HBIM of the Galleria Grande in the Reggia di Venaria Reale: A Scan-To-BIM Workflow towards Digital Twin Integration

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Abstract

This paper reports the current progress of the Venaria Reale pilot within the EU Horizon Europe project HERITALISE (2025 – 2028), using the Galleria Grande as a test case for a preventive-conservation Scan-to-BIM workflow towards digital twin integration. The workflow aims to deliver an HBIM base model that is geometrically reliable, semantically queryable, and traceable to its sources. Multi-sensor datasets, including terrestrial laser scanning (TLS), SLAM-based mobile mapping, and uncrewed aerial vehicle (UAV) photogrammetry, are georeferenced within a unified coordinate framework. Point-cloud processing uses a controlled UAV-TLS baseline as the primary modelling reference, with X70 SLAM data added only as local infill for verified gaps. Deliverables are organised through raw, working, and deliverable layers, supported by logged parameters, transformation matrices, and quality-control notes. Baseline quality is assessed through registration residuals, section-based inspection, and distance-based checks in critical indoor-outdoor junctions. Geometric modelling adopts a Revit-Rhino workflow guided by four decision factors: structural interpretability, semantic management needs, evidence strength, and modelling feasibility. Parametric, hybrid, and lightweight representations are combined according to object requirements and evidence limits. Dense sculptural and relief elements are reconstructed selectively through Rhino-based procedures and reintegrated into Revit as replaceable families, while complex vault surfaces and upper roof-truss layers are represented through differentiated LOG strategies. Semantic enrichment follows HERITALISE CDE/BEP governance. ObjectID anchors HBIM elements as information containers linked to an external SQL database. A first room/space crosswalk aligns 3,310 records across historical and current naming systems, supporting legacy linkage and interdisciplinary collaboration.

1. Introduction

1.1 Background

In recent years, heritage digitisation has increasingly moved beyond recording and visualisation toward long–term data governance for conservation and operation. In preventive conservation, a digital–twin vision depends less on a single final model and more on a 3D backbone that can be updated, queried, and checked against its sources. This is difficult for heritage assets because they commonly include irregular geometry, heterogeneous materials and construction systems, multi–phase transformations, and complex deterioration patterns. As a result, any move towards digital twin integration requires clear control of survey quality, modelling assumptions, and information traceability across time and teams.

Heritage Building Information Modelling (HBIM) extends BIM concepts to heritage contexts by organising geometry and information around explicit objects (spaces, components, and systems). HBIM is not a digital twin, and it cannot guarantee both speed and full geometric fidelity for highly complex surfaces and decorative details through a single modelling route. However, HBIM is a practical way to support later digital twin integration because it provides structured objects, supports links between survey evidence and model elements, and enables controlled updates under collaboration settings. Therefore, this paper reports the Venaria Reale pilot progress within HERITALISE (https://heritalise–eccch.eu/) through a reproducible scan–to–BIM workflow, with emphasis on a verifiable point–cloud baseline, explainable modelling decisions, and evidence–aware semantic linkage.

1.2 Project Context and Case Study

This study is carried out within the EU Horizon Europe project HERITALISE (2025-2028). In line with the goals of the European Collaborative Cloud for Cultural Heritage (ECCCH), HERITALISE promotes a cloud–based, interoperable and web–oriented ecosystem for heritage digitisation, where datasets can be shared, reused, and reviewed across teams. A key focus is the systematic use of metadata and paradata (e.g., measurement uncertainty, digitisation settings, and environmental conditions) to improve transparency and enable reuse (Matrone et al., 2025). The general structure and main operational components of the HERITALISE project are summarised in Figure 1.

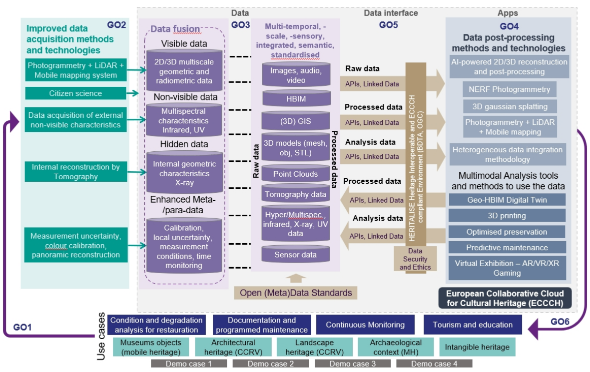

Figure 1. Main overview of the HERITALISE project

Within the HERITALISE case-study portfolio, the Reggia di Venaria Reale is treated as a multi–scale heritage system that includes monumental buildings, historic landscapes, and movable assets. The origins of Venaria Reale date back to the mid–seventeenth century, when Duke Carlo Emanuele II of Savoy commissioned a new residence for leisure and hunting. Rather than being conceived as a palace alone, the project was planned as an integrated architectural and environmental estate, combining the residence, gardens, village, and hunting domain into a single spatial system. Over the following decades, the complex was transformed and expanded by major architects including Amedeo di Castellamonte, Michelangelo Garove, Filippo Juvarra, and Benedetto Alfieri, eventually becoming one of the most important Baroque residences of the House of Savoy and part of the UNESCO–listed Royal Residences of the House of Savoy. Figure 2 situates the Reggia di Venaria Reale and the Galleria Grande within this broader architectural complex.

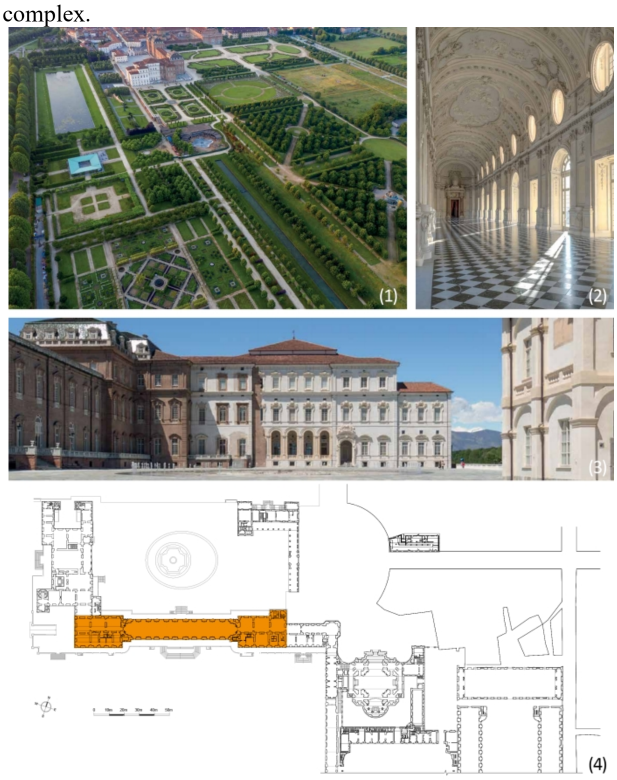

Figure 2. Reggia di Venaria Reale: exterior views (1, 3), location of the Galleria Grande within the complex (4), and interior view of the gallery (2).

Within the broader Venaria pilot, the present paper focuses on the Galleria Grande as the first operational scope, while future work will progressively extend to other buildings and outdoor areas of the complex. The gallery is one of the most remarkable eighteenth–century spaces of the Reggia and one of Juvarra’s best–known interventions within the southern wing originally conceived by Garove. It connected the apartments of the King and the Crown Prince and is exceptional in scale, measuring about 80 m in length, 12 m in width, and 15 m at the highest point of the vault. Its architectural significance is further reinforced by its rich decoration and by the strong light effects produced by 44 tall windows and 22 ceiling openings. These qualities make the Galleria Grande not only a highly representative heritage space within Venaria Reale, but also a particularly demanding test case for scan–to–BIM modelling, as it combines elongated geometry, ornamental density, and the need for structured semantic organisation.

1.3 State of the Art

Heritage digitisation is increasingly expected to support preventive conservation through long–term data governance rather than one–off 3D deliverables. A recurring issue is the lack of widely accepted procedures to define and communicate quality, completeness, and accuracy in a way that remains reusable across teams and platforms. Recent reviews of HBIM practice also highlight that information requirements and implementation choices are often not made explicit, which limits comparability and reuse across projects (Lovell et al., 2023). In this context, HERITALISE explicitly promotes traceable workflows and the systematic use of metadata/paradata to improve transparency and reuse (Matrone et al., 2025).

At the project level, multi–sensor and multi–scale surveys are now common, but they introduce practical risks in fusion and alignment due to heterogeneous density, error structures, and radiometric behaviour, especially at indoor–outdoor transitions.

The Venaria case within HERITALISE stresses structured data flows and quantitative checks (e.g., section–based inspection and distance inspection in key junction areas) to validate and document point–cloud outputs before they are used as modelling references (Martino et al., 2025). In parallel, HBIM research has proposed explicit ways to describe modelling generation and accuracy, such as Grade of Generation (GOG), Grade of Accuracy (GOA), and Level of Geometry (LOG), and to link point–cloud deviations to tolerances, supporting controlled simplification and reuse in CDE settings (Banfi, 2019; Brumana et al., 2022).

In scan–to–BIM practice, point clouds are still largely converted into objects through manual or semi–automatic processes, because heritage geometry is often non–standard and information requirements are heterogeneous (Lovell et al., 2023).

Recent work towards digital twin integration highlights that open interoperability (e.g., Industry Foundation Classes, IFC) and object–level semantic archiving are necessary to share diagnostic content and to support collaboration beyond BIM–native environments (Spanò et al., 2023). More broadly, platform and framework studies emphasise that HBIM alone is insufficient for long–term updates; stable object identifiers, evidence–aware metadata, and links to external databases/sensor systems are needed to support version tracking and cross–domain use (Fattore et al., 2025; Jouan and Hallot, 2020; Niccolucci and Felicetti, 2024).

Documentation–oriented HBIM data modelling studies further support the use of stable identifiers and external databases to keep heterogeneous records consistent across time and across systems (Li et al., 2025).

Overall, the literature provides building blocks for (i) quantitative validation of multi–source survey outputs, (ii) controlled modelling strategies and explicit accuracy statements, and (iii) semantic and platform–level linkage (Banfi, 2019; Brumana et al., 2022; Fattore et al., 2025; Li et al., 2025). DT–oriented studies that focus on monitoring and prediction further underline the need for reliable data linkage and traceable inputs for preventive conservation (Shang et al., 2025). However, reporting a single reproducible chain that connects point–cloud processing, explainable modelling decisions, and object–level governance (including legacy linkage) remains relatively limited, especially for complex interiors under ongoing survey updates, which motivates the workflow and pilot outputs presented in this paper.

1.4 Research Objectives and Paper Structure

This paper reports the current progress of the Venaria Reale pilot by addressing a practical question: how a scan–to–BIM workflow can deliver a geometric and semantic base that is maintainable, update–ready, and clearly linked to its sources, while supporting later digital twin integration. The paper does not aim to propose a new conceptual framework. Instead, it consolidates multi–source data organisation, baseline quality checking, modelling decisions, and semantic linkage into a reproducible production chain.

The study pursues three main objectives. First, it aims to produce a versioned geometric baseline under a unified coordinate framework, with explicit roles for reference and patch datasets and documented quality checks. Second, it applies an explainable modelling logic that links structural interpretability, semantic management needs, strength of evidence, and modelling feasibility/cost to operational choices within a Revit–Rhino hybrid workflow. Third, it implements object-level semantic linkage under CDE governance, aligning naming and identification rules within HERITALISE and using ObjectID to connect HBIM elements, understood as information containers, with external databases and legacy information from the Guarini restoration database (Ceresa et al., 2002), a project-based archive created during the large-scale restoration campaign (1998-2007) of the Reggia di Venaria Reale and used here as a key historical source for the current data-linkage strategy.

The paper is structured as follows. Section 2 presents materials and methods. Section 3 reports the baseline and HBIM outputs and discusses completeness, consistency, and evidence documentation. Section 4 concludes with implications for ongoing updates and later digital twin integration.

2. Materials and Methods

2.1 *Workflow overview*

This paper adopts a scan–to–BIM workflow for the Galleria Grande that produces a geometric and semantic base suitable for ongoing updates and later digital twin integration. Workflow execution follows the HERITALISE BEP/CDE workflow, in which a shared BIM Execution Plan defines common rules for file, material, and software naming, model–level applications, key parameter structures, version control, and deliverable packaging.

Survey and modelling data are managed in three layers, raw, working, and deliverable, with a log bundle (key parameters, transformation matrices, and QC notes) to support review and rollback.

As summarised in Figure 3, the workflow is organised into four linked steps. (1) Data governance and multi–source organisation: datasets from different sensors and campaigns are stored in the CDE with explicit roles (reference vs. patch) and controlled handover packages. (2) Point–cloud preparation and quality control: point clouds are aligned in a unified coordinate framework and merged in a controlled way to generate a modelling baseline, while documenting gaps and evidence limits. (3) Geometric modelling: a Revit–Rhino hybrid pipeline is used, and modelling strategies are selected through a decision logic that balances structural interpretability, semantic management needs, strength of evidence, and modelling feasibility/cost. (4) Semantic enrichment and updates: objects are consistently identified through ObjectID and shared parameters, and linked to external databases and legacy information (Guarini) under HERITALISE naming/coding rules.

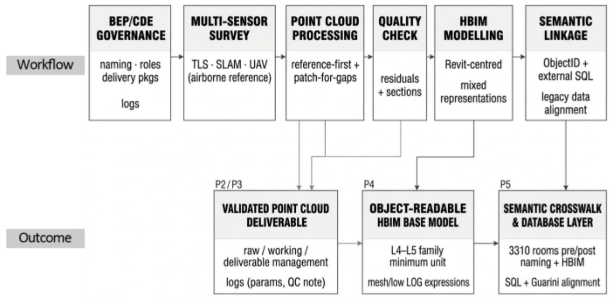

Figure 3. Proposed Scan–to–BIM Workflow overview

2.2 Multi–sensor survey and acquisition

To ensure continuous geometric referencing from site scale to component scale, the Venaria pilot combines surveys conducted between January and March 2025 with relevant existing datasets in a single control framework. TLS, SLAM–based mobile mapping, aerial and UAV photogrammetry are used with complementary roles to balance accuracy, coverage, and practical constraints.

TLS was acquired with a Leica RTC360 (345 scan stations) and registered in Cyclone REGISTER 360; the Galleria Grande subset includes 9 stations with a mean cloud–to–cloud registration error of 0.005 m.

SLAM mobile mapping was carried out with Stonex X70GO and X120GO systems, processed in GOpost, and integrated with the TLS dataset. UAV photogrammetry targeted areas with limited TLS coverage (e.g., roofs and domes), using DJI Matrice 350 with Zenmuse P1; georeferencing was obtained via Global Navigation Satellite System real–time kinematic (GNSS RTK) measurements and ground control points (GCPs) measured with a total station and tied to the existing control network.

An airborne LiDAR/imagery dataset is used only as a site-scale background reference and for completeness checks, not as the close-range geometric baseline.

For baseline construction, the georeferenced UAV survey is used as the primary spatial reference; TLS provides the main close-range geometric core for interior and adjacent exterior areas; SLAM is used mainly as local tile-based infill for verified missing zones to avoid unstable fusion and visible artefacts caused by large overlaps and heterogeneous density. The resulting multi-source point-cloud outputs and baseline scope are shown in Figure 4.

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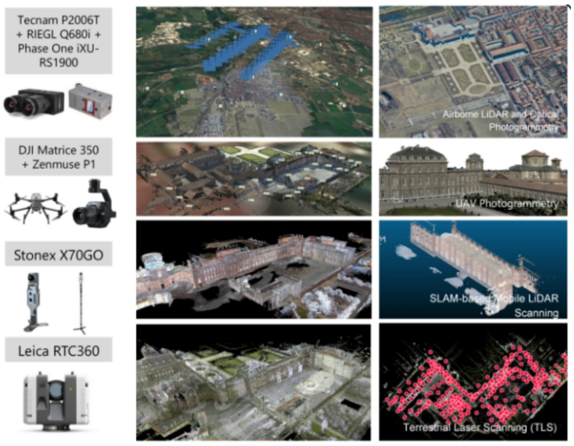

Figure 4. Point–cloud output (overview of multi–source datasets and baseline scope)

2.3 Point–cloud preparation and quality control

Point–cloud preparation aims to deliver a modelling baseline with a unified coordinate framework, controlled fusion, and reportable acceptance criteria. Given differences in density, error structure, and radiometric behavior across sensors, the georeferenced UAV survey, anchored by GCPs–based control, is used as the primary spatial reference, while additional datasets are integrated only according to a reference–first and patch–only–for–gaps rule to reduce redundancy and maintain a consistent modelling reference.

All key milestones generate versioned artefacts together with a log bundle (key parameters, transformation matrices, and QC notes), enabling review and rollback under ongoing survey updates.

Processing combines batch execution and targeted interactive checks in CloudCompare. Batch processing is used for consistent operations on large datasets (merging, subsampling, and statistical outlier removal, SOR), while interactive steps support region–of–interest (ROI) segmentation, overlap diagnostics, and local adjustment in critical junction areas. The full protocol (steps, key settings, outputs, and quality–control, QC, records) is summarised in Table 1, and the reference–first baseline logic is illustrated in Figure 5.

Quality control is reported at two levels. At the global level, alignment consistency is documented through registration reports, with residuals controlled within 0.01–0.05 m on the GCPs and following the cloud–to–cloud approach depending on datasets and junction areas. At the local level, section–based inspection and distance checks focus on sensitive elements and junction areas, especially indoor–outdoor connections, and gap typologies are recorded (occlusions, inaccessible zones, high reflectance, etc.) to keep evidence limits explicit.

Step	Action	Key parameters	Output	QC / records
P0	Ingest & versioning	CDE naming; dataset ID	*_raw	Metadata; version note
P1	Merge TLS core	CC CLI merge	GG_TLS_001–007_merged.e57	Input list; point count
P2	Normalise density	Spatial subsampling: 3.5 mm	*_SS0035.e57	Point count; density/spacing summary
P3	Remove noise	SOR: (8, 2.0)	*_SOR8_2.0.e57	Removed ratio; edge check
P4	Controlled fusion	UAV/TLS–first, patch–only–for–gaps	Validated baseline (.e57/.las)	Residuals 0.01–0.05 m; sections
P5	Publish package	export + log bundle	Baseline package + logs	Transforms; gap typology; evidence limits

Table 1. Point–cloud baseline construction protocol (processing settings, versioning and QC criteria)

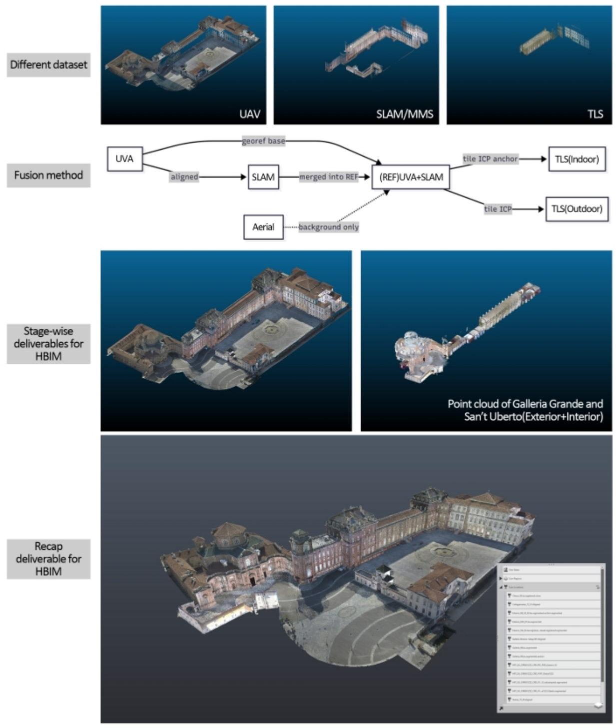

Figure 5. Reference–first baseline construction with controlled patch integration (UAV as georeferenced outdoor frame; TLS as near–range geometric core; SLAM as tile–based patch)

2.4 Geometric modelling

The goal of geometric modelling is not full high–fidelity reconstruction of all heritage details, but a maintainable HBIM base model whose choices can be explained and checked. As shown in Figure 6, modelling is guided by a four-dimensional decision logic: structural interpretability, semantic management needs, strength of evidence, and modelling feasibility/cost. Based on these factors, elements are assigned to one of three representation strategies: parametric (system–level equivalent where needed), hybrid (Revit–Rhino for irregular but meaningful objects), or lightweight (identifiable placeholders when evidence is weak).

Where the real construction unit (e.g., individual bricks) is impractical or adds limited value, the model adopts an equivalent system/assembly representation and records key assumptions through parameters.

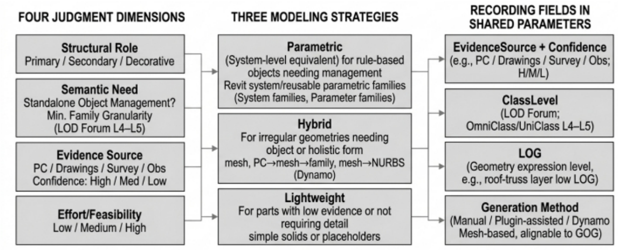

Figure 6. Four–dimensional decision logic for HBIM modelling strategy

2.4.1 Revit-based object structure and system-level representation

Revit is used as the host platform to build the object structure and parameter framework. Modelling starts from the same spatial setup as the point-cloud baseline, including levels, grids/reference planes, and main spatial boundaries. The modelling process starts with regularisable components: walls, floors/vault systems, columns/beams, openings, and stairs are created as editable objects so that they remain computable for quantities, zones, and later updates. For structurally important elements that are not suitable for unit-by-unit modelling, such as masonry walls, we use a system-level equivalent representation, including typified types, layer-based description, and key dimensions, while recording construction type, material composition, and assumption limits as parameters. The resulting Revit-based HBIM geometric model is shown in Figure 7.

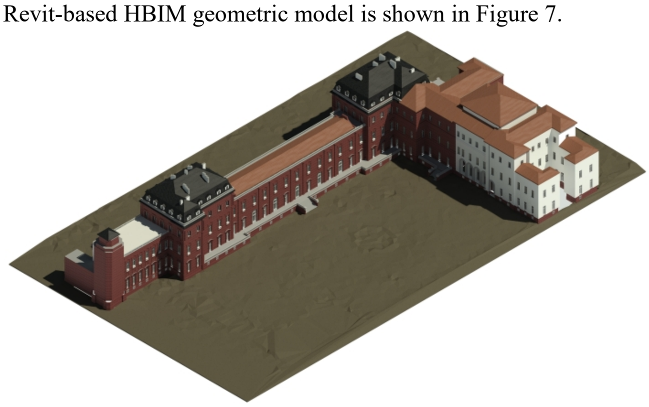

Figure 7. Geometric modelling in HBIM

2.4.2 Controlled freeform enrichment in Rhino and hybrid integration

Rhino is used when geometry is highly irregular, such as elements with strong curvature continuity or dense ornamentation, and when the element needs to be managed as a distinct object. In the Galleria Grande, this applies mainly to dense sculptural and relief elements, where a mesh-to-NURBS workflow and Grasshopper support controlled reconstruction before reintegration into Revit.

Freeform geometry does not replace the main structural model; it is modelled as an explicit surface, decoration, or auxiliary layer linked to a host element. When importing the geometry back into Revit, object hierarchy and semantic boundaries are kept clear, for example through nested components or controlled host association, so that the model remains maintainable. When elements belong to the same construction system but must be split for feasibility, geometric splitting is allowed, while system membership and connection assumptions are recorded through relationship parameters to avoid semantic breaks. Representative examples of the hybrid modelling outputs are shown in Figure 8.

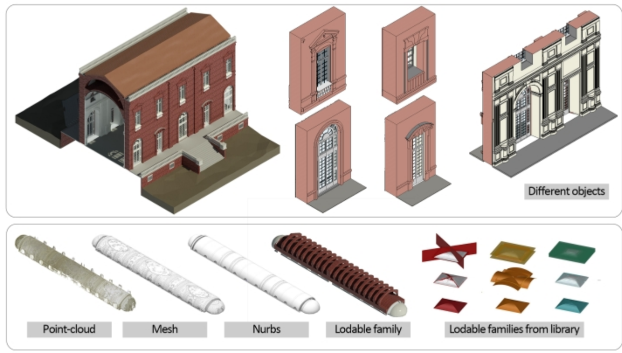

Figure 8. Hybrid modelling of typical elements

2.4.3 Model–to–cloud checking and explicit abstraction boundaries

Model–to–point–cloud checking is used to support iteration and to manage abstraction limits. Checks are carried out at two levels: global checks to scan overall deviations of main structural elements, and local checks for critical nodes (e.g., springing zones, opening edges, surface transitions) where simplification or missing evidence can cause systematic errors. For areas with weak evidence or limited access, the model avoids structural invention and records boundary conditions through parameters such as abstraction level, assumption notes, and evidence source, including point clouds, drawings, archival records, and on-site observation. An example of local model-to-cloud deviation checking is shown in Figure 9.

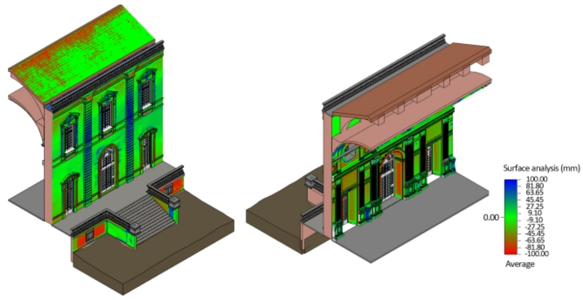

Figure 9. Local deviation analysis between the point cloud and the HBIM model in a selected area of the Galleria Grande. (Deviation values are shown in mm, and higher deviations are mainly concentrated in areas affected by incomplete scan coverage, edge conditions, and simplified model transitions.)

2.5 Semantic enrichment

To support collaboration and interoperability within HERITALISE, this study follows the shared BEP/CDE rules at delivery level, including naming and coding conventions, material naming, LOD/LOI definitions, and classification codes. In the Venaria pilot, these common rules provide the baseline environment for consistent data exchange, deliverable handover, and semantic alignment across teams and workflows. At the same time, the project needs to connect local historical information assets, especially the Guarini database, and to

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support evidence recording in a preventive–conservation context. We therefore adopt a compatible local extension layer that does not redefine the global core semantics, but adds only the incremental fields required for project execution and for mapping legacy content into the shared environment.

Within this framework, HBIM semantic information is organised through a four–level structure comprising building, zone, system, and component. HBIM elements act as information containers for those attributes that are directly related to identifiable architectural objects and need to remain queryable within the model environment. Key properties are attached through shared parameters, including classification, material–related description, modelling strategy, and evidence–related tags where needed.

Linkage is implemented through two complementary mechanisms. At object level, ObjectID is used as the primary persistent anchor for cross–platform linkage, while Revit ElementID is retained as an auxiliary platform–specific key for synchronisation and element tracing within the authoring environment. In parallel, the external SQL database acts as the first storage layer for heterogeneous information, including both records that can be linked to HBIM elements and records that are difficult or inefficient to embed directly in model parameters. At space level, legacy alignment is supported through a room/space crosswalk, which provides a stable connection between the current HBIM environment and legacy naming systems where historical or heterogeneous records cannot yet be assigned reliably to individual building components.

In addition to general descriptive properties, we attach a minimal set of evidence–and–decision metadata to support traceability and review, including evidence type and references, confidence or assumption limits, and strategy tags aligned with the modelling logic (e.g., parametric, hybrid, lightweight representation). This semantic structure supports more consistent updates under collaboration and establishes a stable basis for future extension towards database integration and digital twin development. The semantic organisation and linkage framework adopted for the Venaria pilot are summarised in Figure 10.

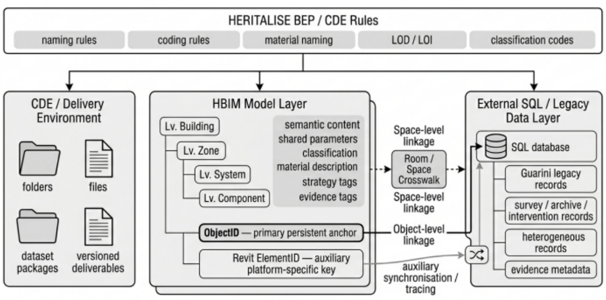

Figure 10. Semantic organisation and linkage framework adopted for the Venaria pilot following the HERITALISE proposal.

3. Results and Discussion

3.1 Point–cloud baseline outputs

In the Venaria pilot, a point–cloud baseline for HBIM modelling was delivered and managed through a three–layer structure: raw–working–deliverable. The raw layer preserves unmodified datasets and metadata by sensor and campaign. The working layer hosts rollback–ready operations (cropping, alignment, fusion, and checks). The deliverable layer releases only validated baseline point clouds together with a log bundle (key parameters, transformation matrices, and QC notes). This setup improves handover and review across teams, and it allows the project to rely on a stable modelling reference while survey acquisition continues. In the validated baseline, the georeferenced UAV survey provides the primary spatial reference, TLS supplies the main close–range geometric core, and SLAM data are retained only as local infill in verified missing zones. In practice, it allows HBIM modelling to proceed while limiting repeated rework during ongoing survey updates.

The main value of the raw–working–deliverable structure is that it supports rollback and iterative updates without overwriting validated releases. However, in a long–running survey project, new campaigns (new instruments, new operators, new time windows) still trigger substantial rework in the working layer, especially in junction areas and indoor–outdoor connections.

A second challenge is update decision–making: when new data arrives, it is often unclear whether it should replace older data or be merged with it, because a robust and repeatable comparison protocol is still missing. At minimum, batches should be compared in a traceable way across coverage and gap types, registration residuals and cloud–to–cloud consistency, density and noise patterns, geometric continuity in critical junction areas, and radiometric consistency (RGB/lighting). Without such quantifiable criteria, the baseline can grow in complexity over time, which increases risk for later HBIM updates and for appearance–based interpretation tasks (e.g., material mapping or visual condition checks). At this stage, baseline validation still relies on registration residuals, cloud–to–cloud checks, and local section–based or distance–based inspection in critical junction areas, but a more systematic protocol for replacement–versus–merge decisions remains to be formalised.

3.2 HBIM outputs and modelling choices

At this stage, an HBIM framework has been produced to support collaborative refinement. In line with the three representation strategies defined in Section 2, the current outputs combine parametric system–level modelling, hybrid Revit–Rhino reconstruction for irregular but meaningful elements, and lightweight representations where evidence remains limited. The exterior model covers the area from the Hall of Diana to the Galleria Grande and extends to the connection between Sant'Uberto and the Galleria Grande. To speed up coverage, similar elements are mainly replicated by categories and system type. The façade includes recognisable objects such as walls, opening surrounds, moldings, decorative columns, under–eaves supporting components, steps, and terraces.

Inside, the Galleria Grande is modelled with a "decomposable components" principle, including bay–by–bay decorative objects and the main molding systems up to the 1st–2nd floor level; for most major elements, geometric accuracy against the point cloud is about 1–5 cm. Vaults and upper structures follow a split strategy: the second–level vault is represented through a point–cloud–to–mesh–to–family workflow to preserve detailed shape, while the roof–truss level above is modelled from restoration drawings with a low LOG expression. For dense sculptural and relief elements in the Galleria Grande, Rhino is applied selectively through mesh–to–NURBS conversion and

Grasshopper, and the outputs are reintegrated into Revit as replaceable families.

The key goal of this phase is to obtain a model base that is object–readable, replaceable, and update–friendly. Modelling choices are driven by a four–factor logic (structural interpretability, semantic management needs, strength of evidence, and modelling feasibility/cost) and documented through shared parameters, including evidence source and assumption notes, classification, modelling strategy, and evidence–related tags. The main benefit is speed and maintainability: many improvements can be made through family updates and replacements rather than large–scale remodelling. Clear limits remain. Category–based replication may introduce local over–homogenisation and therefore requires later checks and targeted replacements in critical areas.

Mesh–based vault families preserve geometry but provide limited semantic granularity and interoperability, and are better treated as a shape–reference layer. More broadly, future uses remain an open question: VR/AR, preventive–conservation analysis, and 3D printing require different levels of geometry and semantics, so the current model must evolve in a task–driven way. The workflow is still mainly manual or semi–automatic (plugins and Dynamo), and direct point–cloud–to–BIM automation is not yet reliably applied.

3.3 Semantic enrichment outputs: ObjectID, evidence metadata/paradata, and legacy linkage

BEP/CDE rules for naming, coding, classification, and parameter structures are applied in the Venaria pilot to improve consistency in task exchange and deliverable handover. HBIM information is organised through a building–zone–system–component hierarchy, while room/space–based alignment is used separately as a space–level linkage mechanism for legacy integration. Within the current HBIM environment, the main embedded semantic fields include classification, material–related description, modelling strategy, and evidence–related tags.

HBIM parameters alone cannot cover all heterogeneous content; therefore, the external SQL database acts as the first storage layer for both element–linkable records and records that are difficult to embed directly in model parameters. This arrangement keeps model–embedded attributes and externally stored heterogeneous records distinct, while preserving stable linkage across platforms and updates. At object level, shared parameters and ObjectID provide stable cross–platform references between HBIM elements and external records, while Revit ElementID is retained as an auxiliary platform–specific key for synchronisation and element tracing. Basic evidence notes can be kept consistent across updates.

For legacy integration, the Guarini restoration database is used as a key historical source; as a first operational step, a stable three–way room/space crosswalk has been implemented for 3,310 rooms/spaces, connecting pre–2016 naming, post–2016 naming, and the HBIM room setup.

The crosswalk provides a stable space–level linkage for connecting historical records with the current HBIM environment during ongoing changes, but current linkage remains mainly at space level and does not yet solve component–level alignment or the systematic attachment of weakly related information.

3.4 Discussion: implications for collaboration, reproducibility, and use–driven evaluation

As shown in Sections 3.1 and 3.3, the Venaria pilot frames Scan–to–BIM not as a one–off modelling task, but as a repeatable production chain that can operate under continuous survey updates. Within HERITALISE, this matters because the work is inherently interdisciplinary: geomatics teams, modellers, conservators, and data managers need shared rules to exchange files, review changes, and reuse outputs. BEP/CDE governance (naming, coding, classification, parameter structures, deliverable packaging, and logs) together with object-level and space-level linkage mechanisms (e.g., ObjectID and the room/space crosswalk) reduce ambiguity in handover and make results easier to reproduce across roles and organisations. In this setting, reproducibility does not mean that any team will rebuild the same model from scratch, but that key steps and decisions can be traced, checked, and updated without breaking the shared information structure. This is supported in practice by versioned baseline artefacts, logged processing parameters, transformation matrices, and local model-to-point-cloud checks in critical junction areas.

A key implication is that HBIM quality should be judged against target uses rather than against a single universal "best" model level. Requirements for VR/AR applications, preventive–conservation analysis, and 3D printing differ in geometry detail, semantic granularity, and editability. The pilot therefore prioritises an object–readable base model with explicit records of evidence sources, modelling choices, and limits, while combining parametric, hybrid, and lightweight representations so that refinement can be task–driven and performed by replacement rather than full remodelling. The main weaknesses remain typical for heritage scan–to–BIM: much of the workflow is manual or semi–automatic, repeated work still occurs when new datasets arrive, and a robust quantitative protocol to compare "new vs. old" datasets and support replacement-versus-merge decisions is still missing.

These points define clear directions for future work in the project: strengthen use–driven evaluation criteria, improve update rules, and reduce dependence on manual steps while keeping traceability.

4. Conclusions and Future Work

This paper reports the current progress of the Venaria Reale pilot within HERITALISE, using the Galleria Grande as a test case for a scan–to–BIM workflow that can support interdisciplinary collaboration and later digital twin integration. The pilot consolidates three practical outcomes. First, multi–source point clouds are managed through a raw–working–deliverable structure and a reference–first baseline strategy, enabling rollback and stable handover under ongoing survey updates. In this baseline, the georeferenced UAV survey provides the primary spatial reference, TLS supplies the main close-range geometric core, and SLAM is retained only as local infill in verified missing zones. Second, an object–readable HBIM base model is produced through a Revit–centred workflow and controlled mixed representations, with modelling choices documented by evidence sources, assumption notes, classification, modelling strategy, and evidence-related tags. The current outputs combine parametric, hybrid, and lightweight representations according to structural interpretability, semantic management needs, strength of evidence, and modelling feasibility/cost. Third, semantic linkage extends beyond the model: an external SQL layer acts as the first storage layer for heterogeneous information, and a stable room/space crosswalk (3,310 rooms/spaces) aligns pre-2016 naming, post-2016 naming, and the HBIM room setup to keep legacy records usable.

The work also clarifies current limits. Much of the workflow remains manual or semi–automatic, and new survey campaigns still trigger rework. A robust quantitative protocol to compare "new vs. old" datasets to support replacement-versus-merge decisions is still missing.

Future work will therefore focus on three directions: (i) establishing use–driven evaluation criteria and acceptance rules for geometry and semantics under continuous updates; (ii) strengthening HBIM automation (semantic recognition and reliable automated geometry generation) to reduce dependence on manual steps; and (iii) extending database integration and linkage methods for future information management needs, while applying the same governance and semantic structure to additional Venaria assets and use cases, including VR/AR applications, preventive-conservation analysis, and 3D printing.

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