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Integrated survey for heritage digitization. The case study of Venaria Reale within HERITALISE project

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Abstract

The documentation and digitization of Cultural Heritage (CH) assets are fundamental for their conservation, monitoring, and long-term accessibility. HERITALISE is a research project aimed at developing a cloud-based, interoperable ecosystem aligned with the European Collaborative Cloud for Cultural Heritage (ECCCH), enabling the structured acquisition, management, and sharing of heterogeneous CH data.

The project, currently at its earliest stage, applies advanced geomatics techniques - including Terrestrial Laser Scanning (TLS), SLAM-based mobile mapping, and UAV photogrammetry - in a multiscale framework for the 3D digitization of the UNESCO site Reggia di Venaria Reale (Italy). Particular focus is given to the Great Gallery and the St. Uberto Church, where high-resolution metric data are integrated with environmental and microclimatic monitoring, material analyses, and historical documentation to support diagnostics, maintenance, and interpretation.

The approach extends to landscape heritage and movable assets, such as the Gardens of Fluid Sculptures and 18th-century wooden furniture, combining 3D documentation, tomography, and digital fabrication. HERITALISE proposes a scientific methodology for bridging traditional and digital CH practices, fostering sustainable and interdisciplinary preservation strategies.

CCS Concepts: • ***General and reference*** → Evaluation; • ***Applied computing*** → Architecture (buildings); • ***Theory of computation*** → Data integration; • ***Hardware***→ Technology-Mapping;

CH involves a wide array of institutions and disciplines, each generating diverse and complex data. Comprehensive documentation requires integration of these datasets and contextual understanding of the environments. Digital recording plays a crucial role not only in preservation but also in the communication of cultural values. Recent literature offers extensive reviews of geomatics applications in CH [BDG*17], including photogrammetry [Jeb22, MDS20], TLS [LAW23], and mobile mapping [DCG*21]. Standards and initiatives such as the Italian Piano Nazionale di Digitalizzazione [PND23], the Geospatial Survey Specifications [Geo24], and the VIGIE study on 3D digitization quality [Stu22] have laid the groundwork for best practices in CH documentation, further endorsed by the European Commission's DCHE Expert Group [Dig25].

HERITALISE contributes to this framework by developing an ECCCH-compliant digital ecosystem, with the key goal of improving 2D/3D acquisition technologies and their integration, enhancing documentation capabilities across multiple scales and CH types. The work presented here outlines the first phase of survey activities conducted at the Reggia di Venaria Reale, focusing on data acquisition strategies for both architectural and landscape elements.

Among the HERITALISE case studies, the Reggia di Venaria Reale (RVR25) represents a complex CH system combining monumental architecture and historical landscape (Figure 1). Located near Turin, it encompasses 80,000 m² of built heritage, 60 hectares of gardens, and the adjacent La Mandria Park. A major restoration project culminated in its reopening in 2007. Through a multiscale strategy, the project aims to digitize both the exterior and interior of key structures, primarily the Church of St. Hubert, affected by humidity and monitored microclimatically, and the 80-meter-long Great Gallery, notable for its luminous flooring and complex geometry.

The gardens include the Fluid Sculptures by Giuseppe Penone, whose evolving forms and organic materials require specific methods to document temporal transformations. Furniture from the 18th century also forms part of the investigation, supporting the broader goal of CH data integration across material types.

Figure 1: *Aerial view of the Reggia di Venaria UNESCO asset and detail of the Great Gallery.*

A field campaign conducted between January and March 2025 employed multiple survey techniques. TLS data have been collected using a Leica RTC360, resulting in 345 scans across four macro-areas. Processing and registration have been performed with Leica Cyclone REGISTER 360, with final local accuracies reported in Table 1.

		Number of scans	Registration error [m]
Outdoor environment	**Facades**	252	0.004
	Garden of Fluid Sculptures	60	0.007
Indoor environment	**St. Uberto**	24	0.003
	Galleria	9	0.005

Table 1: *TLS scans ICP registration error.*

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The Stonex X70GO (Table 2) has been used in environments such as the Church of St. Hubert, the Great Gallery, Hercules Fountain, and the main façades. A total of 23 mobile scans were processed with GOpost and integrated with TLS data using Cyclone REGISTER 360 (Figure 2).

LiDAR	Livox MID-360
Range	0.1 m – 70 m
Scanning frequency	200,000 pts/s
Relative accuracy	6 mm
FOV	360°H x 59°V
Cameras	12 MP
Cameras FOV	100° (Diagonal)

Table 2: *STONEX® X120^{GO} SLAM Laser Scanner and STONEX® X70^{GO} SLAM Laser Scanner main technical specification.*

Figure 5: *A portion of the registered MMS point cloud on Cyclone Register 360.*

UAV-based photogrammetry supported the survey of roofs and the dome of Sant'Uberto's Church using drones like DJI Matrice 350 with Zenmuse P1 sensor (Table 3) and sub-250g UAVs such as DJI Mini 3 Pro, DJI Spark and Autel EVO Nano II. The 3D model (Figure 3) has been georeferenced via GCPs measured with GNSS RTK and total stations anchored to existing survey networks.

Camera	Full-frame CMOS
Focal Length	35 mm
Sensor Size	35.9 x 24 mm
Pixel Size	4.4 µm

Table 3: *Zenmuse P1 sensor main specification*

Figure 3: *3D model and High-Resolution Orthomosaic of Reggia di Venaria generated via UAS and processed using the commercial software Agisoft Metashape Pro.*

Beyond geometric data, ongoing analysis includes tomography and 3D documentation of historical wooden furniture. Microclimatic data are also being correlated with surface condition mapping to support conservation diagnostics.

The large volume of data required robust validation. Point clouds have been checked via section views, overlapping comparisons, and RMSe analysis. Particular focus has been placed on transitions between indoor and outdoor areas, minimizing gaps and misalignments. A reference network using total stations and RTK receivers has been established around the Great Gallery, with additional campaigns planned for the Church and garden areas.

A structured data flow is being implemented to manage acquisition, processing, validation, and archiving. It ensures traceability, version control, and standardized documentation.

Future developments include semi-automated tools for alignment, error detection, and semantic enrichment to support scalability and reproducibility.

The integration of datasets from different technologies introduces redundancy and heterogeneity in density. Optimization through spatial filtering, uncertainty-based reduction, and semantic segmentation is necessary. Multiresolution models (LOD and LOIN) will enable adaptability to different platforms, ranging from HBIM and GIS to XR applications. Associating comprehensive metadata supports transparency, provenance tracking, and long-term sustainability, in alignment with international CH standards.

The preliminary activities at the Reggia di Venaria demonstrate the feasibility of combining diverse survey methods to produce accurate, multiscale, and semantically enriched digital models of CH assets. These models not only assist in documentation and conservation but also enable innovative forms of interpretation and access. HERITALISE thus lays the foundation for scalable, interoperable, and sustainable digital practices aligned with ECCCH principles.

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