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An Interoperable HBIM-Based Information System for Constructive Characterization and Condition Assessment of Residential Built Heritage

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Abstract

The documentation and condition assessment of residential built heritage are often hindered by fragmented records, limited object–data traceability, and weak interoperability between modelling, inspection, database, and analytical environments. This study develops and functionally evaluates an interoperable HBIM-based workflow for constructive characterization and condition-data management. The workflow integrates ARCHICAD, IFC exchange, BIMvision, the BimOndare plug-in, SQLite, and Power BI. It was tested through a pilot demonstrator based on a real multi-storey residential building in San Sebastián, Spain, whose structural configurations and material assignments were deliberately extended to represent reinforced-concrete, steel, timber, and masonry systems. The IFC GlobalId served as the relational key between modelled components and externally stored records. The demonstrator comprised 1281 IFC elements, 183 inspection records, and 354 photographs. Object–data correspondence was additionally verified on 12 structural components with multiple associated records. The implementation demonstrated functional interoperability across the tested environments and supported component-level consultation and building-level filtering by element type, material, location, inspection information, and intervention-related attributes. The study demonstrates the technical feasibility of the proposed information architecture, while longitudinal persistence, model versioning, full-building diagnostic interpretation, usability, and comparative performance require further validation.

Keywords: HBIM; residential built heritage; constructive characterization; condition assessment; IFC; interoperability; relational database; object–data traceability; information management

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1. Introduction

Historic Building Information Modelling (HBIM) has progressively evolved from geometry-centred digital reconstruction towards the structured management of historical,

constructive, diagnostic, and conservation-related information. Recent reviews nevertheless continue to identify limitations concerning semantic enrichment, interoperability, information updating, heterogeneous data integration, and accessibility for different professional users [1–6]. These limitations are particularly relevant to condition assessment, where observations, measurements, photographs, diagnostic tests, and intervention records must remain explicitly associated with identifiable building components while accommodating information generated by different specialists and at different stages of investigation.

Several HBIM studies have addressed this challenge from the perspective of inspection and diagnostic information. Han et al. [7] developed HBIM-based workflows for condition-inspection documentation in which building components, defects, photographs, and thematic outputs were organized through Revit, A360, and external tabular resources. Bruno and Fatiguso [8] incorporated diagnostic information derived from visual surveys and non-destructive tests as structured parameters associated with BIM objects. More recently, Chelaru et al. [9] integrated geometric, historical, and condition-assessment information into HBIM and used object parameters, schedules, and graphical filters to represent deterioration. Martinelli et al. [10] emphasized that the breakdown of historic buildings into separately modelled construction elements should be defined according to model use and information requirements rather than through a uniform level of geometric detail. These studies demonstrate that component-level condition documentation and material-specific information structuring are established HBIM research concerns.

The use of external information repositories is likewise not new. Bruno and Roncella [11] proposed an HBIM system in which a specifically designed relational database was linked to model components through unique identifiers and accessed through both a BIM plug-in and a web interface. Cursi et al. [12], in a review dedicated to the linkage of external knowledge to HBIM, identified relational databases as a recurrent strategy for extending the information-management capabilities of BIM authoring environments and distinguished relational and ontological approaches to semantic enrichment. Khan et al. [13] also used IFC-compatible object identifiers and external information resources to support heritage management and information retrieval. Consequently, neither external database storage nor object-level linkage alone constitutes a novel contribution; rather, research needs to clarify the information requirements, domain-specific workflows, interoperability mechanisms, and operational purposes for which these architectures are implemented.

Previous research has also addressed temporal information and analytical or monitoring environments. Mol et al. [14] implemented repeated HBIM-based assessments of historic timber components at different time stages, enabling direct comparison of geometric changes, non-destructive test results, photographs, and decay conditions. Their work constitutes an example of empirically demonstrated longitudinal condition tracking rather than merely a database structure capable of storing successive records. Martinelli et al. [15] subsequently developed an open HBIM-IoT platform based on IFC, external data management, and web visualization for static and dynamic monitoring information, while Vignali et al. [16] implemented interactive visualization and analytical tools for the long-term structural monitoring system of the Piazza del Duomo in Pisa. Recent interoperable frameworks have further combined IFC-based HBIM with external asset-management databases and visualization environments [17], and HBIM-based maintenance protocols have been proposed for structuring inspection and maintenance information over the operational life of historic buildings [18].

Within this broader body of work, comparatively less attention has been directed towards practical information systems for the constructive characterization and condition assessment of ordinary, non-listed residential built heritage. Such buildings may combine heterogeneous structural systems and materials while being characterized by fragmented

documentation, limited resources, successive alterations, and professional workflows that differ substantially from those available for major monuments or institutionally managed heritage sites [1,4,6]. The earlier development of BIMOndare addressed this context through its application to the Garai Urtuena farmhouse, integrating multidisciplinary heritage assessment, constructive condition, and preliminary intervention criteria at component level [19]. The subsequent development of the tool extended these principles to structured characterization protocols for reinforced concrete, steel, timber, and masonry systems and to interoperability with external data-management environments [20].

The present study therefore focuses not on introducing external databases, IFC-based object identifiers, or analytical visualization as independent innovations, but on their specific integration within a controlled workflow for residential built heritage. The framework uses IFC as the vendor-neutral exchange layer [21], BIMvision and BIMOndare for component selection and material- and element-specific information capture, SQLite for external relational storage, and Power BI for building-level and component-level consultation. The pilot demonstrator is derived from the geometry of a real non-listed residential building, while selected structural configurations and material assignments were deliberately modified to test the capability of the workflow to accommodate heterogeneous construction systems. Accordingly, the study evaluates the functionality of the information architecture rather than claiming to provide a complete diagnostic characterization of the physical building.

The main contribution of this study is the implementation and functional evaluation of an object-centred HBIM workflow tailored to residential built heritage that combines material- and element-specific constructive characterization protocols, IFC-based object traceability, external relational storage, and dual-scale analytical consultation while maintaining dynamic inspection information outside the authoring model.

The study addresses the following research questions:

RQ1. To what extent can the proposed IFC-based workflow maintain retrievable object–data correspondence between HBIM components and externally stored technical, photographic, and inspection records across the authoring, visualization, database, and analytical environments?

RQ2. How can material- and element-specific constructive characterization and condition-assessment information be structured outside the geometric HBIM model while remaining associated with individually identifiable building components?

RQ3. What object-level and building-level consultation capabilities can be generated from the resulting relational dataset, and what limitations remain regarding longitudinal persistence, model versioning, and full-building diagnostic interpretation?

These research questions deliberately distinguish between functionality demonstrated in the present pilot and capabilities that the architecture is designed to support but that require further empirical validation. In particular, the present study does not claim to demonstrate long-term condition evolution through a complete series of repeated inspection campaigns, nor does it quantify efficiency relative to conventional inspection methods. Instead, it examines technical interoperability, object-level traceability, structured information management, and analytical consultation under controlled implementation conditions.

2. Materials and Methods

2.1. Research Design

This study followed an applied methodological research design aimed at developing and functionally evaluating an interoperable HBIM-based information workflow for the constructive characterization and condition-data management of residential built heritage. The research design was structured to address the three research questions

formulated in Section 1 through the implementation and verification of a complete information-management workflow.

The methodology comprised five consecutive stages: (1) documentary review, geometric information processing, and HBIM; (2) IFC-based model exchange; (3) object-based technical data capture through BIMvision and BimOndare; (4) structured storage in an external SQLite relational database; and (5) component-level and building-level consultation through Power BI. The architecture followed an object-centred relational approach in which technical, photographic, and inspection records were stored externally and associated with individually identifiable IFC components through their GlobalId.

The validation focused on technical interoperability, object–data traceability, information coverage, operational execution, and analytical consultation. The study was not designed as a complete diagnostic survey of the physical building, a longitudinal deterioration study, or a controlled comparison with conventional inspection procedures. These distinctions were established to separate the functionality demonstrated by the pilot from capabilities that require further empirical validation.

2.2. Pilot Case Study

The proposed workflow was implemented and functionally validated through a pilot demonstrator based on the HBIM model of a multi-storey residential building located in San Sebastián, in the Basque Country, northern Spain, and constructed during the first half of the twentieth century. Although the property is not formally listed, it represents a locally relevant residential typology characterised by perimeter stone masonry walls and a timber-framed load-bearing system. The base model comprised six spatial levels: a ground floor, four upper floors, and an under-roof level.

To broaden the range of construction systems represented in the functional validation, the digital demonstrator was deliberately modified beyond the material and structural configuration of the physical building. While the geometry, spatial organization, and residential configuration of the actual building were retained, selected structural elements and material assignments were adapted to incorporate reinforced-concrete, steel, timber, and masonry solutions representative of the characterization protocols implemented in BimOndare. The resulting model therefore constituted a controlled demonstrator intended to test heterogeneous combinations of structural element type and material within the same workflow.

This distinction is methodologically important: the inspection records included in the demonstrator should not be interpreted as a complete condition survey or diagnostic characterization of the physical building. The original building consists primarily of stone masonry perimeter walls and a timber structural system. Condition records relating to timber and stone masonry were derived from observations of the case-study building, whereas representative deterioration records for reinforced-concrete and steel components were drawn from other buildings and incorporated into the demonstrator for methodological testing. The pilot was therefore designed to evaluate whether the proposed information architecture could accommodate heterogeneous material- and element-specific records, maintain their association with model objects, and transfer the resulting information across the different software environments.

2.3. HBIM-Based Information Workflow

2.3.1. Stage 1: Documentary Review, Geometric Information Processing, and HBIM

The modelling stage began with the review of the available documentary and geometric information concerning the building. The HBIM demonstrator was developed in ARCHICAD 22, maintaining the geometry and spatial organization of the physical resi-

dential building while incorporating the additional structural and material configurations required for functional testing.

All structural components relevant to the functional demonstrator were modelled at LOD 300. This level was selected to provide sufficient geometric and object-level definition for the independent identification, selection, and association of technical records with beams, columns, walls, floors, roof components, and other structural entities. The pilot residential building and its corresponding HBIM representation are shown in Figure 1.



(**a**) (**b**)

Figure 1. Pilot residential building used as the basis of the functional demonstrator: (**a**) photograph of the existing building in San Sebastián, taken on 10 September 2022; (**b**) clean three-dimensional HBIM representation used in the proposed workflow, corresponding to the building condition documented on 10 September 2022.

The model used ARCHICAD Classification 21 as its classification system. Each inspectable component was represented as an individually selectable model object and categorized according to its construction-element type, including wall, beam, column, floor, and roof elements. This segmentation originated in the ARCHICAD object structure and was maintained after IFC export and import into BIMvision. Within BimOndare, element type was subsequently combined with material classification so that the applicable technical and diagnostic fields could be activated according to each element–material combination.

For the purposes of this study, an "inspectable component" therefore refers to an individually modelled and uniquely identifiable building element that can be selected independently in the visualization environment and associated with its own technical, photographic, or inspection records. This object-based segmentation was necessary because information was linked to discrete model entities rather than to general drawings or undifferentiated building areas.

2.3.2. Stage 2: IFC Export and Interoperable Model Exchange

The HBIM model was exported from ARCHICAD 22 using the IFC2x3 schema and the Coordination View 2.0 Model View Definition (MVD). This combination was selected because it provided stable interoperability with BIMvision v2.27.7 within the software configuration tested in the project. The export transferred the modelled components together with their geometry, material information, element type, project-assigned identifier, and IFC GlobalId.

The IFC GlobalId was used as the operational relational key for associating each model object with its externally stored records. After export, the IFC model was imported into BIMvision and reviewed to verify the accessibility of individual components, their element classification and attributes, and the availability of their GlobalIds for subsequent data association. The IFC layer therefore acted as the vendor-neutral exchange mechanism between the HBIM authoring environment and the downstream inspection workflow.

The present implementation did not include a systematic test of GlobalId persistence after substantial deletion, remodelling, or recreation of objects in successive HBIM versions. Consequently, long-term identifier persistence across model revisions is not assumed to have been validated and is addressed separately as a model-governance requirement.

2.3.3. Stage 3: Object-Based Inspection and Semantic Enrichment

After IFC import, BIMvision provided the visualization and object-selection environment, while BimOndare acted as the dedicated technical data-entry and consultation layer. The plug-in identifies the selected IFC component and, according to its element type and material, presents the corresponding set of characterization and condition-assessment fields. Users can enter or consult technical parameters, measurements, observations, photographs, and linked documentary records associated with that individual component.

The software responsibilities within the workflow were therefore differentiated. ARCHICAD 22 generated the HBIM model and exported geometry, material, element type, project identifier, and GlobalId; BIMvision provided IFC visualization and object selection; BimOndare controlled the material- and element-specific data-entry structure and generated the associated records; DB Browser for SQLite v3.12.2 stored the resulting structured information and links to photographs or documents; and Power BI subsequently combined the IFC representation and database information for analytical consultation.

The information fields implemented in BimOndare were differentiated according to the principal material families considered in the project: reinforced concrete, steel, timber, and masonry. Table 1 summarizes the main categories supported by the system. These fields represent the information capacity of the workflow and should not be interpreted as tests or measurements systematically performed on every component of the physical building. During the pilot, fields were populated selectively to verify the functionality of different element–material combinations; most photographic evidence corresponded to the real building, whereas the technical dataset was not intended to constitute a complete diagnostic survey.

Table 1. Material-specific inspection and diagnostic information fields supported by the BimOndare workflow.

Material System	Principal Variables and Records
Reinforced concrete	Cracking, spalling, exposed or corroded reinforcement, moisture, deformation, carbonation depth, chloride content, reinforcement detection, core testing, and ultrasonic measurements
Steel	Corrosion, residual section, coating deterioration, condition of joints and fasteners, missing connection elements, cracking in welds, and local or global deformation
Timber	Moisture, fungal or insect attack, cracking, section loss, deformation, visual grading, resistographic testing, and mechanical-wave propagation measurements
Masonry	Cracking, out-of-plumb displacement, moisture, erosion or disaggregation, condition and thickness of joints, unit dimensions, wall thickness, and material consistency

The forms also supported the attachment of photographic evidence, free-text observations, dates and times of inspection, measurement units, and external files such as technical reports or laboratory results. This structure made it possible to preserve both qualitative expert observations and quantitative diagnostic data without incorporating all dynamic information directly into the geometric model.

The information model was also configured to support transversal querying according to storey, spatial zone, material, construction system, deterioration type, or inspection date. In the present pilot, this functionality was evaluated as an information-consultation capability rather than as a means of deriving validated deterioration patterns from the physical building.

2.3.4. Stage 4: Relational Database Structure

The information entered through BimOndare was stored in an SQLite relational database. SQLite was selected because of its portability, limited implementation requirements, low deployment cost, and compatibility with external database-management and analytical applications.

The database schema was organized around interrelated tables containing information on:

- The building asset;
- Spatial organization and storeys;
- IFC building components;
- Inspection events;
- Observed deterioration;
- Geometric and technical measurements;
- Material-specific diagnostic tests;
- Photographic and documentary evidence;
- Participating users or inspectors.

The GlobalId of each IFC entity was used to associate the database records with the corresponding geometric object. This arrangement separated the dynamic inspection information from the HBIM authoring file while preserving the connection between both environments.

The relational schema followed a one-to-many structure that allowed several dated records, photographs, measurements, or documentary entries to be associated with the same IFC component without overwriting previously stored information. During the pilot, multiple records and photographs were entered for selected components at different dates to verify this functionality. However, these records did not constitute a controlled longitudinal campaign designed to measure actual deterioration progression over time. The implementation therefore demonstrates the capability of the database structure to accommodate successive records, rather than empirical validation of long-term condition evolution.

To prevent database inconsistencies, simultaneous editing through BIMvision–BimOndare and an external SQLite database editor was avoided. The procedural documentation specifies that the database may remain locked while it is being accessed through the plug-in; therefore, editing and verification operations were performed sequentially.

2.3.5. Stage 5: Data Visualization and Analytical Dashboards

The structured SQLite records were connected to Power BI together with the IFC model and the directory containing the associated photographs and technical documents. Power BI was used as the commercial visualization environment; the contribution developed specifically for this research consisted of configuring the data relationships, filters, and

two automated consultation interfaces required to interrogate the information generated through BimOndare.

The first interface provides a building-level view of the demonstrator. It combines the three-dimensional model with summaries of recorded incidents and allows the dataset to be filtered according to attributes such as element type, material, urgency, intervention status, and other available record fields. The interface also provides aggregated counts and supports the identification of components for which incidents or subsequent actions have been registered (see Figure 2).



Figure 2. Building-level Power BI interface developed for the pilot demonstrator, integrating the IFC model with aggregated incident information and filtering options.

The second interface provides an object-level technical view. When an individual component is selected, the interface consolidates its identification data, photograph, geometric observations, technical measurements, specialist notes, tests, and linked documentary evidence within a single screen (see Figure 3).

These interfaces were developed to test whether information initially entered at component level could be reorganized and consulted at different scales. They were not used in the present study to derive a validated deterioration pattern for the physical building, because the demonstrator dataset was not generated through a complete diagnostic campaign. Accordingly, the analytical layer is evaluated here in terms of data integration, filtering, aggregation, and consultation functionality rather than as evidence of new building-pathology knowledge.

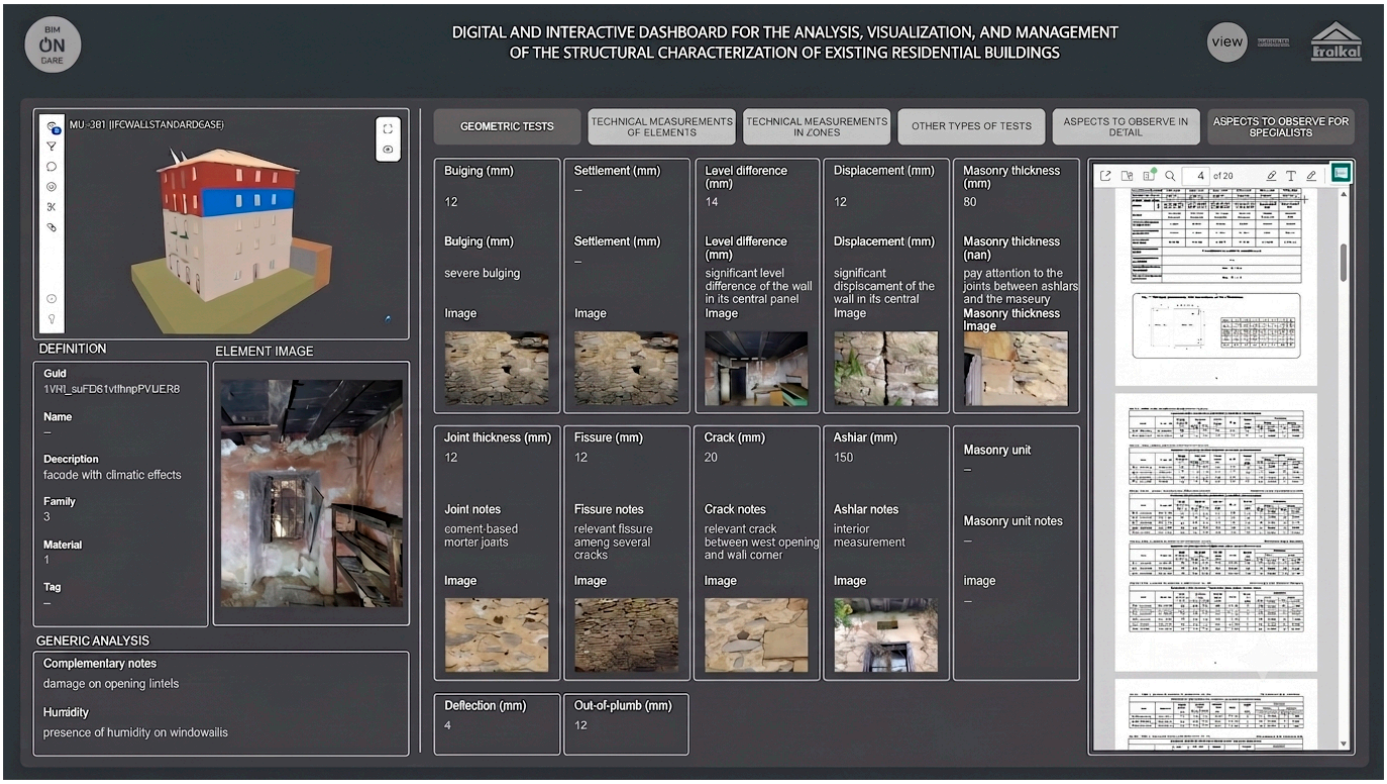


Figure 3. Object-level Power BI technical record integrating the selected IFC component with photographic evidence, measurements, observations, tests, and linked documentation.

2.4. Functional Validation Strategy

The proposed workflow was evaluated through technical and operational verification of the complete information chain, from the HBIM authoring environment to the final consultation interfaces. The purpose of the validation was to determine whether the architecture performed the functions for which it had been configured, rather than to compare predictive algorithms, quantify diagnostic accuracy, or evaluate statistically representative user performance.

Five validation dimensions were considered: interoperability, object–data traceability, information coverage, operational execution, and analytical consultation (see Table 2). Interoperability was assessed by verifying the transfer and accessibility of the model and its relevant object information across ARCHICAD, IFC2x3, BIMvision, BIMOndare, SQLite, and Power BI.

Table 2. Functional validation dimensions and verification criteria.

Validation Dimension	Aspect Assessed	Verification Criterion
Interoperability	Transfer between ARCHICAD, IFC2x3, BIMvision, BimOndare, SQLite, and Power BI	Model and relevant object information remain accessible throughout the tested workflow
Object–data traceability	Correspondence between IFC components and external records	Project ID and GUID exported from ARCHICAD correspond to the records retrieved from SQLite for the 12 sampled structural components
Information coverage	Capacity to accommodate material- and element-specific information	Supported fields cover the characterization and condition categories defined for reinforced concrete, steel, timber, and masonry

Table 2. *Cont.*

Validation Dimension	Aspect Assessed	Verification Criterion
Operational execution	Practical object selection, data entry, storage, and retrieval	Technical users can create, associate, store, and subsequently consult records within the implemented workflow
Analytical consultation	Transformation of relational data into component- and building-level views	Database information can populate the two Power BI interfaces and be filtered and aggregated using the configured attributes

Object–data traceability was additionally checked through an internal verification procedure. A CSV file containing the project-assigned identifiers and corresponding IFC GUIDs of the structural elements was exported from ARCHICAD. Twelve structural components, each associated with several records of different types, were selected for cross-checking against the SQLite database. The verification confirmed that the records retrieved from the database corresponded to the intended model components in the tested sample. This procedure evaluated object–record correspondence within the implemented workflow; it did not constitute a stress test of all 1281 IFC elements or a version-control test involving deletion and recreation of model objects.

Information coverage was evaluated by verifying that the BimOndare forms could accommodate the element- and material-specific categories defined for reinforced concrete, steel, timber, and masonry. Operational execution was assessed exploratorily by the technical team during object selection, data entry, photograph and document association, record storage, and subsequent consultation. No standardized usability questionnaire, independent user sample, or controlled task protocol was employed.

Analytical consultation was evaluated by verifying that the relational dataset could populate both building-level and object-level Power BI interfaces and support filtering, aggregation, and retrieval of the information entered during the pilot. No information-retrieval time, record-creation time, error-rate comparison, or diagnostic-performance comparison with conventional documentation was measured.

3. Results and Discussion

3.1. Technical and Operational Validation of the Workflow

The pilot implementation confirmed that the complete information workflow could be executed across the tested software environments. The sequence from ARCHICAD 22 through IFC2x3, BIMvision–BimOndare, SQLite, and Power BI was completed while maintaining access to the model objects and their associated information within the implemented configuration. The result therefore demonstrates functional interoperability of the tested workflow rather than universal interoperability across alternative software versions, IFC schemas, or model configurations.

The HBIM model provided the object structure required to treat walls, columns, beams, floors, roof components, and other structural elements as individually selectable information units. After IFC export, the project-assigned identifiers and IFC GlobalIds remained available in BIMvision and could be used to establish correspondence with the records generated through BimOndare and stored in SQLite.

The additional traceability verification described in Section 2.4 was performed on 12 structural components, each containing multiple records of different types. Cross-checking the project-assigned identifier and IFC GUID exported from ARCHICAD against the corresponding SQLite entries confirmed the expected object–record correspondence for all 12 sampled components. This result provides direct evidence of traceability within the

tested sample, but it should not be interpreted as a stress test of the complete population of 1281 IFC elements or as evidence of identifier persistence after substantial model revision.

The quantitative outputs in Table 3 describe the scale of the implemented demonstrator rather than the condition of the physical building. The 183 records and 354 photographs show that the architecture could accommodate a non-trivial set of heterogeneous information associated with model components. However, because the demonstrator combined condition records from the original timber and stone-masonry systems of the case-study building with representative reinforced-concrete and steel deterioration records obtained from other buildings for methodological testing, the 183 records should not be interpreted statistically as a deterioration survey of the actual residential building.

Table 3. Quantitative outputs and traceability-verification scope of the pilot demonstrator.

Metric	Value
IFC elements available for information association	1281
Inspection/technical records populated in the demonstrator	183
Photographs associated with records	354
Structural components cross-checked for object–data traceability	12

No measurements of data-entry time, information-retrieval time, error frequency, or diagnostic accuracy relative to conventional documentation were collected. Accordingly, the results support technical feasibility and sampled object–data correspondence, but they do not demonstrate superior efficiency, accuracy, or usability.

3.2. Object-Based Data Capture and Relational Database Integration

The implementation demonstrated that heterogeneous technical information could be converted into structured, queryable records associated with individually identifiable IFC components. The combination of BIMvision and BimOndare enabled the element type and material of the selected component to determine the relevant characterization fields, while SQLite stored the resulting technical parameters, observations, measurements, photographs, and documentary links outside the HBIM authoring file.

This material- and element-specific structure allowed reinforced-concrete, steel, timber, and masonry information to coexist within the same relational architecture. As described in Table 1, the system includes fields covering visual observations, geometric measurements, material deterioration, diagnostic tests, photographs, and complementary documentation. These categories represent the information supported by the workflow; their presence in the database schema does not mean that every corresponding test was physically performed during the pilot.

The external database also supported one-to-many relationships between a model component and its associated records. Several records, photographs, or observations with different dates could therefore be retained without overwriting previous entries. Selected components in the demonstrator contained records and photographs associated with different dates, confirming that the database structure can store successive entries for the same object. However, these entries were generated to verify system functionality and did not constitute a controlled longitudinal inspection campaign capable of quantifying deterioration progression.

This distinction is important when comparing the present study with genuinely longitudinal HBIM applications. Mol et al. [14], for example, compared historic timber elements investigated in 2014 and 2019 using repeated geometric surveys, photographs, and non-destructive testing, thereby demonstrating actual condition change across defined time stages. The present demonstrator establishes the information structure required to

retain successive records, but longitudinal condition tracking remains to be validated through repeated inspections of the same physical components under a controlled protocol.

3.3. Analytical Consultation at Building and Object Levels

The Power BI implementation demonstrated that the relational information generated through BimOndare could be reorganized and consulted at two complementary scales. The contribution of this stage did not consist of developing a new Business Intelligence algorithm or extending Power BI itself. Rather, the research configured the relationships between the IFC model, the SQLite dataset, and the associated photographic and documentary resources and developed two automated interfaces specifically for the proposed workflow.

At building level, the configured interface aggregated the populated records and enabled filtering according to available attributes such as structural element type, material, urgency, intervention status, and other record categories (Figure 2). This view demonstrated that information entered independently at component level could subsequently be aggregated and filtered without returning to individual inspection forms.

At object level, the second interface consolidated the selected component together with its identifying information, photograph, geometric observations, measurements, technical records, specialist notes, tests, and linked documents (Figure 3). The principal functional result was therefore the ability to move between an aggregated building view and a detailed component view while retaining the relationship with the same underlying dataset.

The present pilot did not provide a scientifically validated example of a deterioration mechanism discovered through transversal analysis. Because the dataset was configured primarily to test heterogeneous element–material combinations and workflow functionality, patterns such as repeated moisture paths, vertically aligned cracking, or material-specific deterioration concentrations cannot be interpreted as findings concerning the physical case-study building. The analytical contribution demonstrated here is therefore limited to information aggregation, filtering, navigation, and retrieval. A complete diagnostic campaign across one or more buildings is required before the analytical layer can be evaluated for its capacity to generate new knowledge about spatial or recurrent deterioration patterns.

This scope differs from monitoring-oriented HBIM environments such as the platform developed by Martinelli et al. [15], which integrates static HBIM information with dynamic IoT sensor data, and the interactive monitoring environment presented by Vignali et al. [16]. The current workflow is neither an IoT monitoring system nor a digital twin; its focus is the structured management and consultation of inspection and characterization records.

3.4. Positioning Against Previous HBIM and Document-Centred Information Practices

Document-centred and fragmented information-management practices have been reported in several heritage contexts, although their specific characteristics vary according to organization, project, and professional workflow. Han et al. [7] highlighted the difficulty of managing large quantities of multidisciplinary inspection information through predominantly two-dimensional documentation. Khan et al. [13] reported the use of 2D drawings and multiple information formats in an existing heritage-management context, where stakeholders identified difficulties in accessing, querying, retrieving, and updating information. More recently, Freire et al. [18] identified fragmented information storage, limited accessibility, and the absence of structured documentation within the maintenance practices examined in their case study. Table 4 therefore compares characteristics reported in these studies with functions demonstrated by the present workflow; it should not be interpreted as describing all conventional heritage-inspection practice.

Table 4. Literature-supported comparison between document-centred heritage information practices and the implemented HBIM-based workflow.

Information-Management Dimension	Document-Centred Practices Reported in the Literature [7,13,18]	Implemented HBIM-Based Workflow
Information organization	Technical information may remain distributed among drawings, reports, spreadsheets, photographs, and other files.	Technical and documentary records are structured in an external relational database.
Component reference	Observations may depend on drawings, written descriptions, labels, or separate documentary references.	Records are associated with individually selectable IFC components through object identifiers.
Information retrieval	Consultation may require navigation across separate files or formats.	Records can be filtered and retrieved through building-level and object-level interfaces.
Successive records	Records produced at different stages may require cross-referencing among separate documents.	Multiple dated records can be associated with the same database-linked component; longitudinal condition change was not validated in this pilot.
Photographic and documentary evidence	Images and reports may be maintained as separate documentary resources.	Photographs and documents can be linked to the corresponding technical record and component.
Updating	Changes may require updating multiple independent information sources.	Inspection records can be modified or added externally without modifying the principal HBIM geometry.
Interoperability	Exchange depends on the formats and applications used in the specific workflow.	IFC2x3 provides the open exchange layer between ARCHICAD and BIMvision; downstream consultation also depends on BimOndare, SQLite, and Power BI.

The proposed workflow should also be positioned within the relational approach to HBIM semantic enrichment described by Cursi et al. [12]. External relational databases linked to BIM objects are already well established in the literature, and Bruno and Roncella [11], among others, demonstrated object–database linkage through unique identifiers together with dedicated user interfaces. Consequently, the use of an external database or a unique object identifier is not claimed here as an independent innovation.

Likewise, the capability to retain records from different time stages has precedents in HBIM research [14], while monitoring and visualization platforms have incorporated static and dynamic information at building scale [15,16]. The specific contribution of the present implementation lies instead in combining these established concepts within a workflow tailored to ordinary residential built heritage, in which element type and material jointly determine structured constructive-characterization fields, dynamic records remain external to the authoring model, and the resulting information can be consulted through both component-level and building-level interfaces.

This positioning also clarifies the evolution of BimOndare. Its earlier application to the Garai Urtuena farmhouse focused on multidisciplinary heritage-value assessment and constructive diagnosis [19]. The present work does not claim the initial creation of BimOndare as its novelty; it evaluates an extended workflow linking the tool to IFC-based exchange, material-specific structural characterization, an external SQLite database, and downstream analytical consultation.

3.5. Limitations and Model-Governance Requirements

Several limitations define the scope within which the results should be interpreted. First, the study used a single controlled demonstrator. Although its geometry and spatial organization were derived from a real residential building, selected structural configurations and material assignments were deliberately modified to test the different element–material combinations supported by BimOndare. Accordingly, the condition dataset also combines observations from the original timber and stone-masonry systems of the case-study building with representative reinforced-concrete and steel deterioration records derived from other buildings to test the material-specific workflow. The populated dataset therefore cannot be interpreted as a complete diagnostic characterization of the physical building or generalized as evidence of deterioration patterns in residential heritage.

Second, the system was designed to accommodate successive inspection records, and multiple dated entries were incorporated for selected components, but no controlled longitudinal campaign was undertaken. Consequently, the study demonstrates the capacity to store successive information rather than long-term deterioration tracking or persistent technical memory validated over time.

Third, object–data correspondence was specifically cross-checked for 12 structural components with multiple associated records. Although all sampled cases produced the expected correspondence, this verification represents only a limited sample and not a stress test of all 1281 IFC objects. Furthermore, the study did not test the effect of repeatedly deleting, recreating, or substantially remodelling components across successive authoring-model versions.

Fourth, no controlled comparison with conventional documentation methods was conducted, and no standardized usability questionnaire, independent user group, task-completion protocol, retrieval-time measurement, record-creation-time measurement, or diagnostic-performance assessment was employed. Claims regarding efficiency, usability, error reduction, or improved diagnostic accuracy therefore remain outside the evidence provided by this study.

Fifth, the object–database relationship depends operationally on the IFC GlobalId. This dependency becomes critical when an authoring model is substantially revised, because deleting and recreating an element may generate a new GlobalId and disconnect the new model object from records associated with the previous identifier. The project-assigned element identifier used during the pilot provides a useful basis for introducing an additional persistent mapping mechanism, but systematic version reconciliation was not implemented or validated in the present study.

For future professional implementation, a model-governance protocol is therefore proposed. Each physical component should retain a project-defined persistent element identifier independent of the IFC GlobalId. At every approved model release, a versioned mapping table should be exported containing, at minimum, the persistent project identifier, current GlobalId, element type, storey or spatial location, model version, and export date. Unchanged components should retain the same persistent identifier across model versions; newly introduced physical components should receive new identifiers; and removed or replaced components should be retained in the historical mapping as inactive rather than overwritten. Before new inspection records are accepted following an IFC re-export, the current mapping should be reconciled against the previous version, with ambiguous or unmatched components subjected to manual review. The versioned IFC file, identifier-mapping table, SQLite backup, and model change log should then be archived together as one controlled information release.

This proposed protocol uses the same principle as the project-ID/GUID mapping employed during the internal verification of the pilot but extends it into a formal version-

control procedure. Its effectiveness across repeated model revisions remains to be tested empirically and is therefore proposed as a requirement for future validation rather than as a capability demonstrated in the present study.

Sixth, SQLite was suitable for the portable and relatively lightweight demonstrator, but larger inventories, simultaneous multiuser access, centralized institutional deployment, and web-based services may require a server-based database with more advanced access-control, synchronization, backup, and security mechanisms.

Finally, software openness and information-exchange openness should be distinguished. IFC2x3 provides the vendor-neutral exchange layer used in the proposed workflow, but not every software component is open source. BimOndare operates as a plug-in within the BIMvision environment and can be accessed through the BIMvision software ecosystem; however, its source code is not publicly released. Consequently, complete source-code-level reproduction of this specific implementation is not currently possible. To improve methodological transparency, the workflow procedure and the technical documentation describing the information structure, material-specific fields, database handling, and analytical consultation process are provided as Supplementary Materials. Future developments should further improve reproducibility through openly documented interfaces, APIs, or research-access mechanisms.

4. Conclusions

This study developed and functionally evaluated an interoperable, object-centred HBIM workflow for the constructive characterization and condition-data management of residential built heritage. The implemented architecture connected ARCHICAD 22, IFC2x3, BIMvision–BimOndare, an external SQLite relational database, and Power BI while maintaining the association between model components and their corresponding technical, photographic, and inspection records.

The pilot demonstrator comprised 1281 IFC elements, 183 populated technical or inspection records, and 354 associated photographs. Object–data correspondence was specifically cross-checked for 12 structural components containing multiple associated records, with the expected project identifier–GUID–database correspondence confirmed in all sampled cases. These results support the technical feasibility of the implemented information chain and demonstrate that heterogeneous material- and element-specific records can be stored externally to the authoring model while remaining retrievable through individually identifiable IFC components.

The workflow also demonstrated two complementary forms of information consultation. At component level, technical measurements, observations, photographs, tests, and documentary resources could be consolidated around a selected object. At building level, the populated dataset could be aggregated and filtered according to attributes such as element type, material, urgency, and intervention status. These results demonstrate information integration, filtering, and retrieval functionality; they do not demonstrate that the analytical layer identified validated deterioration patterns in the physical building, because the demonstrator was not produced through a complete diagnostic campaign.

The study further confirms the importance of distinguishing between a system capability and its longitudinal validation. The relational architecture can retain multiple dated records associated with the same component without overwriting previous entries, but the present research did not undertake repeated controlled inspections capable of demonstrating actual deterioration progression over time. Similarly, the GlobalId provided an effective relational key within the tested implementation, but its persistence after substantial model modification, deletion, or recreation of elements was not empirically validated.

A project-defined persistent identifier combined with versioned GlobalId mapping is therefore proposed as a model-governance requirement for future long-term implementations.

The contribution of the study lies in the specific integration of established HBIM, open-format exchange, relational data-management, and analytical-consultation concepts within a workflow tailored to ordinary residential built heritage and to heterogeneous reinforced-concrete, steel, timber, and masonry characterization requirements. The results should therefore be interpreted as a functional evaluation of the proposed information architecture rather than as a complete condition assessment of the case-study building, a longitudinal monitoring experiment, a formal usability evaluation, or a digital-twin implementation.

Future research should apply the workflow to complete characterization campaigns in multiple residential heritage buildings with different structural configurations and material systems; conduct repeated inspections of the same physical components; test identifier persistence and reconciliation across successive HBIM model versions; quantify data-entry, retrieval, and error rates relative to alternative documentation methods; and evaluate usability with independent professional users. Such studies will be necessary to determine whether the demonstrated information-management capabilities translate into measurable benefits for long-term conservation, maintenance, and rehabilitation practice.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/heritage9100404/s1, Supplementary File S1, an operational HBIM workflow manual illustrating IFC export, BIMvision–BimOndare data entry, SQLite database handling, and Power BI consultation; Supplementary File S2, technical documentation of the HBIM characterization tool, including the material-specific information structure, supported inspection and diagnostic fields, and data-management procedure.

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Data Availability Statement: The methodological and technical documentation supporting the information architecture developed in this study is provided in the Supplementary Materials. The complete inspection dataset, photographs, and condition-assessment records associated with the physical residential property are not publicly available because they contain building-specific information whose disclosure is restricted by confidentiality considerations. Selected non-sensitive information may be made available by the corresponding author upon reasonable request, subject to these restrictions.

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Abbreviations

The following abbreviations are used in this manuscript:

Abbreviation	Meaning
BIM	Building Information Modelling
HBIM	Historic/Heritage Building Information Modelling
IFC	Industry Foundation Classes
LOD	Level of Development
SQLite	Lightweight relational database management system
IoT	Internet of Things

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