collaborative Cloud for Cultural Heritage with an interoperable web-based Ecosystem, advanced input data from improved digitalisation methodologies and preservation supporting tools, which will be achieved by meeting the projects general objectives.

Keywords: heritage · digitisation · HHBIM · memory twin · virtual museums · ECCCH

1 Heritage Buildings and Objects' Digitisation and Visualisation Within the Cloud

The HERITALISE mission is to research and develop advanced digitisation techniques and solutions for documenting and representing diverse CH assets, giving a full comprehension of the diverse CH features, visible and non-visible. In addition, AI-powered tools including Machine Learning (ML) will be developed for

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improved and optimised data post-processing and integration based on standard and expanded methodologies. All this will be connected through a knowledge graph environment that allows the individual aspects known about the CH object to be related and retrievable. As with Wikipedia, by following links it will be possible to learn more about a particular object, what research has been done, and what results have been derived from it (Fig. 1).

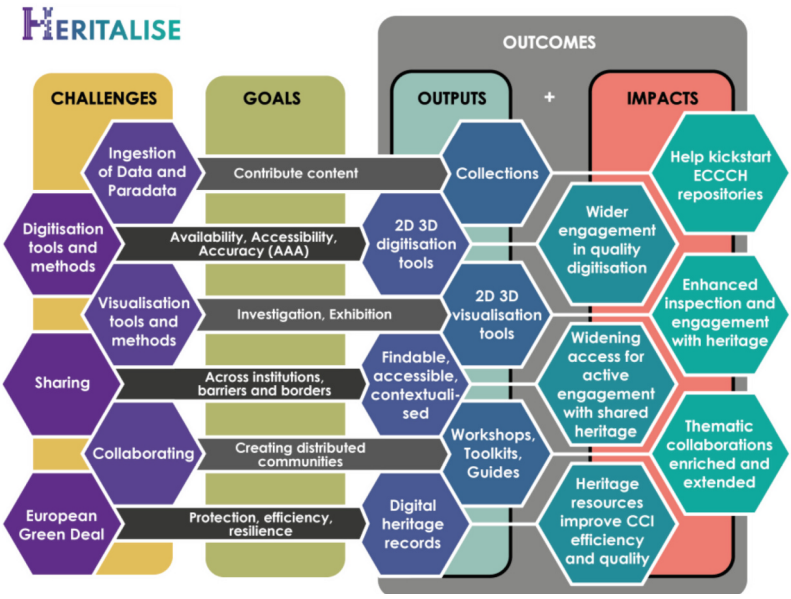

Fig. 1. Challenges, Goals, Outputs and Impacts for the HERITALISE project.

2 Context

Cultural Heritage (CH) is a complex ecosystem, involving institutions and actors that continuously produce and utilised multifaceted data and knowledge related to various types of CH objects. These objects can range from movable assets, architectural heritage [1], archaeological contexts, and natural environments, and may be of different nature and materials, whether tangible or intangible, which can be represented in a digital format. Complex and very diverse data are required to effectively document, study and support the preservation of such artifacts. New potential is enabled by recent technologies for data survey, analysis and sharing. In addition, data about the CH context and environment are often critical to complement their proper understanding and protection.

The digital recording of CH is an essential step in understanding and preserving the values of memory of the past. It creates an accurate digital record for the

future and provides a means to transmit and communicate the knowledge and value of the material objects to society. Therefore, the main goal is to understand and appreciate the various values and meanings of the CH object - artistic, historical, scientific, aesthetic, social, and economic. This understanding can only be achieved if the individual aspects can be related to each other and are always available to users as a knowledge graph that allows traversing from one aspect to another seemingly. The creation and maintenance of this knowledge graph requires compliance with certain standards and best practices. Both aspects as well as the technical realization of the knowledge graph are the focus of HERITALISE. However, there is no internationally accepted framework, methodology or standard procedure for specifying the quality of detail, completeness, and accuracy in CH digitisation. Documentation projects are typically determined on a case-by-case basis using the many available methods and often require significant multi- and interdisciplinary cooperation. An object needs to be carefully examined, studied, and inspected to define the best available digitisation options for 2D/3D data acquisition and processing, visualization, and usage. Therefore, the recording of tangible CH requires a thorough understanding of the stakeholder requirements, the necessary technical specifications, the existing environmental conditions, the intended use of the final 3D digital model, its metrical accuracy and fidelity to the physical CH. Selection of the optimal human resources and digitisation technology are usually related to the size, complexity, material, texture, location, accessibility, Intellectual Property Rights of the CH artefact. For visible characteristics, nowadays consolidated technologies exist for 2D/3D digitization, e.g., laser scanning, structured light systems, and photogrammetry techniques. However, the use of artificial intelligence and other advanced technologies opens new possibilities. In addition, the heritage sector demands for the asset digitisation the aggregation of new types of data such as advanced hyper/multi-spectral and panoramic detection, data uncertainty local assessment, or detection of non-reachable surfaces by tomography. The use and improvement of these new techniques for CH still require further research, and furthermore, the fusion of all this information requires new data pre- and post-processing software (SW) tools that make use of the latest innovations on Information and Communication Technologies (ICT).

3 Aims and Objectives of the HERITALISE Project

HERITALISE will provide the upcoming ECCCH with a interoperable web-based Ecosystem, advanced input data from improved digitalisation methodologies and preservation supporting tools, which will be achieved by meeting the following General Objectives (GO) and setting the conditions for a wide-scale replicability and scalability across European CH institutions/organisations across European CH institutions/organisations:

GO1: State-of-the-art review of current digitisation standards and methodologies defining the data requirements for CH tangible and intangible objects'

digitisation and sharing, identifying the gaps, and defining objectives and protocols for HERITALISE.

GO2: Improve 3D/2D Data acquisition methods and technologies, to increase the capability of traditional and well-consolidated one and covering a wide array of data typology such as visible/non-visible, and large/small scale characteristics. Development of specific dimensional and calibration procedures for panoramic acquisition of digitised data.

GO3: Data post-processing methods and technologies will be adopted, including new AI-powered digitisation methods and the development of data fusion techniques to mix various multi-modal digitisation approaches (multi sensory, multiscale, multi-spectral, external, and internal). CH sector professionals will benefit of this smoother and faster workflow to better curate, analyse and monitor visible or hidden characteristics of complex assemblies. Non-tangible data like temperature, humidity, light, sound, or flow of visitors, will be integrated.

GO4: Development of methodologies and solutions as Hardware (HW) and/or Software (SW) services (3D printing techniques, Monitoring & Analysis/preservation platform -to cope with the phenomena of deterioration Geo-HBIM based DTE, VR/AR/XR Game engine) that make use of previously mentioned CH data (including data modeling) that enable a wide range of CH organisations to draw upon CH in different ways.

GO5: Development of ECCCH-compliant open interoperability components enabling connecting and sharing data and modular services in a distributed web-based architecture. Such components will streamline the upload and sharing of data, including those data resulting from the new survey and processing methodologies, as structured and documented (with metadata and paradata) data.

GO6: Increasing the Impact of current and developing digitisation technologies of objects and buildings by overcoming the common problems related to technology transfer to museums, touring companies, and dissemination to individual end users. This includes the implementation of standardized web platforms of digitised assets and virtual touring. In this regard, HERITALISE brings in 4 different Use Cases as Proof of Concept.

These objectives will be translated into technical objectives addressing the following areas.

To define methodologies and guidelines for user-friendly digitisation and visualization, to enable the adoption of developed tools by the Heritage sector.

To develop new user-friendly tools for CH sector professionals (researchers, curators and conservators) to better study 3D assets (like objects or architectural details) and 2D assets (like paintings) by i) adding multiscale data fusion where macro detail data (geometry) combines with microscale data (scratches and cracks); and ii) adding multispectral data fusion by combining visible and non-visible spectrum (infrared, UV and X-ray) that also allows to better understand the deterioration processes tackling it through automation under the precepts of active preventive conservation.

To address in the CH sector important metrology concepts such as measurement uncertainty, accuracy, completeness, radiometric (colour) calibration, wide angle lenses panoramic reconstruction, and internal reconstruction of assets with computer tomography.

Advance the state of the art in 2D/3D post-processing methods using new technologies such as Artificial Intelligence and Algorithmic scripting for point-cloud processing, final digital asset data cleaning, segmentation and automatic categorization, to improve efficiency in massive digitisation scenarios.

To apply developed tools to improve the Home museum concept and enhanced CH analysis/management opportunities to allow general people access world CH for study or recreational purposes, and experts to multiscale enhanced data, through Digital Twin Environments (DTE) including Geo-HBIM models, Augmented and Virtual Reality as well as Game Engine technologies underpinned by relevant standard APIs and data encoding standards.

To increase Findability, Accessibility, Interoperability and Reusability (FAIR) of the Heritage information and by standardization of components, tools, procedures, metadata, visualization, and data structures, to incorporate results within the European Collaborative Cloud for CH (ECCCH).

To demonstrate developed tools and methodologies by 4 case studies in real uncontrolled scenarios, with a focus on the actual needs of the current CH sector professionals and users. The four case studies will be, West Highland Museum and the Timespan Museum in the Highlands of Scotland, Reggia di Venaria Reale in Torino and Villa Portelli in Malta.

4 Methodological Approach

HERITALISE will enable new improved management (restoration, documentation and maintenance, monitoring, tourism, and education) of CH. The project will develop improved digitisation of CH (GO2), including visible, nonvisible, hidden information and enhanced descriptions (GO3). F.A.I.R. management of data following standards, Open exchange protocols and semantic technologies will ensure machine-readable, consistent, open and secure communication of the information about CH in an enhanced ecosystem including all the related information (environmental, geographical, cultural context) (GO5). Such information will be effective input to new.

HERITALISE advanced methods and tools for processing and analysis (AI, data validation and integration) and use of data (GeoHBIM, Digital Twins, Augmented, Virtual, eXtended Reality, gaming) (GO4). Starting point are requirements from representative demo cases (covering diverse kinds of heritage and different use cases and conditions) (GO1), in which the solutions will be iteratively tested in close connection with stakeholders (GO6).

The work methodology, as shown in the following figure, is divided into four pillars/GOs: 1) HERITALISE Requirements and Methodology; 2) CH data acquisition techniques; 3) CH data processing/post-processing; 4) Services based on CH data; 5) ECCCH-compliant and interoperable ICT Ecosystem; and 6)

TRL 5–6 Validations to enable European scale scalability and replication. Therefore, the first pillar begins with research and definition of a methodology for digitising CH objects (and premises) focusing on HERITALISE Demo Sites and Use Cases. Then, in the second pillar, digital technologies are defined and further developed to improve CH tangible and non-tangible data. In the third pillar, AI-powered SW is developed and customized to enhance the processing and post-processing of data acquired whereas pillar 4 aims at developing HW and SW services that make use and boost the usability of all this CH data acquired and processed/post-processed. In between, Pillar 5 is responsible for the development of the ECCCH-compliant and interoperable ICT Ecosystem enabling FAIR CH data, paradata, and metadata exchange amongst CH stakeholders in accordance with defined user roles, rights, and data privacy/ethics aspects. Finally, overall validation is carried out in 4 diverse demo sites in Pillar 6, aiming at further scalability and replication across European CH institutions (Fig. 2).

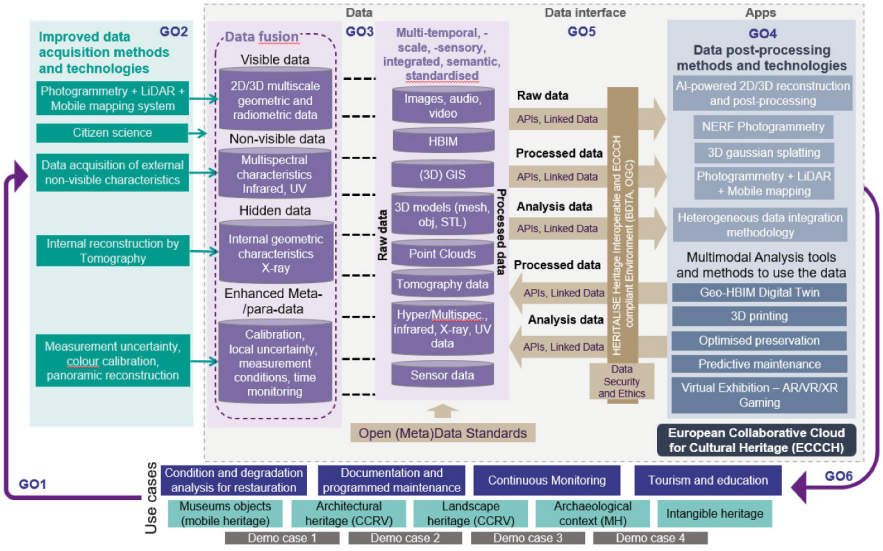

Fig. 2. Four pillars of the HERITALISE methodology.

5 Phases

The projects work will be organised into six phases.

Phase 1: CH Digitisation requirements and methodology definition: This phase aims at the definition of the basic requirements for the development and implementation of HERITALISE solutions, technologies and, further the ICT tool development passing along the data concepts (standards, ontologies), AI

techniques, ... that will serve later to enable the tools and services deployment. This Phase is corresponding to the Pillars of development 1 and 2.

Phase 2: Digitisation tools' development and testing at lab scale: This phase, along with Phase 3 will represent the core technology research activity of the project. CH digitisation tools/components for enhanced data acquisition will be developed. All the activities will be carried out by strongly coupling numerical and experimental development according to an iterative process, benchmarking the results at each stage of development with the KPIs defined in Phase 1 [2].

Phase 3: CH data processing and post-processing: This phase complements the previous phase in technology research activities, taking as inputs the data sets gathered by the technologies involved in Phase 2. Innovative data processing, and post-processing tools will be developed by implementing latest technologies powered by Artificial Intelligence and scripting for automation, useful for large data scenarios. This phase corresponds to Pillar 3 [3].

Phase 4: CH data Services development: This phase is key to achieve one of the main objectives of HERITALISE: the development of a set of services combining the potential of different CH data streams, considering the complexity and cost of the solutions. Finally, an integration of the innovative technologies and ICT techniques and tools in a centralised ICT environment will be carried out, underpinned by webAPI services, leading to Phase 5 [4].

Phase 5: Interoperable ICT architecture: The developed methodologies and processing tools within the project, as well as the produced data, will need to comply to the Findability Accessibility Interoperability and Reusability (FAIR) principles. Thus, a standard-based data structures and vocabularies profile will be developed, as well as recommendations and components supporting FAIRness of developed pieces of SW [5].

Phase 6: HERITALISE implementation at Real Use Cases and TRL6 validation, aiming at EU level replication and scalability strategies: This phase represents the core outcome of HERITALISE development and includes the implementation of the different solutions researched and developed in previous phases in 4 demonstration sites in 3 different countries. This phase will also include the evaluation of the solutions to define the advancement up to TRL6 overall (with a different range of TRL depending on the solution/services) after project ends [6].

6 Use Cases and Pillars

There will be four use cases in the HERITALISE project. These are focussed on the West Highland Museum and Timespan Museum in Scotland, the Reggia di Venaria Reale, in Torino Italy, and the Villa Portelli, Malta [7]. Table 1 describes the heritage and goals for each use case. There will be four use cases in the HERITALISE project. These are focussed on the West Highland Museum and Timespan Museum [8] in Scotland, the Reggia di Venaria Reale, in Torino Italy, and the Villa Portelli, Malta [7]. Table 1 describes the heritage and goals for each use case.

Through this work Heritalise aims to advance the state of the art in the following areas.

6.1 Digitisation Standards

CH digitisation is currently a very dynamic field, each CH item requires a careful planning of the digitization workflow according to the dimension, materials, movability, fragility, and degradation state of the item itself. CH digitisation is largely unregulated and lacking generally accepted definitions on relevant aspects. The combination of range in digitisable artefacts and accelerating pace of relevant technological advances makes the definition of standards and general methodologies nontrivial. A comprehensive review in the relevant state of the art with consideration to the use cases and relevant solutions and technologies with be used to define the requirements and methodologies which will be used. CT scan and 3D printing: A combination of artefact specifics, in terms of features, and technical capabilities in terms resolution will define and dictate the achievable requirements and methodology that will be applied and used.

Defining requirements and methodologies for the utilization of CT scans and 3D printing in CH is crucial. It sets the guidelines for data acquisition, processing, and replication, ensuring accuracy and authenticity in preserving cultural artifacts. The process involves reviewing the relevant state of the art, close collaboration with CH experts and stakeholders to establish the specific data needs, formats, and preservation goals. By defining robust methodologies, including scanning techniques, material selection, and printing parameters, we ensure that the digitization process remains faithful to the original artefacts and highlights hidden or important features. Ultimately, these requirements and methodologies serve as the foundation for responsible CH preservation, facilitating access and research while safeguarding our shared history for future generations.

6.2 Digitisation Tools

Digitisation techniques have gathered during the last years the interest of experts in the field of CH. The creation of a 3D model of artefacts, without doubt, brings several advantages. Firstly, the possibility of fully documenting an item and creating a trustworthy digital replica, which includes data regarding the over all aspect, geometry, colour, texture, and morphology of the asset. Secondly, digital twins of artefacts can be archived to virtually preserve an artefact and monitor its state of preservation over time, in consideration of future degradation or non-predictable damage or loss. 3D models can be employed as an active tool for the study of an artifact by documenting and monitoring the morphology and aspect of an item, along with its conservation or during interventions, as traditionally done with 2D technical imaging, but with the advantage of having a model that can be virtually manipulated. Moreover, a virtual replica also finds applications among the public, enabling virtual access to items from all over the world. Eventually, 3D models can even be employed to create 3D-printed replicas

Table 1. HERITALISE Use Cases

Demo Site	Type of Heritage	Use Case Goals
West Highland Museum [8]	Cultural landscape, including objects, buildings, scenes, and intangible heritage	Digitise highland cultural landscape related to Gaelic Intangible heritage. Digitise artefacts, building and scenes, ingest into ECCCH and implement museum at home, game engine solution
Timespan	Object Collections (archaeological, working tools, artwork, textiles); Vernacular Fishing Village Architecture; Archaeological Landscapes; Intangible Heritage	i) Create themed content in ECCCH connected with the exploration of visualization; ii) Create digital twins of landscapes, buildings, objects, and scenes, based on GeoHBIM DTE including VR/AR/XR experience; iii) Record and collect intangible CH, songs, stories, and poetry, to tell stories of climate change and colonialism; iv) Develop metadata and para data which enables connections to be established and replicated within visualisation scenarios
Reggia di Venana Reale	Mobile objects (statues, paintings, furniture), Architecture, Landscape and historical gardens	i) Multiscale and multisensor data integration for the digitization of both the outdoor historical gardens and the indoor environments with also the cultural objects; ii) 3D data completion and integration-development of an HBIM [9] model standardized and able to collect monitoring data for the planned maintenance and preventive conservation plan; iii) Application of tomography on artefacts for study, research and touristic purposes, including CT scan and 3D printing
Villa Portelli	CH site-Villa and Gardens, Artefacts, intangible heritage	GeoHBIM digitization based on LiDAR/photogrammetry [10] 3D model of the villa to be used for documentation purposes, before and after restoration and reuse; ii) Creating a virtual site that can be explored using VR/unreal gaming engine - will also include a virtual museum of the site. iii) Creation of digital outreach test products related to CH interpretation; iv) Create a DT which shows how the site looked before the landscape around the Villa changed; v) Exploring the digitization of cultural intangible CH through collecting memories of people who have worked in or around the villa itself. The creation of a XR tool which will allow visitors to explore the site with the help of an AI powered avatar. The concept of digital twin will be extended to memory twin, where the digital twin acts as a gateway to intangible as well as tangible heritage [11]

of an artefact that can be exploited to create more inclusive tactile exhibitions or for innovative displays.

6.3 Data Processing Supported by AI

The innovative elements, beyond the state-of-the-art, of the proposed solution are: i) Combination of NeRFs, semantic segmentation, decay identification and recognition for complete and semantically enriched 3D models; ii) Data fusion with the integration of the internal parts of CH (such as statues) with the external one, thanks to tomography [12]; iii) Creation of standards and guidelines on data acquisition and expected accuracy based on the different types of instruments and sensors used; iv) The introduction of new indicators on the quality of the data acquired and processed thanks to the characteristics of the sensor and statistical methods. This will allow you to have a new awareness of the quality of the data; and v) Automatic interpretation, starting from multi-sensor techniques, of 3D models for the identification and recognition of the types of degradation.

6.4 Services Development

Digital Twins are one of the most relevant trends presently found among digitalization across all the sectors. In the same way scale models has been used since humanity started to use tools, their evolved Digital counterparts could offer the same benefits and beyond. From health1 to environment2, Digital Twinning appears as an unstoppable wave although they are often targeting just one of the most relevant benefits attached to the Digital Twin Environments: to be an effective PLM (Product Lifecycle Management) tool3 focused on CH buildings and objects. By avoiding data silos among stakeholders across any complex workflow, DTs allow a better decision taking based on comprehensive (not necessary complex) and updated information. Moreover, DTs allow another inherent benefit, the predictive purpose, which is by itself more than enough to justify the effort of developing Digital Twins of any connected physical object. Ambition 2 In the case of the CH sector, virtual experiences are being increasingly offered, according to home museum concept, based on digital replicas of CH buildings/objects and the integration of tools such VR/AR/XR into this CH DTE [13]. Ambition 3: Consistent integration methodology of multisource data will be developed starting from the project use cases requirements. HBIM, documenting detailed construction elements, will be used to represent architectures and building behaviours, supporting documentation, operation, and maintenance. GIS data, including data coming from integration and conversion from the HBIM, will relate each CH object (either tangible or intangible) into its context, enabling holistic and GIS-based queries and analysis, besides an enhanced Home Museum potential. Additional data (e.g., sensor data, environmental data, imagery) will be used to enhance the analysis potential and support further use cases. Linked data and the OGC RAINBOW are key technologies for the semantic integrations.

6.5 AR/VR Visualisation

Methods of visualising 3D digitised heritage artifacts can be applied to different types of heritage artifacts and can be presented in different use cases. Heritage Objects may be pieces of art, artifacts such as vases, monuments, buildings or archaeological sites. With improved graphics and processing powers it is now increasingly practical to represent landscapes, sea scapes and city scapes. This gives us three scales of digital heritage objects; each scale shares many characteristics. We will refer to these scales as artefact, scene and vista. Augmented Reality and Virtual Reality can be thought of as a sliding scale. At the augmented end our interactions with the real world are augmented digitally. At the Virtual Reality end, we are immersed in "complete" virtual representations. In cross or X reality we can interact simultaneously with the virtual and augmented world.

6.6 Digital Twins

These take a digital representation at any of the artifact, scene and vista scales, and supplement it with data which describes the relationship between the digital representation and the real world. Digital twin applications themselves can cover a wide spectrum from real time control applications through to digital objects with descriptions and interactions attached. In the context of tools for ECCCH, we are interested in developing applications which enable digital twins to be developed from digital models at each of the scales to be deployed in web, mobile and museum contexts.

Ambition: Through building on existing applications developed by project partners and deploy them within use cases. This will play the basis for design of tools for the ECCCH which enable museums to develop mobile, web and kiosk applications of digital twins at the scale of collections of artefacts, digital scenes and vistas.

6.7 Cultural Heritage Conservation Module

Engage stakeholders in conservation and preservation to gain insights, perspectives, and support for their preservation purposes. Develop specific, measurable, achievable, relevant, and time-bound goals for the proposed CH preventive conservation technology. Prioritize actions that need to be taken to achieve the identified conservation and preservation goals. Create a method outlining the actions required to achieve the goals for integrate the CH conservation technology/tool of HW/SW into an integrated ITC ecosystem.

Related KPIs: 4 CH sites in three countries that includes different categories of CH objects (monuments/artefacts, tangibles/intangibles) and engage a heterogeneous group of stakeholders and experts in the field with expertise in a representative variety of CH typology and historical periods.

6.8 CT SCAN Based 3D Printing

From educational institutions to museums, the combination of CT scan data processing and 3D printing can become an indispensable tool in unlocking the secrets and preserving the beauty of our shared human history. 3D printing has become significantly more accessible both by individuals for personal use, and in addition to institutions. This work aims to establish the methods by which the data can be processed and made widely available for reuse, hence realising the potential of these technologies in CH.

7 Impact

Cultural Heritage practitioners in Europe, including curators, conservators and researchers of CH, use a common set of new innovative tools and methods for the digitisation and visualisation of CH objects (3D and enhanced 2D). Our collective work will elevate the precision, accuracy, speed and consistency with which digitisation can take place. HERITALISE will also develop innovative tools supporting new ways of visualising heritage objects.

The European Collaborative Cloud for CH (ECCCH) provides CH institutions and professionals with enhanced technological and methodological capabilities to study CH objects, to share related data of their visible and non-visible properties and characteristics, and to develop new forms of collaboration. Contribution from provide innovative tools that redefine and extend the way we engage with CH. Is, we will add value to the way museums can engage with both their collections and audiences.

By connecting digital objects with Sustainable Development Goals [14] and tasks we will contribute to the role of museums in education, economy and society.

A digital ecosystem open to all stakeholders' professions and activities will enable interaction with each other contributing to a new digital commons through extending the ECCCH ecosystem with interoperable tools and using open standards we will ensure the tools and outputs of this project extend the new digital commons to include the creation of a best use tool box made up of the different case studies and plot projects and research from the project - which can be used by any CH organisation engaged in digitisation and visualisaiton.

Through improving the accuracy and reliability of digitisation, we will make it possible for digital twins to be better mirror real world heritage objects. This will improve authenticity in application that make use of digital twins, improving their effectiveness in heritage organisations and in the creative and cultural industries. At the same time improvements in ease of use, development of support infrastructures and development of communities of practice will increase the quantity of digital twins. This will in turn boost tourism, the creative industries, and quality education. As more digital representations of heritage are made available across Europe this will contribute to the strengthening of European Identity as well as contributing to the preservation, restoration and promotion of CH. Through improving the accuracy, consistency of digitised CH we will

make resources available to museums and to the cultural and creative industries that will enable engagement with CH resulting in the following impacts: 1) Provides the perspective to embrace the green transition by re interpreting the relationship between cultural and natural heritage, 2) Sustain social cohesion by engaging citizens, researchers, and experts within heritage communities. 3) Protects and transmits tangible cultural assets [15].

Contribute to the Green Deal (GD) goals and support an economy that works for people: To achieve the EU GD goals, the heritage sector has a huge role in monitoring, adaptation, mitigation, and communication, promoting climate action to address the climate emergency. Digitisation heritage artifacts creates a record of the current state of heritage which will be important in monitoring and tracking climate change.

8 Summary

The HERITALISE project brings together a consortium of SMEs, Heritage organisations and knowledge institutions with the aim of developing and sharing tools which take the state of the art for the digitisation and visualisation of heritage forward. Contributing to the European Collaborative Cloud for Cultural Heritage ECCCN HERITALISE will help CH practitioners realise the potential of emerging technologies for the promotion and preservation of heritage [16] (Fig. 3).

Fig. 3. HERITALISE project project number 101158081, funded from Call HORIZON-CL2-2023-HERITAGE-ECCCH-01 as an RIA action.

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