POLITECNICO DI TORINO
Repository ISTITUZIONALE

Bio-sourced Flame Retardants for textiles: where we are and where we are going

Original
Bio-sourced Flame Retardants for textiles: where we are and where we are going / Malucelli, G.. - In: MOLECULES. - ISSN 1420-3049. - ELETTRONICO. - 29:13(2024). [10.3390/molecules29133067]

Availability:
This version is available at: 11583/2989942 since: 2024-06-27T13:48:19Z

Publisher:
MDPI

Published
DOI:10.3390/molecules29133067

Terms of use:

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

15 November 2026

heritage

MDPI

Article

Translating Preventive and Planned Conservation Needs into Digital Implementation: A Requirement-Driven Framework for Architectural Heritage

Xiang Li *, Filiberto Chiabrando and Monica Naretto

Department of Architecture and Design (DAD), Polytechnic University of Turin, Viale Pier Andrea Mattioli 39, 10125 Torino, Italy; filiberto.chiabrando@polito.it (F.C.); monica.naretto@polito.it (M.N.)
* Correspondence: xiang_li@polito.it

Abstract

Preventive and Planned Conservation (PPC) of architectural heritage requires coordination between multidisciplinary needs and digital implementation. This study develops a requirement-driven framework to reduce misinterpretation and unsupported individual judgements during requirement translation, improve collaboration, and support standardised, traceable and comparable information across stages. PPC knowledge and organisational, asset, project and exchange information requirements inform a role-appropriate question library and a rule-supported translation mechanism. Clients provide project purposes and conditions; specialists supplement professional facts. The system assesses applicability and translates applicable PPC Needs into Digital Requirements. Configuration rules generate Recommendation, and professional review establishes Target. Configuration templates and implementation lists guide digital personnel. Implementation evidence supports Actual assessment, and comparison against acceptance criteria identifies Gap. A software prototype supported application to the Galleria Grande at the Reggia di Venaria Reale, Italy, within HERITALISE, an EU-funded project on cultural heritage digitisation. The knowledge structure contains 34 PPC Needs and 320 Canonical Facts. Case records cover 58 type groups and 1532 Historic Building Information Modelling (HBIM) objects. Shared outputs included building information modelling execution-plan configuration content, naming rules, 12 common data environment directory categories and 13 configuration self-check entries. Linked requirement, configuration, implementation and assessment records supported decision traceability and quantitative comparison within the assessed scope, informing progress checks and subsequent task planning. Project practice also indicated reductions in document interpretation, coordination and duplicated work; their magnitude requires quantification. Complete workflow coverage and cross-case applicability require further validation.

Keywords: preventive and planned conservation; architectural heritage; digital requirements; requirement-driven framework; HBIM; information management; digital twin

Check for updates

Academic Editor: Marco Gaiani

Received: 16 October 2026
Revised: 5 November 2026
Accepted: 7 November 2026
Published: 11 November 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

1.1. Continuous Information Needs in Preventive and Planned Conservation

Preventive and Planned Conservation (PPC) involves periodic inspections, condition assessment, risk identification, maintenance and post-intervention reviews [1–4]. These activities continue over time on the same heritage assets. In Italy, this continuing process is reflected in the planned conservation provisions of Legislative Decree No. 42/2004

(Article 29) and the conservation planning and documentation principles addressed by UNI EN 16853:2026 [5,6]. Current condition information needs to remain linked to previous inspection, maintenance, intervention and monitoring records to support change identification and subsequent work planning.

PPC requires information on geometry, materials, construction, conservation condition, deterioration, environmental risks and conservation activities [3,4,7]. These records differ in spatial scope, timescale, source and update frequency, and involve different responsible participants. Stable object identifiers, explicit information sources and traceable temporal relationships provide a basis for their continuing organisation and use.

The scope of digitisation needs to follow conservation and management activities and their information uses. Model complexity, geometric accuracy and information content should be selected and assessed according to intended use. Previous research has examined the relationship between model detail and purpose [8]. In PPC projects, identifying the activities and information requirements provides a basis for defining digital representation, information organisation and quality criteria.

1.2. Multidisciplinary Collaboration and Digital Requirement Translation

Architectural heritage conservation and management involve owners, managers, conservation specialists, researchers and digital personnel. Participants have different professional knowledge, management objectives and responsibilities, and may require different information about the same heritage asset. Previous research has examined multicriteria judgement, stakeholder collaboration and value elicitation in heritage decision-making [9–12]. Projects need to coordinate these perspectives and establish who provides information, which content requires professional interpretation and how judgements inform implementation requirements.

Historic Building Information Modelling (HBIM) provides a technical basis for organising multidisciplinary heritage information. Early research linked survey data, historic building components and parametric models [13]. Later studies extended the organisation of historical documentation, diagnostic information, external databases and conservation management content [14,15]. Reviews have examined developments and limitations in information management, interoperability and long-term knowledge organisation [16–19]. Unclear model uses and insufficient understanding of organisational information requirements can affect subsequent management applications [16]. Requirement interpretation, information selection and the definition of implementation conditions consequently remain specific tasks within digitisation.

Information management standards provide a basis for requirement specification and delivery checking. ISO 19650 defines information management principles across project and asset life cycles [20]. ISO 7817-1 addresses the scope and content of information according to intended use through the Level of Information Need (LoIN) [21]. Information Delivery Specification (IDS) supports machine-readable specification and checking of selected information requirements [22]. Applying these principles requires projects to establish requirement sources, applicable objects, responsibilities and acceptance criteria.

Digital Twin research further addresses continuing updates, risk analysis and conservation decision support. Related approaches connect heritage values, risks and potential interventions with HBIM and preventive conservation [7,23]. Reviews also examine data management, decision support and heterogeneous information integration [24,25]. Continuing use of these digital environments requires explicit connections between needs, information organisation, technical implementation and subsequent updates.

In PPC projects, these connections involve three related questions. How can needs be acquired according to participants' knowledge and responsibilities? How can they inform

professionally confirmed configurations shared by the implementation team? How can delivered results be checked against explicit conditions? Asking clients to make technical selections may increase comprehension demands and allow predefined options to influence their responses. Dispersed documentation and unrecorded judgements may also lead implementation personnel to interpret the same requirement differently. A project-level process is therefore needed to connect requirement acquisition, professional configuration, digital implementation and assessment. It should retain information sources and decision grounds across stages and provide consistent conditions for comparing results.

1.3. Research Aim, Research Questions, and Scope

This study develops a requirement-driven framework for PPC of architectural heritage. It aims to reduce misinterpretation and unsupported individual judgements during requirement translation, improve multidisciplinary coordination and strengthen consistency in information organisation and transfer. Role-appropriate information acquisition, rule-supported translation and professional review connect conservation and management needs to configurations jointly adopted by the implementation team. Requirement grounds, configuration decisions and implementation results are recorded separately, supporting cross-stage traceability, comparison and quantitative progress management.

Three research questions guide the study:

- RQ1: How can multidisciplinary PPC Needs be acquired and translated into explicit, traceable Digital Requirements according to participants' knowledge and responsibilities?
- RQ2: How can rule support and professional review translate Digital Requirements into shared implementation configurations while retaining decision grounds?
- RQ3: How can target configurations and implementation results be compared against explicit acceptance criteria to identify discrepancies and support quantitative progress management?

The framework is applied through a software prototype, with the Galleria Grande at the Reggia di Venaria Reale, Venaria Reale (TO), Italy, as the main case. The case examines operational feasibility within an ongoing heritage digitisation project. The study considers connections between requirement acquisition, shared configuration, HBIM implementation and assessment. Complete workflow validation, systematic expert evaluation and cross-case applicability require further examination.

2. Case Context and Research Basis

2.1. HERITALISE and the Venaria Context

This study is conducted within HERITALISE (Heritage Buildings and Objects Digitisation & Visualisation within the Cloud), a Horizon Europe project (https://heritalise-eccch.eu/). HERITALISE addresses the digitisation, organisation, integration, visualisation, and multidisciplinary use of heterogeneous cultural heritage data within the wider European Collaborative Cloud for Cultural Heritage (ECCCH) environment [26,27].

The Reggia di Venaria Reale is one of the Italian demonstration sites of HERITALISE (https://lavenaria.it/en/). It forms part of the UNESCO World Heritage property Residences of the Royal House of Savoy (https://whc.unesco.org/en/list/823/, accessed on 10 October 2026) [28]. The site includes the palace complex, historic gardens, and related spaces and continues to support public access, cultural activities, conservation, and heritage management. At Venaria, building-scale HERITALISE activities mainly concern the Galleria Grande and the Church of Sant'Uberto, alongside site-level digital recording and information management [26,27]. Figure 1 shows the location of the Galleria Grande within the Reggia di Venaria Reale complex.



Figure 1. Reggia di Venaria Reale and the Galleria Grande demonstration area.

Survey, modelling, historical data organisation, and information management have progressed in parallel within the Venaria pilot. These workflows involve different data sources, update cycles, completion levels, and professional participants. This evolving environment provides the practical context for the case study.

2.2. Galleria Grande as the Demonstration Case

The Galleria Grande was selected as the main demonstration area. Designed by Filippo Juvarra and completed in the eighteenth century, the gallery is approximately 80 m long and 12 m wide. Its central vault reaches a height of about 15 m [29]. The space includes walls, vaults, floors, openings, pilasters, and several types of decorative elements.

The Galleria Grande combines repeated regular components with geometrically complex heritage elements. Openings, walls, and some decorative components support type-based reuse, whereas vaults, complex surfaces, and sculptural elements require different approaches to digital representation and modelling. This combination makes the gallery suitable for examining both the organisation of repeated components and different representation strategies for complex heritage elements.

Existing information related to the Galleria Grande includes digital and paper drawings, historical and site photographs, textual archives, and the Guarini archival database. The Guarini database is linked to documentation generated during the large-scale restoration of the Reggia di Venaria Reale and remains an important legacy source for current heritage information integration [30,31].

Digital surveys have been carried out in the Galleria Grande and related areas using terrestrial laser scanning, Simultaneous Localisation and Mapping (SLAM)-based mobile mapping, and Unmanned Aerial Vehicle (UAV) photogrammetry [27,30]. These datasets have been progressively organised and integrated as the project has developed.

HBIM has progressed in parallel with survey work and document organisation. The model remains under development, and geometric modelling and semantic information are not equally complete across all components. Some objects already have relatively complete digital representations, whereas others are still being modelled, supplemented, or revised.

The data used in this study therefore reflect the evolving state of the HERITALISE Venaria pilot during the research period.

3. Methodology

3.1. Design of the PPC Requirement-Driven Framework

This study proposes a PPC requirement-driven framework that translates conservation and management needs into actionable and assessable digital implementation requirements. Structured acquisition, need assessment, rule-supported configuration and professional confirmation connect participants' needs with digital implementation. Confirmed configurations provide a shared implementation basis, and outputs are checked against corresponding acceptance criteria. Figure 2 presents the overall proposed workflow.

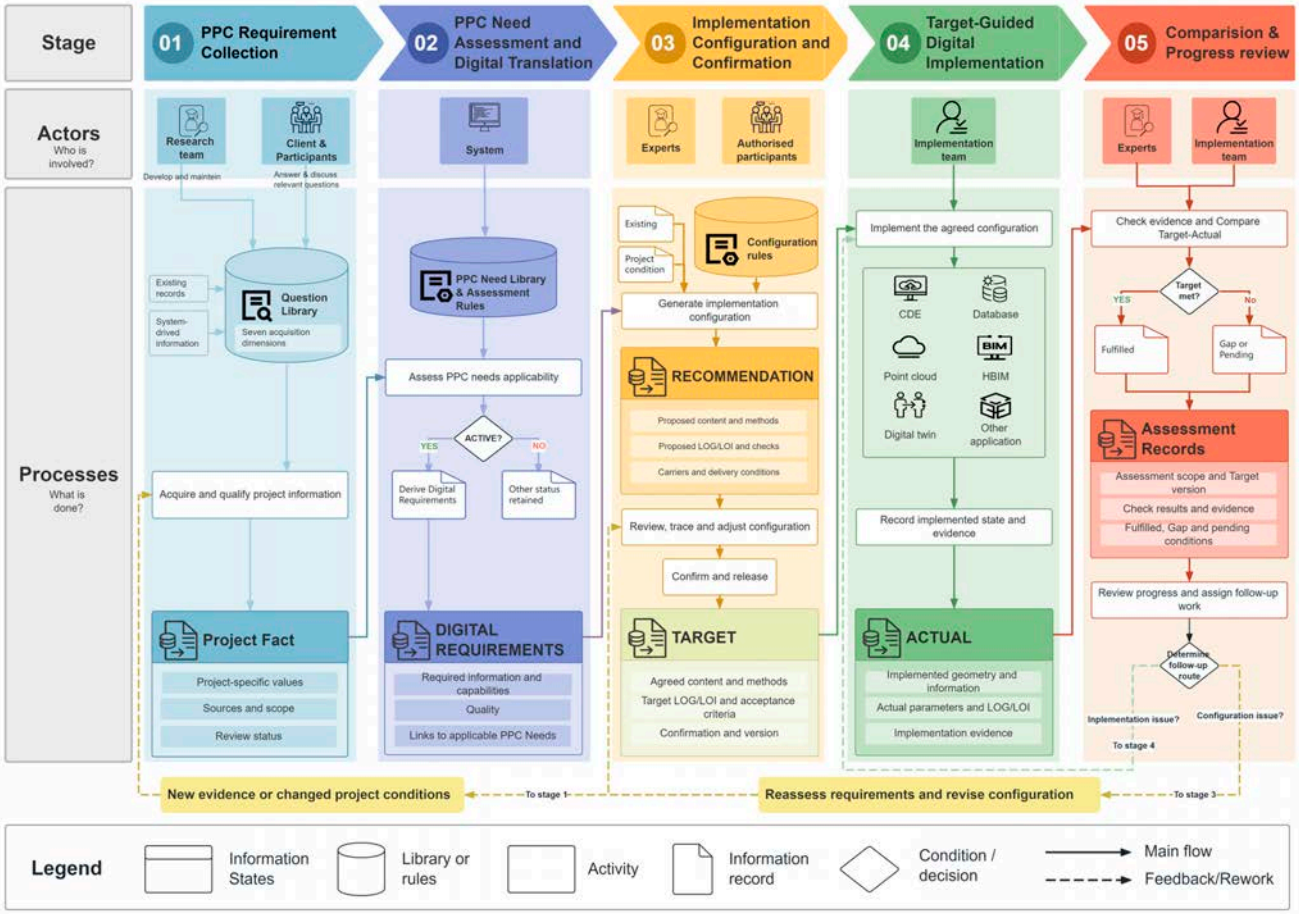


Figure 2. Overall structure of the PPC requirement-driven digital implementation framework.

The knowledge base was developed from the PPC literature, information management standards and project evidence. The PPC literature and guidance informed conservation, condition assessment, monitoring, risk, maintenance and conservation decision-making [1,3,4,7,32,33]. ISO principles and related guidance informed Organisational Information Requirements (OIRs), Asset Information Requirements (AIRs), Project Information Requirements (PIRs) and Exchange Information Requirements (EIRs) [20,34–38]. The HBIM literature and information-delivery standards supported their translation into digital implementation conditions [15–18,21,22].

Information acquisition follows the content needed, available records and participants' responsibilities. Clients primarily provide conservation and management purposes, information uses and project conditions. Applicable existing information is checked and reused.

Specialists assess conservation conditions, evidence fitness and technical constraints. System import, calculation and rule-based derivation follow explicit input conditions. Checked information supports PPC Need applicability assessment, and applicable Needs are translated into platform-neutral Digital Requirements. Required, Existing, Recommendation, Target, Actual and Gap separately record requirement grounds, resource states, proposals, confirmed requirements, implementation results and shortfalls. Table 1 summarises their operational definitions.

Table 1. Operational definitions of the core framework constructs.

Concept	Operational Definition	Main Source/Actor	Function
PPC Needs	Conservation, management, research and digital-management needs that may require digital support	PPC knowledge + project information	Identify relevant needs
Digital Requirements	Platform-neutral information and capability requirements derived from applicable PPC Needs	PPC assessment + digital translation	Define what the digital environment must support
Required	Requirement state represented by applicable Digital Requirements	PPC Needs + Digital Requirements	Provide the configuration basis
Existing	Digital information, resources, evidence and capabilities already available to the project	Existing project resources	Inform implementation configuration
Recommendation	Preliminary implementation configuration generated by the system from Required, Existing and project conditions	Configuration rules + project inputs	Provide a proposal for professional review
Target	Professionally reviewed and project-confirmed implementation requirements released at project, type or object level	Expert and digital technical expert review + authorised project confirmation	Guide implementation and provide the comparison reference
Actual	Digital implementation state assessed and recorded from delivered outputs and implementation evidence	Implementation records + expert and implementation personnel assessment	Record the achieved state
Gap	An implementation shortfall where Actual fails to satisfy the corresponding Target acceptance criterion	Target–Actual comparison	Locate content requiring further attention

The framework retains links between requirement sources, project inputs, configuration decisions, implementation evidence and assessment results. Experts and digital technical experts review proposals, authorised participants confirm Target, and digital implementation personnel undertake the work. Implementation records support Actual assessment, with comparisons retaining the applicable Target version and acceptance criteria. The knowledge structure was iteratively refined during framework development and its application within the Venaria project. Feedback from authors, research supervisors, project participants and stakeholders informed terminology, question wording, requirement coverage and assessment logic. These activities represented iterative project review. Completeness, interpretability and cross-case applicability require systematic expert evaluation.

3.2. Information Acquisition and Translation into Digital Requirements

The framework organises project inputs according to the information needed for PPC Need assessment and digital translation. Source statements are interpreted as need definitions, assessment conditions, project constraints or downstream information requirements. Equivalent meanings are consolidated, while differences in purpose and scope are retained. The resulting knowledge forms the PPC Need Library, Need-specific assessment logic and corresponding Digital Requirement definitions. Figure 3 shows the relationships between knowledge organisation, acquisition and digital translation.

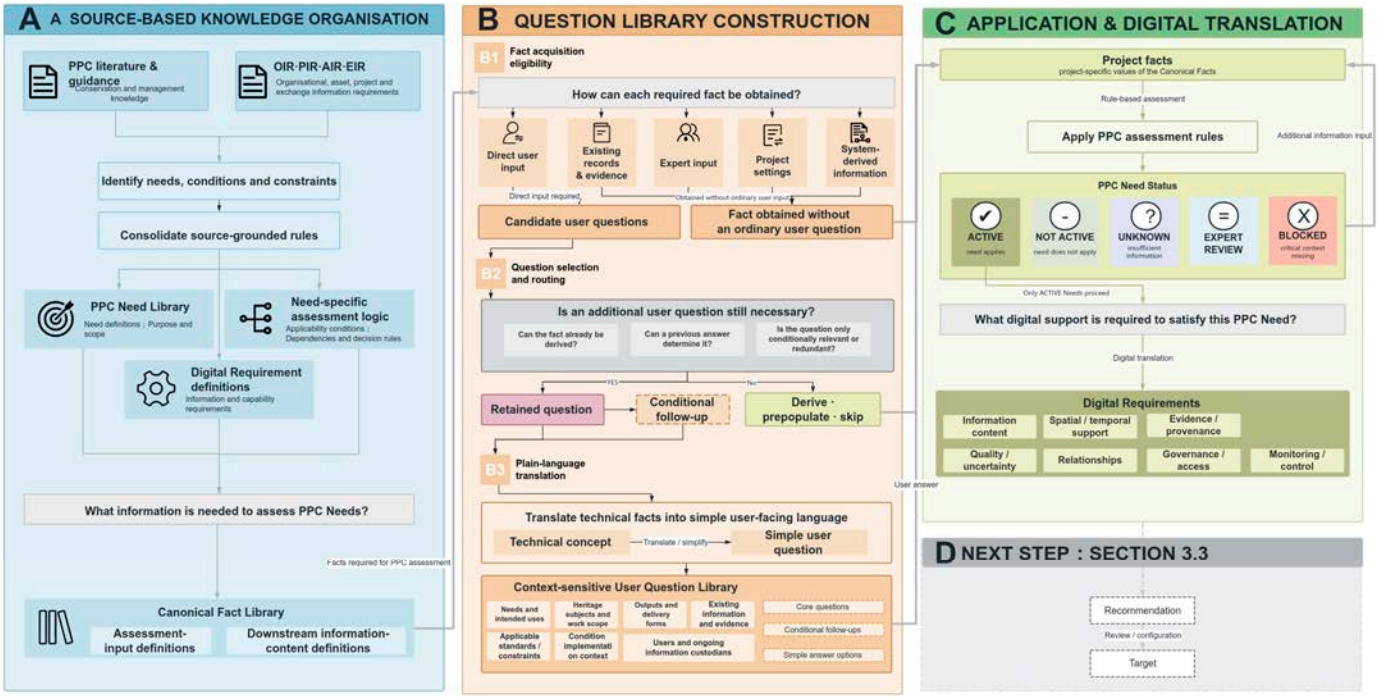


Figure 3. Construction and application of the context-sensitive Question Library for translating PPC Needs into project-specific Digital Requirements.

The Canonical Fact Library provides standardised definitions for this information. Assessment variables describe project conditions requiring verification, and their project-specific values form Project Facts. Downstream content definitions describe what the digital environment should organise and provide once a Need applies. These definitions support need assessment and the specification of Required Information Content, respectively. Acquisition addresses project conditions needed for assessment, while implementation establishes the specified content. Implementation Evidence records delivered content and its supporting grounds for Actual assessment.

User-facing acquisition is organised around seven dimensions: needs and intended uses; heritage subjects and work scope; outputs and delivery forms; existing information and evidence; applicable standards and constraints; heritage condition and implementation context; and users and ongoing information custodians. Project stages, delivery and updating are cross-cutting conditions. OIRs, AIRs, PIRs, EIRs and PPC provide source and requirement perspectives; user questions follow project semantics. Baseline questions capture purposes, scope, output preferences and known conditions. Conditional follow-ups respond to previous answers and missing information. Role-specific tasks address professional checks and project confirmation. Client responses record purposes, interests and preferences; confirmation of professional conditions and selection of technical solutions require relevant professional judgement. Specialists verify conservation assessments,

evidence fitness, technical capabilities, standards and acceptance criteria. Project owners confirm matters requiring decisions or authorisation.

Each input is checked for reusable information before further acquisition. Checks address source, subject scope, time and version; outdated or conflicting records are referred for review. Other inputs are obtained through record extraction, expert judgement, project configuration, system import, calculation or rule-based derivation. Direct questions address missing information requiring user input within the respondent's knowledge. Relevant roles address professional content. System processing follows explicit input conditions and approval requirements, while each information item retains its source, scope and review status.

Approved mappings translate acquired information into Project Facts, which support PPC Need applicability assessment. Missing or conflicting critical inputs leave assessments unresolved, pending additional information or professional review. Unknown information remains unknown. Only PPC Needs assessed as ACTIVE proceed to digital translation. Associated information and capability requirements are instantiated as project Digital Requirements. These may address content, objects and relationships, temporal records, provenance, quality, access and updating. Applicable requirements form Required and retain links to sources, Need definitions and assessment evidence. Resource availability and technical feasibility are considered during subsequent configuration.

Cross-role information use illustrates the relationship between conditional acquisition, fact formation and rule-based assessment. The acquisition design prioritises reuse of applicable records and triggers questions when purposes, users or collaboration needs remain unknown. Answers are checked against information scope and provenance before explicit mappings establish Project Facts. The system assesses Need applicability, while authority-and-responsibility tasks supply content for subsequent configuration. Table 2 illustrates this mapping proposal and its assessment conditions using the Galleria Grande shared-information context.

Table 2. Illustrative conditional acquisition, fact mapping and rule-based assessment for cross-role information use.

Entry and Trigger	Question or Activity	Case Context and Recording Requirements	Mapping and Rule Processing
Purposes or information interests remain unknown; reuse applicable records first	Q-D1-01: Which work will the digitisation outputs support? Q-D1-02: Which heritage information should be accessible?	Managers require operational and event-related queries; researchers use information according to their specialisms. Shared information mainly comprises historical documents, photographs, CAD drawings and repair records.	Records purposes and information interests separately. An inventory task verifies the specific record set and establishes the scope for collaboration assessment.
Intended users remain unknown	Q-D7-01: Who will mainly use the outputs?	Records managers, researchers and digital implementation personnel, distinguishing intended use from current project participation.	Establishes user context. Multiple participant groups alone do not establish collaboration needs or access permissions.
Multidisciplinary participation or exchange commitments exist, and collaboration needs remain unknown	Q-D7-04: Must different disciplines access or exchange the same outputs?	Records collaboration intentions and checks roles, shared records, purposes, scope and response provenance.	The proposed mapping establishes the project value of cross-role access or reuse required (CBF-272). Insufficient information remains unresolved, with further acquisition or role-specific tasks where necessary.

Table 2. *Cont.*

Entry and Trigger	Question or Activity	Case Context and Recording Requirements	Mapping and Rule Processing
Project Facts enter applicability assessment	Execute XRL-PN031-ACT-R001 and the corresponding state controller	Inputs retain provenance, scope, time and confirmation status. No completed execution result is assumed in this example.	TRUE supports PN-031 → ACTIVE, subject to complete required context. Decisive unknowns or missing context retain UNKNOWN or BLOCKED status, respectively. FALSE does not fire the activation rule; the controller determines the final state.
PN-031 is assessed as ACTIVE	Instantiate PPC-DR-029 within Required	Specifies information and capabilities for cross-role access, sharing and reuse.	Requires permissions for reading, writing, approval, sharing and reuse according to role, purpose and sensitivity, with access restrictions and security status recorded.
Authority or responsibilities require clarification; reuse applicable arrangements	Undertake TASK-ACCESS_AUTHORITY, with arrangements consolidated by the configuration owner for authorised management confirmation	Records permissions, responsibilities and restrictions separately. Technical production responsibilities for point clouds and HBIM are distinguished.	Supplies downstream configuration content. The system combines Required, Existing and project conditions to generate Recommendation. Expert and digital technical expert review precedes authorised Target confirmation. Implemented settings and check evidence support Actual assessment.

Note: The example links the seven-dimensional acquisition design to existing fact, Need and rule definitions. It does not report completed end-to-end execution or validation. Case information was supplied by the project researcher and requires corroboration against records. An existing CDE or cloud platform alone does not establish collaboration needs. Unknown inputs remain unresolved; permission confirmation may proceed alongside acquisition.

3.3. From Digital Requirements to Target Definition

Digital Requirements provide the basis for implementation configuration. The framework combines Required, Existing and relevant project conditions to generate Recommendation through a rule-supported mechanism. Proposals may address project-level information organisation, naming and classification, information carriers, modelling approaches, parameters, delivery and quality checks. Each proposal retains links to corresponding Digital Requirements for professional examination of coverage and implementation conditions.

After Recommendation is generated, relevant experts and digital technical experts review the proposal. They use available evidence, object characteristics and implementation conditions to identify missing information, conflicts and unspecified requirements. Conservation specialists review content related to conservation tasks. Digital technical experts examine implementation approaches, feasibility and ongoing information maintenance. Project owners confirm responsibilities, authorisation and delivery arrangements. Matters requiring multidisciplinary judgement are considered jointly. Reviewers can accept proposals, add content, request adjustments or retain items pending verification. Reasons and implementation implications are recorded. Pending items retain their information sources, responsible personnel and processing status for subsequent supplementation and review. Limitations in Existing can affect approaches, phasing or additional work, while Required retains the corresponding requirement grounds.

Authorised participants confirm the configuration, including its scope, responsibilities and acceptance criteria, before releasing it as Target. Records identify how unresolved items affect release and implementation; unconfirmed content remains pending. Recommendation, professional review and Target confirmation are recorded separately; approval records establish formal confirmation. Project-level requirements can be organised through a Building Information Modelling (BIM) execution plan (BEP) and controlled records. These

include Common Data Environment (CDE) planning, naming, classification and delivery conditions. Type-level and object-level requirements link to corresponding components or information units, specifying content, parameters, metadata, processing-history records and acceptance criteria.

Review comments, configuration adjustments, confirming parties, scope and version records support decision traceability. Changes after Target release undergo further review and confirmation to produce a revised version. Previous versions and applicable relationships are retained. Digital implementation personnel work according to the released configuration. Subsequent Actual assessments use the corresponding Target version and acceptance criteria.

3.4. Target-Guided Digital Implementation

After Target release, digital implementation personnel and relevant teams undertake the work according to the confirmed configuration. Personnel can consult linked requirements, source evidence and review records to establish the grounds and applicability of configuration conditions. Activities may include acquisition, HBIM, database configuration, information entry, documentary linking and monitoring information integration. Their combination follows the adopted configuration. Project-level requirements specify shared naming, classification, file organisation, exchange and delivery conditions. Type-level requirements define common representation approaches, methods, parameters and content for similar components. Object-level requirements record conditions specific to individual components. Differences requiring professional judgement are referred for review. Changes to Target conditions require confirmation before becoming a revised implementation basis.

Implementation produces digital outputs and supporting records. Metadata describes output identity, sources, responsibilities, versions and associated objects. Paradata records the acquisition, processing, modelling and interpretation methods used, together with reasons for relevant decisions. Personnel record Actual parameters, quality-check results, evidence links and update status. Configured values and values obtained during implementation are stored separately, retaining object and version associations.

In HBIM, type and object identifiers link configuration records to model components. Shared type requirements can map to type parameters or associated records. Object-specific information is stored in instance parameters or external structures. Geometric representation, information fields, documentary relationships and source records follow their respective Target conditions. External documentation is associated with components through agreed identifiers or relationships to support specific information requirements. For external exchange, the framework defines mapping relationships between project object identifiers and Industry Foundation Classes (IFC) entities and properties, applicable Target information fields and IDS-checkable conditions, and deliverable metadata and CDE records [22,39,40]. Object identity, provenance and version references provide corresponding linkage points for future Digital Twin integration.

Once outputs reach an assessable state, implementation personnel compile Actual parameters, content, relationships and evidence. Responsible personnel use these records to assess Actual. In Galleria Grande, Level of Geometry (LOG) and Level of Information (LOI) separately describe geometric representation and information state. Actual is determined from implemented outputs, and its assessment is logically independent from Target definition. Target provides the subsequent comparison reference. Records identify scope, assessment time and the corresponding Target version. Unchecked conditions and insufficient evidence remain pending assessment. This mechanism applies to new work and the checking and updating of existing resources. Workstreams can produce assessable outputs at different stages of progress.

3.5. Procedures for Actual Assessment and Gap Evaluation

Experts and digital implementation personnel assess Actual using delivered outputs and supporting records. Assessment identifies the relevant objects, implementation scope, time and applicable Target version. Implementation personnel provide output parameters, records and technical check results. Relevant experts review content requiring professional judgement. Actual states and comparison conditions are recorded separately for subsequent examination.

Target–Actual comparison uses the acceptance criteria specified for each configuration. These may concern minimum levels, maximum tolerances, mandatory information, valid associations, categorical matches or other explicit rules. LOG and LOI are assessed separately using compatible definitions, scopes and checking conditions. Thresholds and measured results are stored separately, and level judgements retain evidence from the underlying checks. Conditions meeting acceptance criteria are recorded as fulfilled. Evidence-supported shortfalls are recorded as Gap. Unchecked conditions and insufficient evidence remain pending assessment.

Checks can be organised at the object, type, system or project level. Conclusions identify supporting records and assessment coverage. Shared configurations provide common criteria for multiple objects. Type- and system-level summaries follow Actual assessment records and identify the objects covered. Progress reporting distinguishes configuration confirmation, implementation records and Actual assessment coverage. Each statistic identifies scope, reporting time, counting unit and denominator. Fulfilment rates use assessed records; assessment coverage uses all applicable records as its reference. Fulfilled, unmet and pending conditions are presented together. Comparisons retain their respective criteria, and aggregate scores require explicit common assessment rules.

Each Gap links to its Target condition, implementation evidence and Digital Requirements. Where the traceability chain is available, teams can examine the PPC Need and conservation task associated with an information shortfall. Professionals and project owners determine subsequent actions, including additional modelling, information entry or evidence linking, followed by Actual reassessment. Physical heritage condition, intervention necessity and conservation priority are determined through the relevant professional assessments.

Implementation adjustments update outputs and Actual against the existing Target. New conservation information or project conditions may trigger reassessment of PPC Needs and Digital Requirements. Where Target requires modification, the revised configuration undergoes review and confirmation. Subsequent comparisons use the applicable version and examine whether existing Actual evidence supports the revised acceptance criteria. Updated comparison results are recorded separately.

4. Results

The framework underwent an initial application in Galleria Grande. The results report the knowledge and acquisition design alongside case records of requirements, implementation configurations, HBIM outputs and assessments.

4.1. Requirement Inputs and Digital Requirement Translation

Source extraction produced 305 source-native content units: 53 from OIRs, 158 from AIRs, 41 from PIRs and 53 from EIRs. A further 68 effective evidence units were retained from PPC-domain sources. Knowledge organisation produced 34 canonical PPC Needs, retaining Need-specific assessment logic, provenance, semantic roles and processing records. The executable assessment layer contained 44 rules, 51 conditions and 48 actions.

Fact organisation registered 364 occurrences and produced 320 Canonical Fact definitions. Shared definitions retained references across Needs, while content with distinct

assessment meanings was registered separately. Of these definitions, 70 concerned upstream assessment and runtime inputs, and 250 described downstream information content. The 34 PPC Needs were linked to corresponding framework-level Digital Requirement definitions. The downstream model contained 267 Need-specific content associations involving 250 distinct information-content definitions.

The user-facing acquisition design registered 40 fields, with 30 addressed through question entries and ten through role-specific tasks. Question entries comprised 22 assigned to clients, seven to project owners and one to a technical maintenance owner. Client entries included 11 baseline questions, ten conditional follow-ups and one continued-updating entry. Each entry recorded its respondent, triggering conditions, reuse conditions and stopping criteria. Role-specific tasks addressed subject and scope confirmation, record checks, professional judgement and project configuration. The acquisition design was documented separately from case input and profile records.

In Galleria Grande, management personnel from the Consorzio delle Residenze Reali Sabaude (CRRS) discussed requirements with professors and staff from Politecnico di Torino. The researcher assisted with questionnaire completion and entered responses into the tool. Managers primarily provided purposes, information-use practices and project conditions, while the expert team contributed technical content. Project records retained 46 answer entries, representing stored input records. After meeting inputs were completed, the tool generated a profile containing 26 requirement dimensions. These addressed geometric representation, material and condition information, data linkage and information governance. The resulting Recommendations were reviewed in working discussions involving the researcher, research supervisors and other HERITALISE contributors. The discussions covered PPC priorities, metadata and paradata, BEP and information exchange configurations, and LOG/LOI requirements. Following multidisciplinary review involving CRRS management representatives, the agreed configurations were adopted as Target for the pilot implementation and made available to the HBIM implementation team through the software prototype.

The case profile classified four dimensions as “required”, eleven as “recommended”, eight as “optional” and three as “not required”. Answers, dimension outputs and calculation records were stored separately. This distribution recorded the case profile classifications, while PPC Need applicability assessments were recorded separately.

4.2. Project-Level and Type-Level Digital Implementation Configurations

Configuration outputs covered project-level information organisation and type-level implementation arrangements. Project records contained BEP configuration content, file and object naming rules, coding structures, classification mappings, CDE planning, and software and information organisation settings. Type-level records specified representation scopes, modelling approaches, information carriers and documentary-linking requirements.

Files, objects and deliverables used separate identification rules. File names included a project or asset prefix, content category, short description, year, language and version. Object identifiers combined asset, area, interior or exterior designation, spatial unit, object level, type and running number. Deliverable names linked scope codes, deliverable objects, delivery tiers and versions. Classification records retained project categories and external mappings, including Uniclass, OmniClass and UniFormat.

The CDE plan contained 12 directory categories covering administration, references, original data, context, point clouds, HBIM, databases, monitoring, Geographic Information Systems (GISs), Digital Twin platforms, outputs and archives. Configuration also listed ten register and delivery record requirements. These addressed scope, controlled vocabularies,

software, delivery inventories, review, changes, and database, monitoring and GIS records. Directory plans and register requirements were stored separately.

The BEP configuration self-check contained 13 entries addressing project identity, requirement summaries, CDE planning, registers, naming and unresolved pre-implementation items. Entries retained check methods, status, reference paths and notes. Software self-checks, professional review and project confirmation were recorded separately. Figure 4 shows the software interfaces for recommended CDE directory generation and rule-based ObjectID generation.

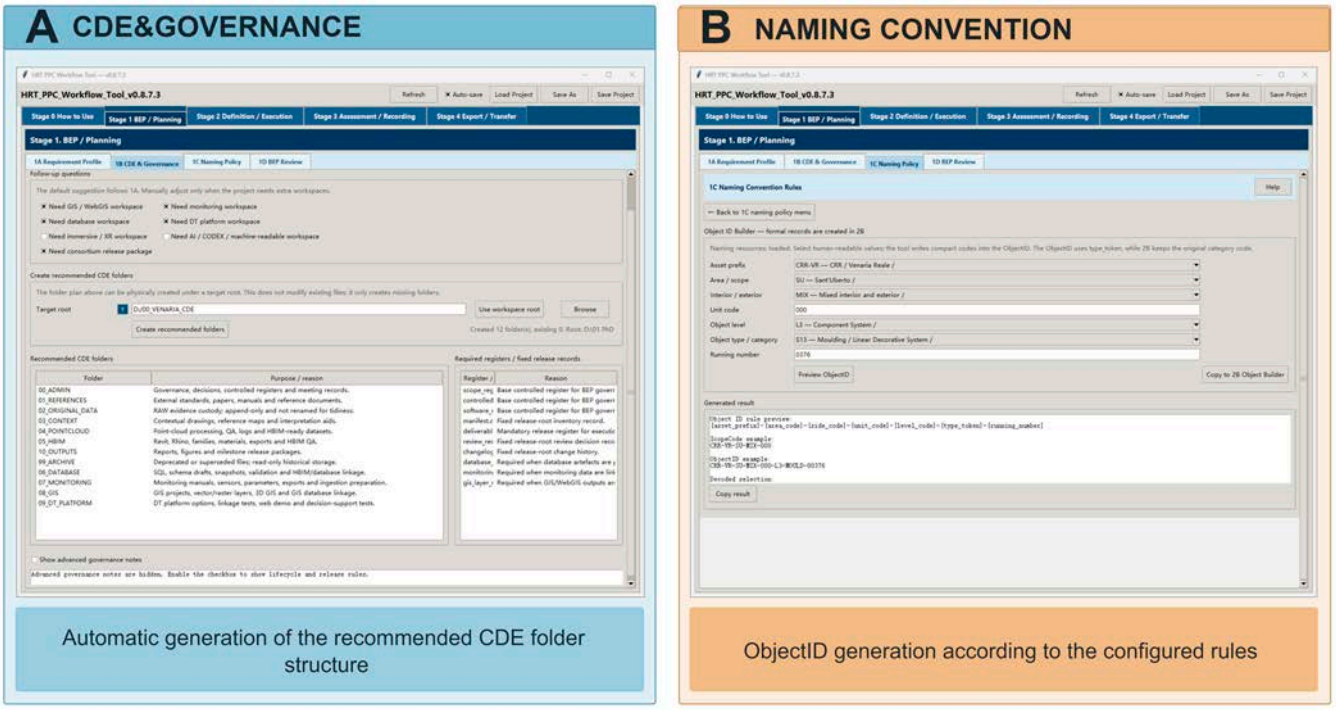


Figure 4. Software interfaces for project-level digital implementation configuration: (**A**) recommended CDE directory generation; (**B**) rule-based ObjectID generation.

Participating digital implementation personnel adopted generated content to coordinate BEP, naming, CDE and software configurations. Rules were applied to information organisation, output naming and technical settings. Saved requirement summaries, configuration rules and register requirements formed shared project-level records consulted during implementation.

The dataset retained 58 component-level implementation strategy records. These organised representation strategies, modelling approaches, LOG/LOI configurations, principal sources, quality-check requirements and information carriers. Door and window bodies were organised separately from surrounds, with different documentary scopes for interior and exterior systems. Necessary nested families within surrounds primarily represented decorative columns and balusters. Other decorative parts remained within the overall system and were not independently registered as subcomponents. Table 3 presents selected representative configurations. Common mandatory information comprised object identifiers, classification and photograph/orthographic image links. Historical documents and repair records were associated according to object use and source applicability.

Table 3. Selected type-level implementation configurations in the Galleria Grande.

Component or System	Geometric Representation Scope	Modelling Route	Information Carrier	Applicable Documentary Content
Door and window bodies	Bodies represented separately from surrounding decoration	Nested-family modelling	Revit loadable family	Historical documents, maintenance and repair records, where available and applicable
Exterior opening-surround system	Overall system with selected nested decorative parts; other parts retained within the system	Family modelling with selected nested families	Revit loadable family	Available historical documents and maintenance records; source coverage remains limited
Interior opening-surround system	Overall system with selected nested decorative parts; other parts retained within the system	Family modelling with selected nested families	Revit loadable family	Historical documents, maintenance methods and repair records applicable to the interior system
Segmented vault system	Segmentation by transverse arches and their spacing; overall surfaces and component relationships	Rhino surface construction and family import; thickness informed by CAD drawings	Revit loadable family	Applicable source drawings and supporting documents
Column element	Base, shaft and capital, defined separately from surrounding decoration	Revit Family Editor modelling	Revit loadable family	Applicable historical documents and supporting records

Note: All selected configurations require object identifiers, classification and photograph/orthographic-image links. Documentary associations depend on source availability and applicability. The table describes configuration requirements; field-entry and linking states are assessed separately. Object hierarchy and LOG are recorded separately. Numerical Targets under reassessment are excluded; current Actual levels appear in Table 4.

Table 4. Actual LOG and LOI for representative component categories in Galleria Grande.

Component or System	Actual LOG	Actual LOI	Recorded Implementation
Door and window bodies	3	3	Body representation and structured object information associated with historical, maintenance and repair records
Exterior opening surrounds	3	1	Overall decorative-system representation; limited historical and maintenance information
Interior opening surrounds	3	3	Overall decorative-system representation with more extensive historical documentation, maintenance methods and repair records
Segmented vaults	2	1	Overall curvature, segment extents and component relationships; limited geometric detail and information content
Columns	3	1	Base, shaft and capital representation; limited information content

Note: Levels derive from assessments completed for the reported components within the selected categories. The system retains classification and assessment records beyond these selected examples. Presented values concern the assessed components involved; object hierarchy, Actual levels and Target conditions are recorded separately.

4.3. Configuration-Guided HBIM Implementation

HBIM implementation used lists associated with type-level configurations. Lists and software records contained modelling methods, reference LOG/LOI, object hierarchy, representation scopes and information requirements. Personnel accessed configuration through

the software and JavaScript Object Notation (JSON), Markdown and comma-separated value (CSV) files. Following task allocation, multiple digital implementation personnel used the shared software prototype to work in parallel, consulting object or type records and applying lists and software rules during modelling and information organisation. Autodesk Interoperability Tools for Revit (v10.0.3) supported the batch creation of shared parameters using project-defined parameter names. The software prototype exported component and configuration records in CSV and JSON formats. These records were matched to corresponding Revit-exported tabular data using parameter names and object identifiers, and selected values were written back to the corresponding Revit elements through the DiRootsOne plug-in. Parameter shortfalls identified during implementation were recorded in the HBIM models for joint review during subsequent model consolidation.

The HBIM dataset contained 1532 object instances organised into 58 category–type groups. Objects were associated with corresponding type records, retaining identity, classification and configuration references. Type records included manual modelling, nested families, hybrid workflows, Rhino/Grasshopper, mesh/proxy representation and profile-based approaches. Figure 5 presents the overall model and representative components.

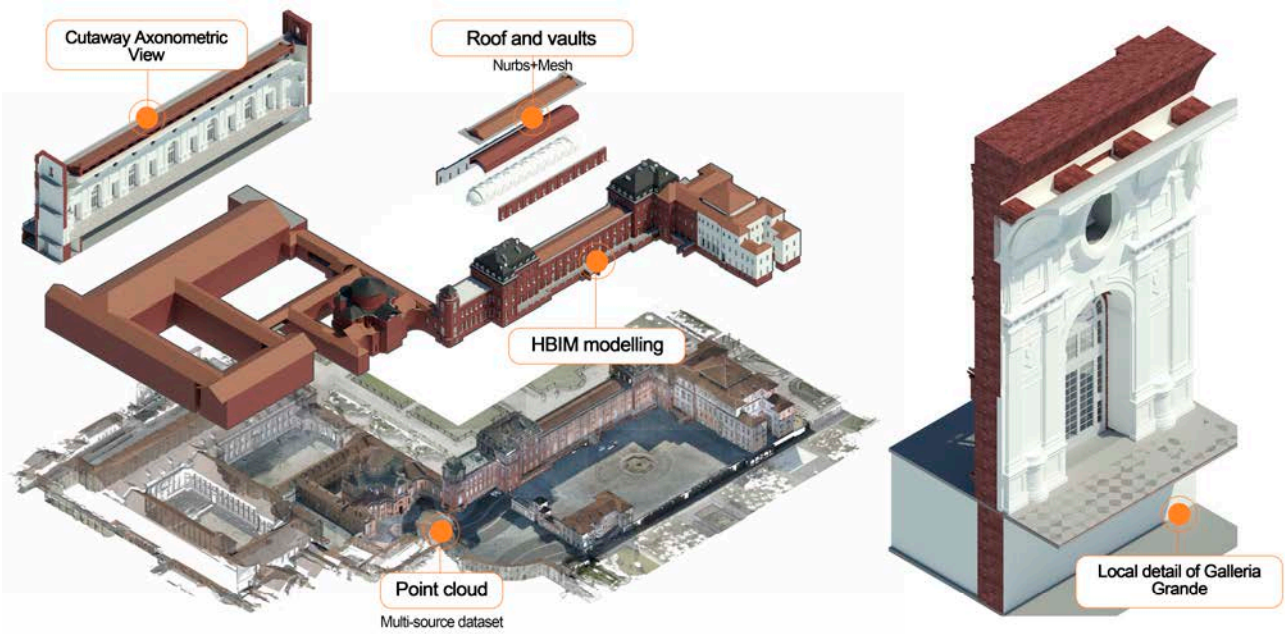


Figure 5. Current HBIM implementation of the Galleria Grande within the Reggia di Venaria Reale.

Representative components used different geometry construction approaches within the scopes reported in Table 3. Necessary nested families in opening surrounds primarily represented decorative columns and balusters; other decorative parts remained within the overall system geometry. Vaults were segmented by transverse arches and their spacing. Rhino surfaces were imported into Revit loadable families, with thickness informed by CAD drawings. Columns were modelled in the Revit Family Editor and included the base, shaft and capital.

An interior mixed wall-column decorative system illustrated the connection between type-level configuration and an individual HBIM object (Figure 6). It was organised as an overall decorative system, with its scope recorded separately from the columns and opening surrounds in Table 3. Point clouds and CAD drawings provided geometric evidence. Software records retained the type group, strategy, representation approach, Target LOG/LOI, sources and quality-check conditions.

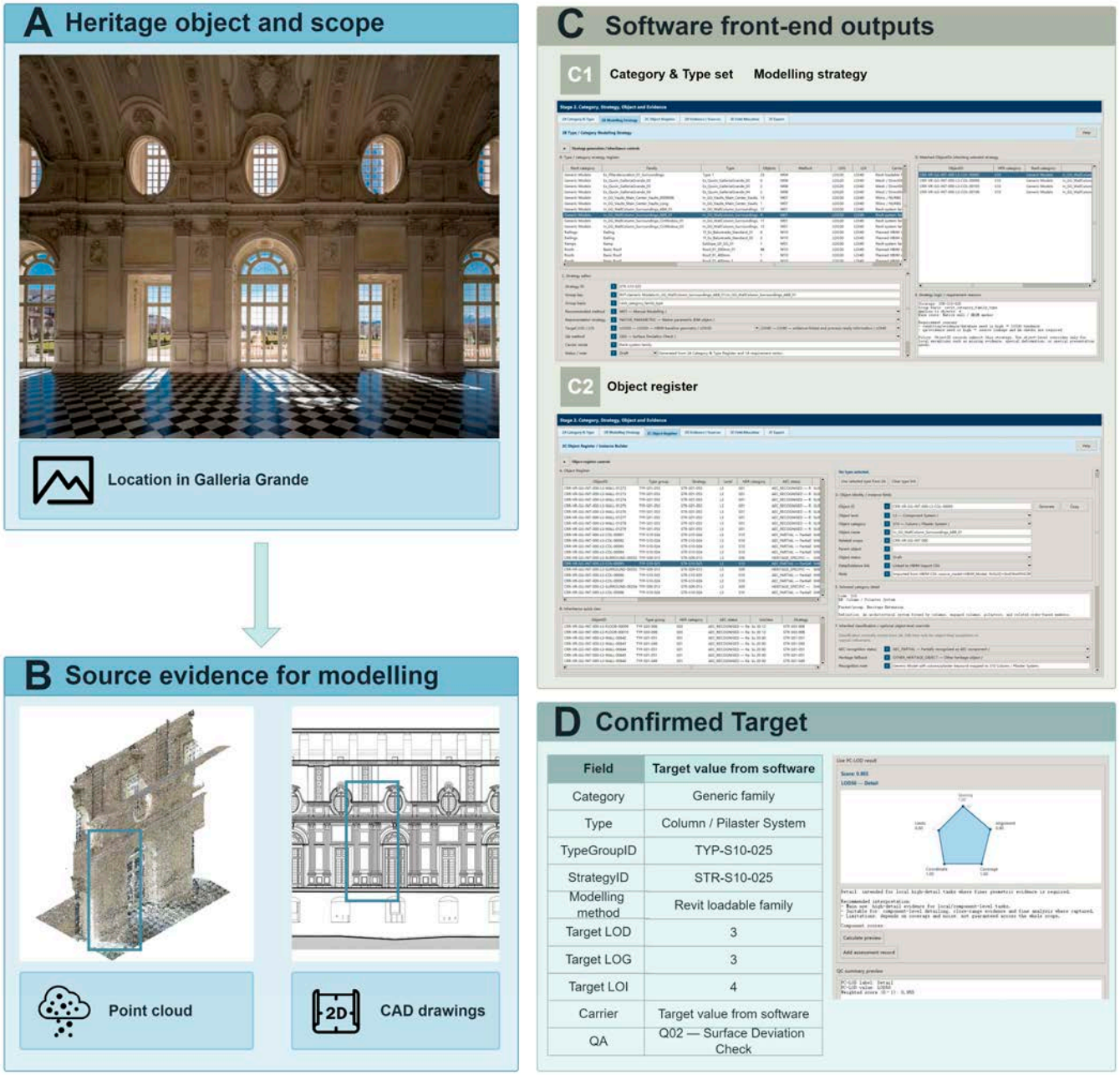


Figure 6. Configuration and source evidence for the representative Galleria Grande wall-column decorative system: (**A**) heritage object and scope; (**B**) point-cloud and CAD evidence; (**C**) software type strategy and object records; and (**D**) confirmed Target.

Shared parameters linked configuration records to the HBIM object through type group, strategy and object identifiers. An initial PostgreSQL database prototype, managed through DBeaver, contained selected HBIM component records. Model and database records were associated using IFC GUID and Revit ElementId fields. Configuration values and subsequent Actual assessments were recorded separately, retaining their object associations. Assessments following modelling and information entry retained the object identifier, linking configuration, delivered outputs and assessment results. Figures 6 and 7 present the Target, source evidence, HBIM parameters, Actual, Gap and implementation progress records for the mixed decorative system.

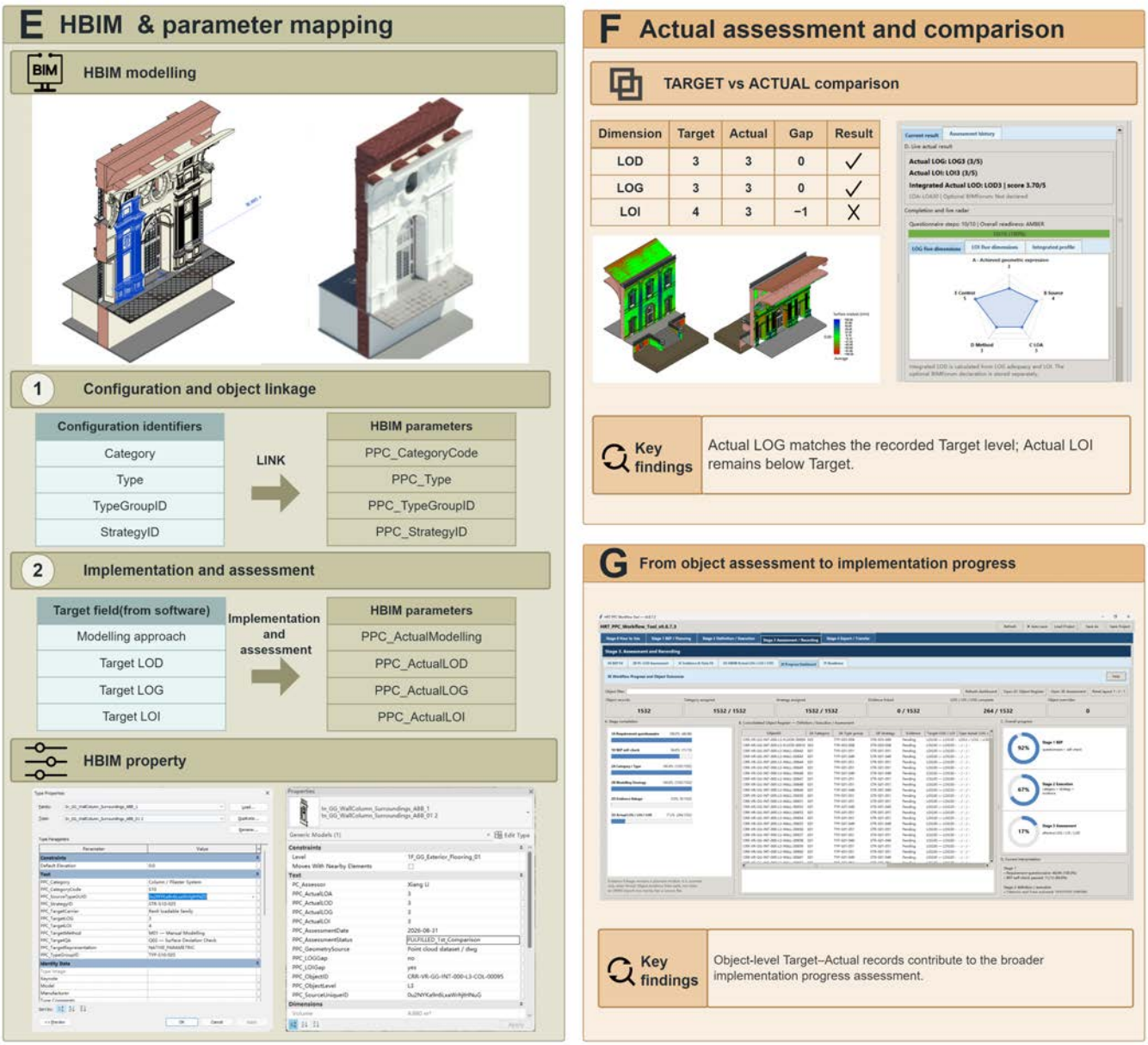


Figure 7. HBIM implementation and assessment of the same wall-column decorative system: (**E**) model representation and parameter associations; (**F**) Actual assessment and Target–Actual comparison; and (**G**) implementation progress reporting. Panel letters continue from Figure 6. Together, Figures 6 and 7 illustrate successive stages of the workflow for the same representative component, from configuration and source evidence to HBIM implementation and assessment. Matching LOG levels do not establish object-specific geometric accuracy acceptance. "FULFILLED" denotes assessment completion, not satisfaction of every Target condition.

Photographs and orthographic images were associated with objects through image links; orthographic images were exported from point clouds. Historical documents, maintenance methods and repair records were linked according to applicable scopes. Door and window bodies and interior surrounds had more extensive associated records. Repair dates, detailed content and material information remained incomplete. Vaults represented overall curvature and component relationships, with fine relief omitted and limited accuracy in thickness representation. Level of Development (LOD) remained an auxiliary integrated description, while LOG and LOI were recorded separately.

4.4. Actual Assessment and Gap Evaluation

The software retained Actual assessment records for different component types and objects. Assessment had covered most repeated components in Galleria Grande. Table 4 presents five representative categories selected from these records: door and window bodies, exterior surrounds, interior surrounds, segmented vaults and columns. Each presented category concerns the corresponding assessed components, with LOG and LOI recorded separately.

Figure 7 includes deviation analysis at wall-system level. Separate maximum and mean deviations and acceptance thresholds are not reported for the illustrated decorative object. Information records remain incomplete regarding some repair dates, detailed content and material information.

The interior mixed wall-column decorative system in Figure 7 had a separate object-level assessment. Comparison used the Target conditions retained for that instance. Target and Actual LOG/LOI were compared using the same project-internal definitions and assessment criteria, which have not yet been fully published. Target LOG and Actual LOG were both recorded as 3. This level comparison does not establish object-specific geometric accuracy acceptance. Target LOI was 4 and Actual LOI was 3, leaving the information level condition unmet and recorded as Gap. Shared parameters retained associations between object identity, type configuration and Actual records.

System assessment records retained their object scopes, Target conditions and assessment states. Table 4 presents Actual for five selected component categories, while Figure 7 presents a separate object-level comparison for the mixed decorative system. Some Targets remain under reassessment. Comparisons and overall fulfilment rates against the reassessed Targets have not yet been calculated.

5. Discussion

5.1. From PPC Needs to Digital Requirements

The method seeks to organise requirement articulation, professional configuration and digital implementation into a process with explicit responsibilities and traceable decision grounds. OIRs, AIRs, EIRs and PPC Needs address different purposes, information uses and delivery requirements. Participants with relevant knowledge and responsibilities need to provide and interpret this content. Clients primarily express project purposes, use needs and known conditions. Professionals supplement relevant judgements, while the system applies rules to organise translation and configuration proposals. Client participation can consequently focus on questions within their understanding and judgement. Technical parameters are determined through professional review once purposes and conditions are established. Digital Requirements connect requirement grounds to configuration, and the BEP records implementation decisions. This arrangement follows the purpose- and use-based definition of information requirements in information management and Level of Information Need [20,21].

Requirement translation depends on explicit relationships between semantic definitions, project values, required information content and implementation evidence. Project Facts support need assessment, Required retains applicable requirement grounds, and Existing provides resource conditions for configuration. Resource limitations can affect implementation approaches, phasing and additional work, while requirements and unresolved issues remain recorded. Professional review connects rule-generated proposals with project decisions, and implementation records support assessment of outputs. Configuration confirmation and Actual assessment have distinct grounds. Participants can examine how requirements were established, how results were assessed and which content needs updating when project conditions change.

The Galleria Grande application indicates that structured configuration can provide a shared implementation basis for a multidisciplinary team. Requirements were acquired through meetings involving managers, professors and staff. Generated content subsequently coordinated BEP, naming, CDE and software configuration and supported HBIM implementation by multiple personnel. Requirements dispersed across sources and professional interpretations were organised into records that participants could jointly consult, refine and apply. Implementers still needed to understand object characteristics and evidence, with shared records supporting requirement interpretation and configuration judgements. The current application supports operational feasibility, while complete requirement-translation coverage requires further validation.

5.2. Role-Appropriate Information Acquisition and Multidisciplinary Participation

Role-appropriate acquisition first addresses what participants need to know and which activities they intend to support. Technical questions beyond clients' knowledge may elicit intuitive answers or agreement with options perceived as advanced or comprehensive. Such responses may be mistaken for confirmed requirements when entered directly into configuration. Asking whether sensors or real-time monitoring are needed may elicit approval without specifying relevant changes, intended decisions or appropriate acquisition frequency. Purpose-first questions ask what clients wish to understand and which activities the information should support. Professional judgement then determines information content and technical approaches.

Translation from intended use to configuration also involves implementation and ongoing management conditions. Monitoring options require consideration of funding, heritage-site conditions, equipment suitability, maintenance personnel and operational arrangements. Clients provide objectives and resource conditions. Experts assist with clarification and assess technical options and operating conditions with relevant participants. Previous research has addressed collaboration in heritage management and dialogue in conservation decision-making [10–12]. Question sequencing, role-specific tasks and review records make these exchanges traceable. Experts may assist during clarification, with clients' Actual purposes retained as grounds for configuration.

Information type and source determine acquisition routes. Canonical Fact definitions used for need assessment correspond to project conditions requiring verification. Values are acquired through existing records, professional judgement, user responses or system processing and recorded as Project Facts. Downstream content definitions organise Required Information Content, while Implementation Evidence records Actual delivery. Knowledge framework size and client question counts therefore have different scopes. Reuse and conditional follow-ups focus questions on outstanding information. Professional tasks address content requiring interpretation, verification or authorisation. Experts can concentrate on these items and retain the grounds for their judgements. Insufficient sources and conflicting information remain pending confirmation by relevant personnel.

In Galleria Grande, requirements were acquired through question-by-question meetings and assisted completion. Managers primarily contributed purposes and management conditions, while experts supplemented technical content. The seven-dimensional acquisition design further organised project questions, conditional follow-ups and professional tasks. Current application still relies on meeting assistance. Client understanding during independent completion and consistency between respondents require examination. The influence of purpose-first questions on response bias, and of role allocation on professional review workload, also requires dedicated assessment.

5.3. Decision Traceability and Implementation Assessment Within a Structured Workflow

Relationships between user needs, Digital Requirements, Recommendation, Target, Actual and Gap organise requirement articulation, configuration, confirmation, implementation and assessment within a structured workflow. Each stage retains distinct definitions, grounds and records, connected through source relationships and object identifiers. Client input, system processing, professional judgement and implementation evidence can be identified and examined within the same process. Participants can trace how information was generated and adjusted, how needs informed configuration and how configurations were realised in assessable outputs.

Separate Target LOG/LOI and Actual LOG/LOI records establish an explicit relationship between objectives and results. Target LOG and Target LOI express confirmed geometric and information requirements. They develop through client-provided purposes and conditions, system processing, and review by experts and digital technical experts. Actual LOG and Actual LOI are assessed from delivered geometry, information content and supporting evidence. Requirements and Actual states have distinct grounds, providing a basis for examining implementation results. This independence concerns the logical and recorded separation of Target confirmation from Actual assessment. Personnel undertaking these responsibilities may overlap according to project organisation.

Professional review covers configuration development, implementation checking and interpretation of results. Participants with appropriate access can trace outputs to applicable Targets, professional adjustments and requirement sources. They can also follow requirements into configuration and implementation records. Gap provides an entry point for examining geometry, information content, evidence associations or implementation conditions. Target revisions retain earlier decision rationales, versions and links to assessments. Existing judgements and subsequent adjustments consequently remain linked to their relevant context. Continuous records support shared understanding of decisions and provide grounds for renewed review.

Quantitative comparison requires compatible level definitions, explicit object scopes, information content and acceptance criteria. Separate Target and Actual records provide the comparison basis, while specific checks provide assessment grounds. LOG/LOI summarise implementation states. Geometric deviations, mandatory fields, source associations and other applicable requirements undergo corresponding checks. Identical levels may correspond to different content and checking conditions, making the associated records necessary. Separately recording fulfilled, unmet and pending requirements allows teams to summarise progress within defined scopes and plan work around specific discrepancies.

The mixed wall-column decorative system shown in Figures 6 and 7 connects evidence, Target, HBIM parameters, Actual, Gap and progress reporting in an object-level record chain. Its Target LOG and Actual LOG are both 3; Target LOI is 4, and Actual LOI is 3. The recorded LOG levels match, while the information level remains below Target. Table 4 presents Actual for five representative categories selected from system assessment records. The table and figures report different assessment scopes and retain their respective comparison criteria. Project-wide reporting requires assessment coverage to be established from the complete record set. The current example supports object-level traceability and comparison, while complete workflow coverage and assessment consistency require further validation.

5.4. Digital Implementation and Team Collaboration Through Shared Configuration

Implementation personnel in Galleria Grande accessed configuration lists through the software and JSON, Markdown and CSV exports. They followed modelling approaches, LOG/LOI, object hierarchy and information requirements during HBIM work. Shared configuration translated professional discussions into accessible implementation guidance.

Technical personnel could focus on object representation, parameters, information associations and quality checks. Photographs, point clouds, drawings and historical materials provided evidence, while configuration records clarified their uses and the checks required for outputs.

Shared configuration reduced repeated reading and interpretation of requirement documents, coordination time and duplicated work during project implementation. Coordinated BEP, naming, CDE and software settings helped organise work across the team. Type-level configuration allowed repeated components to use applicable modelling and information arrangements, concentrating work on Actual object differences. These improvements were observed qualitatively, and their magnitude requires quantification. Meeting assistance and team experience also contributed to coordination. Further assessment needs to distinguish these conditions from the specific contribution of shared configuration.

Structured records give team communication a defined focus. Participants can discuss requirements, components or evidence items and associate adjustments with relevant records. Insufficient sources, distinctive geometry and software constraints identified during implementation provide inputs for professional review. Experts examine whether configuration needs supplementation, while technical personnel explain implementation conditions and output states. Object-level records and associated Gaps provide grounds for locating subsequent information entry, modelling adjustment and review tasks. These exchanges support continuing collaboration and allow implementation experience to inform configuration revisions.

Object identifiers and documentary associations also provide access points for conservation management queries. For example, examining intervention history requires documents to be associated with objects and time. Missing repair dates, detailed content and material information in current records may limit chronological organisation and comparisons between interventions. Configuration requirements and recorded shortfalls allow these limitations to be located. Their effects on specific conservation tasks, and whether supplemented information meets intended uses, require task-based evaluation.

5.5. Limitations and Further Validation

The study concerns a single case, Galleria Grande, encompassing shared configuration, HBIM implementation and assessment records at the current project stage. Meetings, assisted completion and continuing professional involvement supported requirement interpretation and configuration development. These conditions define the scope of the findings. In this pilot, Target configurations were adopted through a multidisciplinary working agreement, including participation by CRRS management representatives, rather than through a formal institutional approval procedure. Framework development and case implementation progressed concurrently, and personnel effort and operational costs were not separately recorded for these activities. Consequently, the pilot does not yet provide a reliable baseline for estimating routine implementation duration or institutional operating costs. Client understanding during independent completion, consistency between expert judgements, and performance under different personnel and resource conditions require further examination.

Complete connections between acquisition design and downstream configuration require validation. The seven-dimensional design organises project-level information, while end-to-end checks remain necessary for its question routing, rule inputs and outputs. Stored inputs require review of their sources, approval states and any retained default values. Some Targets remain under reassessment. Subsequent comparisons require applicable versions and acceptance criteria. Current assessment covers most repeated components, with five categories selected from system records for presentation. Precise type- and object-level

coverage counts remain to be compiled. Project-wide fulfilment rates require explicit assessment scopes and denominators.

The knowledge framework, ontology and exchange mechanisms require further development and validation. Current semantic definitions and record relationships support requirement translation and configuration traceability. Existing definitions and mappings to external concepts also require semantic consistency checks. JSON, Markdown and CSV exports supported team information use. Broader interoperability, including IFC/IDS-based exchange and integration with Digital Twin platforms, remains to be tested for consistent interpretation of identifiers, classifications, units, provenance relationships and version information across systems. Incomplete sources and conflicting evidence may affect rule inputs, professional judgements and implementation assessments. Their uncertainty and review records need to be retained.

Assessment methods require additional reproducible measurement evidence. Geometric checks need documented object scopes, reference data, calculation conditions and measured maximum and mean deviations. Information assessment requires explicit mandatory content, evidence requirements and procedures for handling missing information across object categories. Agreement between personnel assessing the same outputs can help examine the clarity of acceptance criteria. Quantifying collaborative benefits requires defined task scopes, recording procedures and comparison conditions.

Further validation should address workflow operation and practical use. End-to-end checks can examine continuity between requirement sources, configuration adjustments, implementation evidence and assessment results. Applications across cases and teams can test the scope of role allocation and configuration rules. Task-based evaluation can establish whether object-linked information supports the required queries, comparisons and updates. This evaluation should also examine how an evidence-supported Gap is traced to the affected PPC task, reviewed by conservation specialists and, where justified, translated into an authorised request for additional information, inspection or plan adjustment, with subsequent decisions and evidence retained for review. Digital implementation fulfilment and outcomes in conservation management require separate assessment.

6. Conclusions

This study develops a requirement-driven framework for translating preventive and planned conservation needs into digital implementation requirements for architectural heritage. The framework distinguishes conservation and management needs from subsequent technical choices and organises the workflow through Required, Existing, Recommendation, Target, Actual and Gap. User input, rule-based processing, expert review and digital implementation have explicit responsibilities and records. These establish traceable relationships between requirement sources, configuration decisions and implementation results. Targets and Actual results are recorded separately and associated with acceptance criteria, providing a basis for cross-stage comparison and quantitative progress management.

Role-appropriate acquisition allows clients to articulate needs through project purposes and conditions within their understanding and judgement. Professional content and configuration confirmation are addressed through corresponding review arrangements. This organisation provides understandable entry points for client participation and opportunities to clarify misunderstandings in requirement articulation. Digital implementation personnel follow jointly confirmed configurations, while experts have explicit review responsibilities and decision records. The Galleria Grande application supports the operational feasibility of this working arrangement. Shared configuration coordinated digital tasks. Project practice indicated reductions in repeated document reading and interpretation, coordination

time and duplicated work for technical personnel. The magnitude of these improvements requires quantitative assessment.

The study provides evidence from a small-scale, single-case application. Further development and validation are required for the complete acquisition-to-configuration chain, assessment consistency, the knowledge framework, ontology and information exchange mechanisms. Cross-case applications and task-based evaluation in conservation management should examine applicability under different participant, resource and continuing update conditions.

Author Contributions: Conceptualisation, X.L.; methodology, X.L., F.C. and M.N.; software, X.L.; validation, X.L. and M.N.; formal analysis, X.L.; resources, X.L., F.C. and M.N.; data curation, X.L.; writing—original draft preparation, X.L.; writing—review and editing, F.C. and M.N.; visualisation, X.L.; supervision, F.C.; project administration, F.C. and M.N.; funding acquisition, F.C. All authors have read and agreed to the published version of the manuscript.

Funding: This project is funded by the European Union under the Horizon Europe research and innovation programme, HORIZON-CL2-2023-HERITAGE-ECCCH-01 (A European Collaborative Cloud for Cultural Heritage—2023), under Grant Agreement No. 101158081, HERITALISE.

Data Availability Statement: Project-specific HBIM, survey, archival, and heritage datasets are subject to the data management and access conditions of the HERITALISE project and the Consorzio delle Residenze Reali Sabaude.

Acknowledgments: The authors gratefully acknowledge the staff of Consorzio delle Residenze Reali Sabaude (CRRS) for providing access to documentation and datasets, supporting survey activities, and assisting during on-site work.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AIR	Asset Information Requirement
BEP	BIM Execution Plan
BIM	Building Information Modelling
CDE	Common Data Environment
CRRS	Consorzio delle Residenze Reali Sabaude
CSV	Comma-Separated Value
ECCCH	European Collaborative Cloud for Cultural Heritage
EIR	Exchange Information Requirement
GIS	Geographic Information System
HBIM	Historic Building Information Modelling
IDS	Information Delivery Specification
IFC	Industry Foundation Classes
JSON	JavaScript Object Notation
LOD	Level of Development
LOG	Level of Geometry
LOI	Level of Information
LoIN	Level of Information Need
OIR	Organisational Information Requirement
PIR	Project Information Requirement
PPC	Preventive and Planned Conservation
QA	Quality Assurance
SLAM	Simultaneous Localisation and Mapping
UAV	Unmanned Aerial Vehicle

References

1. Della Torre, S. Italian Perspective on the Planned Preventive Conservation of Architectural Heritage. *Front. Archit. Res.* **2021**, *10*, 108–116. [CrossRef]
2. Vandesande, A.; Van Balen, K.; Della Torre, S.; Cardoso, F. Preventive and Planned Conservation as a New Management Approach for Built Heritage: From a Physical Health Check to Empowering Communities and Activating (Lost) Traditions for Local Sustainable Development. *J. Cult. Herit. Manag. Sustain. Dev.* **2018**, *8*, 78–81. [CrossRef]
3. *EN 16096:2012*; Conservation of Cultural Property—Condition Survey and Report of Built Cultural Heritage. European Committee for Standardization: Brussels, Belgium, 2012.
4. Masciotta, M.G.; Morais, M.J.; Ramos, L.F.; Oliveira, D.V.; Sánchez-Aparicio, L.J.; González-Aguilera, D. A Digital-Based Integrated Methodology for the Preventive Conservation of Cultural Heritage: The Experience of HeritageCare Project. *Int. J. Archit. Herit.* **2021**, *15*, 844–863. [CrossRef]
5. Italian Republic. Decreto Legislativo 22 Gennaio 2004, n. 42—Codice dei Beni Culturali e del Paesaggio. *Gazzetta Ufficiale della Repubblica Italiana*. 24 February 2004. No. 45, Supplemento Ordinario No. 28, Art. 29, para. 1. p. 21. Available online: https://www.gazzettaufficiale.it/eli/gu/2004/02/24/45/so/28/sg/pdf (accessed on 10 October 2026).
6. *UNI EN 16853:2026*; Conservation of Cultural Heritage—Conservation Process—Decision Making, Planning, Implementation and Documentation. Ente Italiano di Normazione: Milan, Italy, 2026. Available online: https://store.uni.com/uni-en-16853-2026 (accessed on 10 October 2026).
7. Jouan, P.; Hallot, P. Digital Twin: Research Framework to Support Preventive Conservation Policies. *ISPRS Int. J. Geo-Inf.* **2020**, *9*, 228. [CrossRef]
8. Fai, S.; Rafeiro, J. Establishing an Appropriate Level of Detail (LoD) for a Building Information Model (BIM)—West Block, Parliament Hill, Ottawa, Canada. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2014**, *II-5*, 123–130. [CrossRef]
9. Nadkarni, R.R.; Puthuvayi, B. A Comprehensive Literature Review of Multi-Criteria Decision Making Methods in Heritage Buildings. *J. Build. Eng.* **2020**, *32*, 101814. [CrossRef]
10. Aas, C.; Ladkin, A.; Fletcher, J. Stakeholder Collaboration and Heritage Management. *Ann. Tour. Res.* **2005**, *32*, 28–48. [CrossRef]
11. Henderson, J.; Nakamoto, T. Dialogue in Conservation Decision-Making. *Stud. Conserv.* **2016**, *61*, 67–78. [CrossRef]
12. Chen, D.; Li, J. Process-Led Value Elicitation within Built Heritage Management: A Systematic Literature Review between 2010 and 2020. *J. Archit. Conserv.* **2021**, *27*, 1–16. [CrossRef]
13. Murphy, M.; McGovern, E.; Pavia, S. Historic Building Information Modelling (HBIM). *Struct. Surv.* **2009**, *27*, 311–327. [CrossRef]
14. Dore, C.; Murphy, M. Current State of the Art Historic Building Information Modelling. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2017**, *XLII-2/W5*, 185–192. [CrossRef]
15. Bruno, N.; Roncella, R. HBIM for Conservation: A New Proposal for Information Modeling. *Remote Sens.* **2019**, *11*, 1751. [CrossRef]
16. Lovell, L.J.; Davies, R.J.; Hunt, D.V.L. The Application of Historic Building Information Modelling (HBIM) to Cultural Heritage: A Review. *Heritage* **2023**, *6*, 6691–6717. [CrossRef]
17. Parente, M.; Bruno, N.; Ottoni, F. HBIM and Information Management for Knowledge and Conservation of Architectural Heritage: A Review. *Heritage* **2025**, *8*, 306. [CrossRef]
18. Penjor, T.; Banihashemi, S.; Hajirasouli, A.; Golzad, H. Heritage Building Information Modeling (HBIM) for Heritage Conservation: Framework of Challenges, Gaps, and Existing Limitations of HBIM. *Digit. Appl. Archaeol. Cult. Herit.* **2024**, *35*, e00366. [CrossRef]
19. Ewart, I.J.; Zuecco, V. Heritage Building Information Modelling (HBIM): A Review of Published Case Studies. In *Advances in Informatics and Computing in Civil and Construction Engineering*; Mutis, I., Hartmann, T., Eds.; Springer: Cham, Switzerland, 2019; pp. 35–41. [CrossRef]
20. *ISO 19650-1:2018*; Organization and Digitization of Information about Buildings and Civil Engineering Works, Including Building Information Modelling (BIM)—Information Management Using Building Information Modelling—Part 1: Concepts and Principles. International Organization for Standardization: Geneva, Switzerland, 2018.
21. *ISO 7817-1:2024*; Building Information Modelling—Level of Information Need—Part 1: Concepts and Principles. International Organization for Standardization: Geneva, Switzerland, 2024.
22. buildingSMART International. Information Delivery Specification (IDS) 1.0. 2024. Available online: https://www.buildingsmart.org/standards/bsi-standards/information-delivery-specification-ids/ (accessed on 3 October 2026).
23. Jouan, P.; Hallot, P. Digital Twin: A HBIM-Based Methodology to Support Preventive Conservation of Historic Assets through Heritage Significance Awareness. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2019**, *XLII-2/W15*, 609–615. [CrossRef]
24. Vuoto, A.; Funari, M.F.; Lourenço, P.B. Shaping Digital Twin Concept for Built Cultural Heritage Conservation: A Systematic Literature Review. *Int. J. Archit. Herit.* **2024**, *18*, 1762–1795. [CrossRef]
25. Dang, X.; Liu, W.; Hong, Q.; Wang, Y.; Chen, X. Digital Twin Applications on Cultural World Heritage Sites in China: A State-of-the-Art Overview. *J. Cult. Herit.* **2023**, *64*, 228–243. [CrossRef]
26. HERITALISE. Heritage Buildings and Objects Digitisation & Visualisation Within the Cloud. Horizon Europe Project. Available online: https://heritalise-eccch.eu/ (accessed on 3 October 2026).

27. Martino, A.; Tanduo, B.; Borgogno, E.; Chiabrando, F. Integrated Survey for Heritage Digitisation: The Case Study of Venaria Reale within HERITALISE Project. In *Digital Heritage 2025*; Campana, S., Ferdani, D., Graf, H., Guidi, G., Hegarty, Z., Pescarin, S., Remondino, F., Eds.; The Eurographics Association: Goslar, Germany, 2025. [CrossRef]
28. UNESCO World Heritage Centre. Residences of the Royal House of Savoy. World Heritage List, Property No. 823bis. Available online: https://whc.unesco.org/en/list/823/ (accessed on 10 October 2026).
29. La Venaria Reale. The Great Gallery. Consorzio Delle Residenze Reali Sabaude. Available online: https://lavenaria.it/en/explore-the-venaria-reale/the-masterpieces/the-great-gallery/ (accessed on 10 October 2026).
30. Li, X.; Chiabrando, F. HBIM of the Galleria Grande in the Reggia di Venaria Reale: A Scan-to-BIM Workflow towards Digital Twin Integration. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2026**, *XLIX-B4-2026*, 249–256. [CrossRef]
31. Ceresa, C.; Mosca, V.; Serratrice, G.; Siccardi, D. Guarini Archivi, un Software per l'Ordinamento e per la Valorizzazione degli Archivi Piemontesi. *Arch. Comput.* **2002**, *12*, 71–84.
32. Della Torre, S. *La Conservazione Programmata del Patrimonio Storico Architettonico: Linee Guida per il Piano di Conservazione e Consuntivo Scientifico*; Guerini: Milano, Italy, 2003.
33. Della Torre, S.; Pili, A. Built Heritage Information Modelling/Management. Research Perspectives. In *Digital Transformation of the Design, Construction and Management Processes of the Built Environment*; Daniotti, B., Gianinetto, M., Della Torre, S., Eds.; Springer: Cham, Switzerland, 2020; pp. 231–241. [CrossRef]
34. Historic England. *BIM for Heritage Technical Guidance—Organisational Information Requirements Template*; Historic England: Swindon, UK, 2019.
35. Historic England. *BIM for Heritage Technical Guidance—Asset Information Requirements Template*; Historic England: Swindon, UK, 2019.
36. Historic England. *BIM for Heritage Technical Guidance—Exchange Information Requirements Template*; Historic England: Swindon, UK, 2019.
37. Centre for Digital Built Britain. *BIM Toolkit: Project Information Requirements (PIR) Guidance*; CDBB, University of Cambridge: Cambridge, UK, 2021.
38. UK BIM Framework. *Guidance Part D: Developing Information Requirements*, 2nd ed.; UK BIM Framework: London, UK, 2021.
39. buildingSMART International. Industry Foundation Classes (IFC). Available online: https://www.buildingsmart.org/standards/bsi-standards/industry-foundation-classes/ (accessed on 10 October 2026).
40. UK BIM Framework. *Guidance Part C: Facilitating the Common Data Environment (Workflow and Technical Solutions)*, 1st ed.; UK BIM Framework: London, UK, 2020. Available online: https://ukbimframework.org/wp-content/uploads/2020/09/Guidance-Part-C_Facilitating-the-common-data-environment-workflow-and-technical-solutions_Edition-1.pdf (accessed on 10 October 2026).

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.