

Article

From Executive Design to Heritage Site: Preliminary Development of an Application for Integrating Information on the State of Conservation Within an HBIM Model

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Abstract

In conservation work on historic built heritage, the transition from executive design to the worksite often requires the verification, integration and updating of information acquired during the design phase. This issue is particularly relevant for the documentation of the state of conservation since new accessibility conditions on site may allow previously unreadable areas to be observed and decay maps to be revised. This paper presents the preliminary development and testing of SMAT, an iPadOS application designed to support the in situ updating of decay maps and their reintegration within an HBIM workflow. The experimentation was carried out on the Oratory of San Giovanni Battista in Bussana Vecchia, starting from a previously developed HBIM model. The application allows operators to annotate decay phenomena on reference orthophotos using vector geometries, associate each annotation with semantic and temporal information, and store the data in JSON format. The workflow also includes a differential synchronization procedure based on Dynamo scripts, aimed at comparing successive annotation versions and updating the corresponding two-dimensional views in Autodesk Revit. The preliminary experimentation indicates the potential of the proposed procedure to support the traceable management of information updates between the design and worksite phases and to streamline the intermediate steps between direct observation, graphic restitution, and data reintegration, while maintaining an operational approach compatible with the requirements of the worksite phase in restoration processes.

Keywords: heritage site; decay mapping; HBIM; mobile application; semantic annotation



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1. Introduction

In conservation work on historic built heritage, the transition from design to execution is generally less linear than in new construction. In restoration, this transition does not simply correspond to the implementation of the project on site. The worksite becomes a phase for verifying and updating the knowledge framework, in which some information may be added, while data acquired during the preliminary phases may be refined, integrated or, in some cases, modified. This updating process is mainly related to the level of knowledge that can be achieved, or that has been achieved, during the design phase. It also depends on the complexity of the building, the accessibility limits of the asset, and the availability of economic, human and time resources. The preliminary investigation carried

out during the design phase is fundamental for defining the project. However, it may still include margins of uncertainty. A particularly relevant moment is the initial phase of the restoration site. The installation of temporary works allows the building to be observed from a new and improved perspective compared with that available during the cognitive and design phases. In this sense, the construction site can support a refinement of the knowledge of the asset.

The updated information may concern different aspects. It may involve geometric data, when the survey is corrected or integrated. It may also concern materials and the state of conservation, through the revision of material and decay maps, the identification of previously undetected phenomena, or a more precise definition of their spatial distribution. New archaeological and/or construction-related information may also emerge. This may occur, for example, through the interpretation of relationships between masonry structures, through the possibility of applying dating techniques, or because previously inaccessible points become accessible and hidden parts become visible. These updates may affect not only the level of knowledge of the asset, but also operational decisions. They may confirm or modify the solutions provided by the project. In terms of graphic documentation, this may lead to new intervention maps and/or new drawings documenting construction details. Site documentation therefore does not have only an administrative function. Especially in the case of historic sites, it becomes an integral part of the memory of the intervention and an important support for the management of the asset and for future interventions. For this reason, the information produced on site should be collected, organised, and structured in a coherent, manageable, and communicable way.

A further aspect concerns the plurality of actors involved in the heritage site. Designers, specialist technicians, work supervisors, officers of the Superintendency, restorers, contractors, and operators take part in the process with different skills, schedules, responsibilities and working methods. These actors do not always use the same operational tools or organise information according to the same procedures. For this reason, it is important to provide tools that support the sharing, updating, and validation of information through common references and structured data.

In recent years, Building Information Modeling (BIM), understood as a system for the structured management of different types of information within the design and execution process, has become increasingly widespread. This issue has become particularly relevant following the regulatory framework introduced by Legislative Decree 36/2023 [1]. Article 43 concerns the adoption, by contracting authorities and concession-granting bodies, of digital information management methods and tools for the design and construction of public works, according to the thresholds and conditions established by the regulation (Table 1).

Table 1. Summary of the economic thresholds for the mandatory adoption of BIM technology in public procurement (under Legislative Decree 36/2023 [1], as modified by Legislative Decree 209/2024 [2]).

Type of Intervention	Economic Threshold	Effective Date
New construction works	≥EUR 2,000,000.00	1 January 2025
Interventions on existing buildings	≥EUR 2,000,000.00	1 January 2025

While the application of Legislative Decree 36/2023 appears to be generally consolidated in the field of new construction, the transfer of BIM technology to the existing built heritage still presents several difficulties. When this application concerns heritage assets of historical value, it is referred to as Heritage BIM (HBIM). Historic buildings are characterized by irregular geometries and non-standardized elements, which are often difficult to relate to rigid categories of geometric modelling. Moreover, the available level

of knowledge is often insufficient to describe materials and construction elements. These conditions make the acquisition of the necessary information difficult and, at the same time, make it complex to associate information with the individual elements of the model. Although, in theory, HBIM allows the management of heterogeneous data, its operational application in the field of historic heritage remains complex, especially when information must be updated during the transition between the different phases of a project.

The research is positioned within the transition between the executive design phase and the worksite, with particular attention to the initial moment of verification and updating of information made possible by the new access conditions to the historic asset. The aim is to investigate how an HBIM model can support the collection, management and updating of information related to a historic asset during the first phase of the worksite, with reference to its state of conservation. The experimentation addresses the issue of integrating maps of decay phenomena into the information system, considering the limits related to their geometric modelling and the time required for semantic processing within BIM software. To address this issue, the research proposes the use of electronic devices that are now commonly available, such as tablets, for updating decay maps directly on site. This approach makes it possible to transform direct observation into structured data that can be updated and integrated into the BIM information model. Recording and modifying data directly at the place of observation is intended to limit intermediate steps, subsequent transcriptions, and the possible loss of information. At this stage of development, the application is designed to operate through graphic references already used in the documentation of the state of conservation, while organizing the annotations according to a common structure that can be transferred to the HBIM environment. In this way, the research investigates the potential of Smart Mapping and Annotation Tool—SMAT application to support information continuity among actors who may use different operational tools.

For its application to a real case study, the present research continues a previous experimentation carried out during the design phase of an actual restoration project. Starting from the HBIM model already developed, the study aims to extend the experimentation to the worksite phase, which had meanwhile begun. It therefore investigates the continuity of the information flow between design and execution and assesses the potential and limitations of the proposed prototype for updating and transferring data related to the state of conservation during the initial phase of the worksite.

2. State of the Art

HBIM extends BIM technology to the historical, material and conservation-related complexity of existing buildings [3]. The term was introduced to describe a process aimed at the construction of parametric models of architectural heritage, organized into mutually preparatory phases. The first phase concerns data acquisition and processing through range-based survey techniques, using Laser Scanner technology (tLS), and image-based techniques, through digital photogrammetry and Structure from Motion (SfM). The second phase consists of the construction of the digital model through parametric modelling, geometric reconstruction, and the definition of semantic libraries of historic architectural elements. The third phase involves the extraction of graphic and information outputs, according to progressively automated procedures, as well as the export of data to specific applications outside the BIM environment [4].

In recent years, the application of BIM to existing heritage has produced significant results, particularly through the integration of external tools for geometric modelling, including Non-Uniform Rational B-Splines (NURBS) and Scan-to-BIM procedures based on point cloud segmentation [5,6]. These tools make it possible to compensate for the limited geometric editing capabilities of some BIM software, to manage complex geometries more

efficiently, and to reduce processing times without compromising the level of geometric definition of the model. From a semantic-informational perspective, one of the main lines of development in HBIM research has concerned interoperable data management and the systematic structuring of data. This need stems from the requirement to organize heterogeneous information in a coherent way, including data related to geometry, materials, conservation, and diagnostics, often characterized by different formats.

For this reason, several researchers have addressed the progressive standardization of the HBIM process at the semantic-informational level, through the definition of specific protocols for data classification, organization, and structuring. The objective has been to reduce information redundancy and to support the sharing, updating and systematization of information within HBIM workflows [7,8].

In summary, HBIM represents a promising tool in several fields. However, some critical issues remain, one of which concerns the representation and management of the state of conservation of the built heritage. Some researchers systematically analyzed how different types of metadata, such as geometry, materials, decay, and environmental data, were integrated into the BIM environment through geometric models developed using different approaches, from manual to semi-automatic and automatic modelling. From these analyses, the modelling of decay phenomena emerges as one of the most complex aspects to develop and manage within the HBIM environment [9].

The literature has shown that the integration of decay-related information into the HBIM environment is still largely experimental. This integration is often based on the combination of BIM platforms and external tools, which are needed to achieve a more appropriate semantic structuring of data. In this context, the use of ontological schemas and open interoperability standards, such as IFC, has become increasingly relevant. These tools make it possible to organize, exchange and easily consult the information associated with a historic asset [10]. This is fundamental not only for more effective management of maintenance and conservation processes by designers, but also for supporting the technicians appointed by public administrations, in the context of the mandatory adoption of the HBIM methodology in public procurement [11].

Among the external tools used in this field is Dynamo, which has been employed for condition reporting and for the creation of predictive models. However, some difficulties remain in the modelling of specific decay phenomena, such as cracks and fractures, because they do not interact with the other elements of the model. Further limitations concern losses and missing portions, which are modelled as subtractive 3D elements that do not semantically enrich the architectural elements [12].

The technological development of mobile devices has progressively expanded the possibilities for data acquisition, updating and management directly in the field. To address the difficulties related to data acquisition times, the internal management of information within HBIM models, and the need to use external tools in the case of complex geometries and data, several approaches have been explored. These can be grouped into two main directions: on the one hand, the use of Light Detection and Ranging (LiDAR) systems to support survey activities, with the aim of improving the speed and flexibility of in situ geometric acquisition; on the other hand, the development of semantic annotation interfaces for tablet devices, intended to facilitate the collection and updating of information data directly in the field. About surveying, several researchers have demonstrated that the LiDAR system integrated into latest-generation smartphones can produce sufficiently accurate 3D models. The documentation of an archaeological site in Spain, through a combination of smartphone-based scans and tLS surveys, has shown that these devices make it possible to access areas that are difficult to reach. This overcomes some operational limitations of traditional tripod-based tLS and shows how mobile technology is helping

to make 3D scanning practices more accessible in heritage documentation [13]. About the application of these technologies to the representation of the state of conservation of a historic building, several researchers have assessed the potential of LiDAR, with reference to the system integrated into Apple devices, for 3D acquisition and decay assessment on medieval historic infrastructures. The results showed that the LiDAR system is suitable for small-scale documentation, while its accuracy decreases in the case of larger structures. The authors also identified the lack of dedicated mobile applications as one of the main obstacles to the widespread adoption of LiDAR on Apple devices [14]. Smartphone-based photogrammetry has similarly been validated for the documentation of complex historic surfaces. A recent study demonstrated its applicability to historic ceramic coverings [15], while other authors used Apple's photogrammetric Application Programming Interfaces (APIs) for the rapid creation of 3D models with high metric and documentary quality in the field of cultural heritage [16].

Regarding semantic annotation, the range of available tools has significantly expanded in recent years. The Aioli platform [17,18], developed at the Models and Simulations for Architecture and Heritage Research Unit in Marseille, France, and distributed as a cloud service, enables multidisciplinary communities, including technicians, professionals, clients and managing bodies, to annotate 3D objects directly in a shared environment in a simple and intuitive way. The platform also supports multi-temporal analyses useful for monitoring the state of conservation.

Other researchers have addressed the effectiveness of annotation on 3D models by defining quantitative evaluation criteria, such as projection distance, task completion time and error rate [19]. These criteria, published in 2019, still constitute a reference framework for assessing the performance of annotation systems.

About the visualization of the parametric model through systems and technologies external to the BIM environment, some studies have provided a systematic review of the use of augmented reality (AR), virtual reality (VR) and mixed reality (XR) in cultural heritage. They identified four main fields of application: presentation, interpretation, reconstruction, and documentation. This scientific contribution highlighted that AR technologies applied in the field are still limited by issues related to geometric accuracy, tracking stability and the structured management of the data produced [20]. Other studies have explored the use of Simultaneous Localization and Mapping (SLAM) technology for AR-based annotation of rock art, demonstrating the conceptual feasibility of applying semantic annotations directly to the surfaces of the model [21]. The literature shows that the integration of HBIM, mobile acquisition, semantic annotation and AR/VR/XR tools has produced significant results. However, the operational continuity of information between the executive design phase and the worksite remains only partially addressed, particularly with regard to tools capable of supporting different professional figures involved in the process.

Overall, the literature demonstrates significant advances in HBIM-based information management, mobile acquisition, semantic annotation, and AR/VR/XR-supported interaction with heritage data. However, these research directions mainly address specific stages of the documentation and information-management process. The continuity of conservation-related information between the executive design phase and the operational phase of the worksite remains less extensively investigated, particularly with regard to the in situ verification and updating of existing decay maps and their subsequent reintegration into an HBIM environment. The present research is positioned within this specific gap and explores a preliminary workflow for updating, structuring, and transferring conservation-related information between these two phases.

3. Methodology and Tools

The study proposes an operational procedure for updating the information produced during the transition from the design phase to the worksite phase, with specific reference to the documentation of the state of conservation of a historic building. This procedure responds to the need to collect, organize, and update, in a rapid, clear, and structured way, the information that emerges during the first worksite activities, making it usable by the different actors involved in the process and integrable into a BIM model. The method is based on the preliminary development of an application, through which the information observed directly on site can be recorded by means of vector geometries, associated with predefined information categories, and stored in a structured and interoperable data format.

For the implementation of the complete workflow, the initial inputs consist of an existing HBIM model, and the reference graphic documents associated with its two-dimensional views, such as orthophotos, elevations, and sections. The existing HBIM model, developed in Autodesk Revit 2024, is not developed within the proposed procedure but constitutes the information environment into which the data updated on site are subsequently reintegrated. The methodology is divided into two main phases: the annotation, classification, and structured storage of the information collected on site, and the subsequent transfer and differential synchronization of the updated data with the BIM environment.

3.1. Smart Mapping Annotation Tool (SMAT): Architecture and Workflow of the Application

SMAT is a native iPadOS 17 application, developed in Swift 5.9 according to the Model–View–ViewModel (MVVM) architectural pattern, in line with the SwiftUI framework for the development of user interfaces. The annotation area was implemented using graphical components of Apple’s UIKit framework, to ensure more precise management of the input required for drawing with the Apple Pencil. The application was designed to manage the entire process of annotating decay phenomena, from selecting the data source and loading the orthophoto to drawing the geometries, storing the information in a structured format, and exporting the data for subsequent integration into a BIM environment (Figure 1). Figure 1 was generated with the support of Anthropic’s Claude Sonnet 5 to graphically represent the SMAT workflow described above, based on content and instructions provided by the authors. The generated output was subsequently reviewed and edited by the authors.

Initial access to the data takes place through a common structure, named Storage Source, which allows the user to choose between two equivalent operating modes. The first involves connection to a remote File Transfer Protocol (FTP) server, managed through a URL Session component for file download and upload operations. The second provides access to a local folder synchronized through cloud services, such as iCloud Drive, OneDrive, or Google Drive. The dual operating mode is designed to adapt the use of the tool to different working conditions, including those in which the network connection on site is unstable. In both cases, the data are organized into folders, each containing the source orthophoto and the related annotation file.

The loading of the orthophoto into the annotation environment is managed by a UIView subclass based on CATiledLayer, a component of the Core Animation framework that, in the iOS 17 environment, allows a large image to be divided into smaller portions that are progressively loaded. The subdivision into 512×512 px tiles, organized over five levels of detail, enables the interactive consultation of high-resolution orthophotos, even larger than 4000×3000 pixels, without requiring the entire image to be loaded into memory at the same time. This solution is necessary for managing high-resolution photogrammetric products used in the surveying and analysis of historic architectural heritage and in subsequent restoration projects.

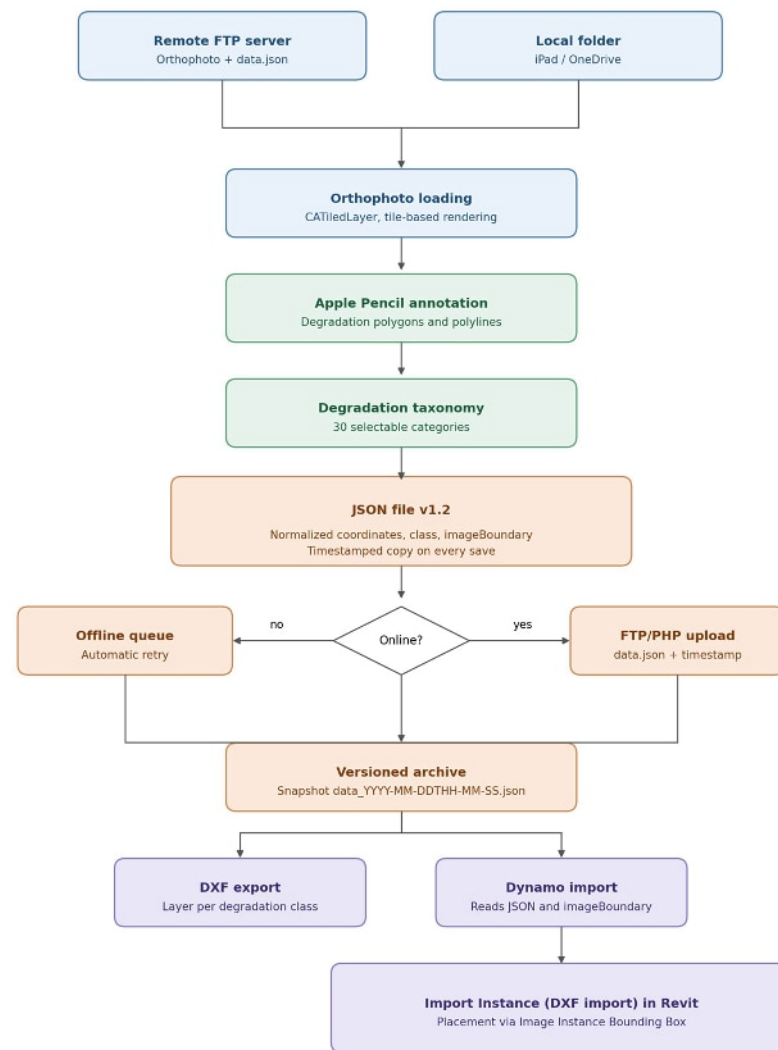


Figure 1. Workflow diagram of the SMAT application for annotating decay phenomena on orthophotos, managing data in JSON format, and subsequently integrating them into the Autodesk Revit (BIM environment).

The drawing of geometries is carried out using the Apple Pencil (Apple Inc., Cupertino, CA, USA). From a technical point of view, the geometric input is managed through a UIPanGestureRecognizer configured to recognise only the UITouch generated by the Apple Pencil, thus avoiding the accidental recording of inputs caused by contact with the user's fingers.

Each point drawn on the orthophoto is acquired in the coordinate system of the user interface, which depends on the zoom level and the scroll offset of the image. It is then converted into the coordinate system of the image itself. The coordinates are subsequently normalised within the interval $[0.0, 1.0]$ with respect to the original dimensions of the orthophoto, to obtain geometries that are independent of resolution and display scale. This normalisation, together with the *image Boundary* field described below, makes it possible to maintain the spatial coherence of the data in the subsequent processing and integration phase within the HBIM model.

The application supports two geometric primitives for representing decay phenomena: closed polygons, used to delimit decay phenomena with surface development, such as erosion, staining and scaling, and open polylines, used to represent linear phenomena, such as fractures and cracks.

For the modification of geometries, the application implements Boolean union, intersection, and difference operations using Clipper2 version 1.5.4, a polygon clipping library implemented in C++. Unlike simpler clipping methods that impose limitations on polygon geometry, Clipper2 can handle polygons with arbitrary concavity. This feature is particularly relevant in the documentation of the state of conservation of historic built heritage, since the boundaries of decay phenomena, such as lacunae, erosion, and detachment areas, may present highly irregular and concave geometries. These operations make it possible to correct or update the shape of annotations by managing overlaps and subtractions without requiring the manual editing of individual vertices. In the current implementation, Boolean operations are applicable only to geometries belonging to the same type of decay, whereas areas referring to different phenomena may freely overlap on the same portion of the surface.

This choice makes it possible to represent the coexistence of multiple forms of deterioration, a recurring situation in the analysis of the state of preservation of historic buildings. The drawn geometries can be associated with an abacus of decay phenomena. The abacus can be structured with reference to established terminology, such as that provided by the UNI 11182:2006 standard concerning the description of alteration forms in natural and artificial stone materials [22]. Selection is performed using a dedicated text search, a method that is well-suited to managing many entries and is more effective than a fixed list in the main interface. Each entry in the abacus can be associated with an identifying color and a geometric attribute, allowing it to be represented as either a polygon or a polyline, in accordance with the development pattern of the phenomenon represented. The annotations can also record the date of acquisition or updating and the technician who created or modified the annotation, thus ensuring the traceability of the data collected on site.

The structured saving of annotations is carried out according to a data schema in JSON format, version 1.2. The file includes the list of annotated geometries, each associated with the corresponding type of decay and with a unique identification code, the dimensional metadata of the source orthophoto, and the *Image Boundary* field. The latter defines a reference rectangle with origin at (0,0) and dimensions corresponding to those of the image in pixels. The unique identifier assigned to each geometry at the time of its creation consists of a *UUID*, a code automatically generated by the application to recognise the individual annotation over time. This code represents the connection key with the elements of the BIM model and makes it possible to identify the same annotation even when its geometric shape is subsequently modified.

At each save operation, the application both overwrites the main file and produces an immutable copy with the timestamp included in the file name, to preserve an ordered archive of the different annotation sessions.

Since the application was designed for updating information directly on site, connectivity management represents a relevant aspect of the operational workflow. For this purpose, a dedicated component monitors the network status and adapts the saving mode accordingly. When a connection is available, the file is transmitted to the server, where it is verified and archived. In the absence of a connection, the file is saved locally and kept pending automatic synchronisation when the network is restored, without requiring any further operation by the user. Finally, the application allows the export of data in Drawing Exchange Format (DXF), with a dedicated layer for each type of decay and a dimensional reference frame. This function was introduced to ensure compatibility with working methods that are still widely used by technicians, allowing further processing to continue in a two-dimensional CAD environment, independently of the subsequent import workflow into BIM model.

3.2. Differential Synchronisation Between the SMAT Application and the BIM Environment (Autodesk Revit)

Before describing the synchronization mechanism in detail, it is useful to clarify the role of the identifiers and data formats involved, since the traceability of an annotation across the workflow depends on their combined use. The *UUID* is generated once in SMAT when an annotation is created (Section 3.1) and remains unchanged thereafter; it is the only identifier that persists across the different representations of the same annotation. The *JSON record* constitutes the human- and machine-readable description of the annotation's current state, including its geometry, decay class, and associated metadata, while successive JSON snapshots provide the basis for detecting changes over time. For the graphical transfer to Revit, each annotation is exported as a separate DXF file named according to its *UUID*. The DXF contains only the geometry and serves as a temporary transfer file rather than a persistent information repository. Once imported into Revit, the resulting Import Instance is associated, through Extensible Storage, with a *PolygonId* corresponding to the same *UUID*. This chain of identifiers and representations maintains the correspondence between the annotation created in SMAT, its structured data, and its graphical representation within the HBIM model during subsequent synchronization operations.

The phase following annotation in SMAT concerns the transfer of the updated information into the HBIM environment, with the aim of reintegrating the data acquired or modified during worksite activities. The documentation of the state of conservation is not a static output, but may be subject to subsequent revisions, integrations, and corrections. For this reason, the system must be able to distinguish between existing geometries, new geometries, modified geometries, and deleted geometries, avoiding the overlap between updated data and obsolete data. To this end, the connection between the SMAT application and the BIM environment was set up according to a logic of differential synchronization. The system is therefore able to compare successive versions of the JSON file and, consequently, to transfer into the model only the changes that are detected. This process is based on two properties of the data schema described above: the normalization of the coordinates with respect to the *image Boundary* field, which makes it possible to maintain the spatial coherence of the annotations in relation to the reference orthophoto; and the unique identifier assigned to each geometry, which allows the same annotation to be recognized over time, even when its shape or related type of decay is modified. In operational terms, each new session in SMAT produces an updated version of the JSON file, in which some geometries may remain unchanged, while others may be added, modified in shape or type, or deleted. Without this mechanism for comparing successive versions, each new import into BIM environment would produce a progressive overlap between obsolete and updated geometries, compromising the readability of the data and the reliability of the information model.

To manage this process, a pair of Dynamo scripts based on CPython 3.8 was developed, conceived as sequential phases of the same operational workflow (Figure 2).

The first script, dedicated to cleaning, removes from the model and from the working folder the elements that are no longer consistent with the updated state of the JSON file. The second script, dedicated to creation, generates, and imports the geometries corresponding to the current state of the annotations. The separation into two distinct scripts responds to a criterion of operational control. The removal of elements from the BIM model is a critical operation and must therefore remain an explicit, verifiable step that can be disabled independently of the creation phase.

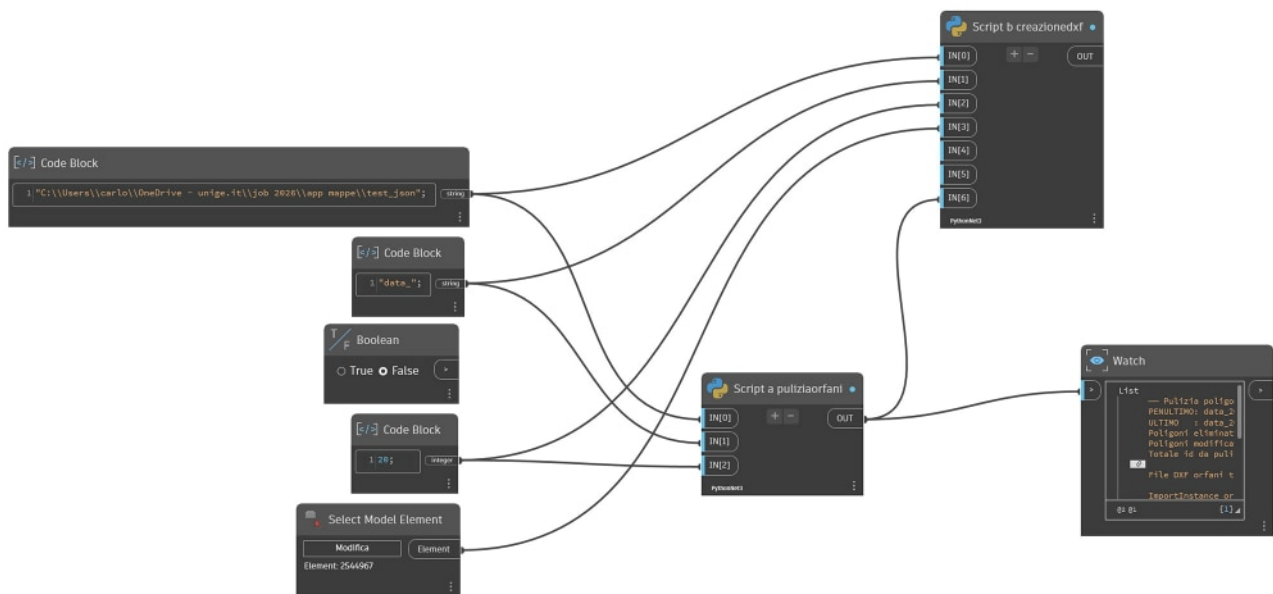


Figure 2. Implementation in Dynamo for Revit 2.18.1 of the synchronisation workflow between SMAT and Autodesk Revit.

The necessary condition for the operation of both scripts is the possibility of persistently linking each element imported into the BIM model to the identifier of the JSON polygon from which it derives. Import Instance elements, generated by the import of a DXF file, do not allow the direct assignment of shared parameters in the same way as Revit BIM parametric families. For this reason, the adopted solution is based on the Extensible Storage mechanism of the Revit API, which allows a custom data schema to be associated with a model element. The schema contains a text field named *PolygonId*, intended to store the identifier of the source polygon. The schema is identified by a fixed GUID, namely a unique identifier shared between the two scripts, and is created only once within the Revit file, if it is not already present. From that moment on, each imported element retains, within the project file, the reference to the JSON polygon from which it originated. This makes it possible to recognize the annotation during subsequent updating, modification, or removal operations. The first script, dedicated to cleaning, compares the two most recent versions of the JSON file stored in the synchronization folder. This comparison assumes that the two most recent snapshots represent consecutive annotation sessions; the script does not verify snapshot continuity, so a skipped intermediate snapshot can leave orphan geometries in the model without a corresponding entry in the source data. This comparison makes it possible to identify two sets of geometries: those present in the previous version but absent from the most recent one, which are therefore considered deleted, and those present in both versions but modified in terms of shape or decay class. In the latter case, the modification is recognized by comparing specific information associated with the geometry, such as the type of decay, the geometric type, and the coordinates of the vertices. Both conditions require the removal of the elements already present in the model. In the case of deleted geometries, the element no longer corresponds to the updated state of the annotation. In the case of modified geometries, removal is necessary because the creation script will generate a new version of the same annotation while maintaining the same identification code. The persistence of the previous version in the model would therefore produce a duplication that is not consistent with the updated data. The search for the elements to be removed is conducted both in the working folder and within the Revit model. In the working folder, the script analyses the DXF files already generated, recognizing the geometry identifier from the file naming convention. In Revit, the script queries the elements imported as

Import Instance objects within the document and reads, for each of them, the value of the *PolygonId* field stored through Extensible Storage. For reasons of operational control, the script includes a verification-only mode. When the confirm real parameter is set to “false”, which is the default value, only a report of the elements that would be removed is produced. The actual deletion is performed only when the parameter is set to “true”, acting both on the elements present in the Revit model and on the corresponding files in the working folder.

The second script, dedicated to creation, operates from the same comparison between successive versions of the JSON file and concerns the geometries that have been added or modified. For each geometry to be updated, a separate DXF file is generated and named according to its unique identifier. This choice makes it possible to maintain a direct correspondence between the individual annotation produced in SMAT, the generated DXF file and the Import Instance element imported into Revit. The dimensional reference required for the correct placement of the geometries in the 2D view is derived from the Bounding Box of an Image Instance element already present in the target view. This information allows the script to determine the origin and conversion scale between the coordinates expressed in pixels, derived from the orthophoto, and the units of measurement used by Revit. The script also recognizes the orientation of the view, whether it is a section, an elevation, or a plan, without requiring manual configuration by the operator. Each DXF file is then imported individually into Revit, and the resulting Import Instance element receives its *PolygonId* identifier through the Extensible Storage schema shared with the cleaning script. In this way, the persistent connection between the original annotation produced in SMAT and its geometric representation within the HBIM model is completed. The execution order of the two scripts within the Dynamo environment must be precisely controlled. The cleaning script must complete the analysis and, if confirmed, the removal of the elements that are no longer consistent before the creation script generates and imports the new geometries. This sequence avoids the temporary coexistence of multiple elements associated with the same identifier. Since Dynamo determines the execution order of nodes according to the logical connections between the different elements of the workflow, and not according to their visual arrangement in the workspace, the sequence is imposed by connecting the output of the cleaning script to an input of the creation script. This connection is not used in the processing logic but ensures that the second script is started only after the first one has been completed. The inputs common to the two scripts (Figure 3), such as the path of the synchronisation folder and the prefix of the JSON files, are connected to the same string nodes, to ensure that both scripts operate on the same dataset. The reference Image Instance element, required only for the creation phase, is instead provided through manual selection of the element in the active Revit view. Within this workflow, most operations are performed without direct operator intervention, including saving and synchronizing the annotation data, comparing successive JSON snapshots, and generating and importing the DXF files corresponding to added or modified geometries. Two operations remain subject to operator control: the removal of elements from the Revit model, which requires explicit confirmation through the cleaning script, and the manual selection of the reference Image Instance required for the creation phase. Figure 3 was also generated with the support of Anthropic’s Claude to schematically represent the differential synchronization workflow between SMAT and Autodesk Revit through Dynamo scripts.

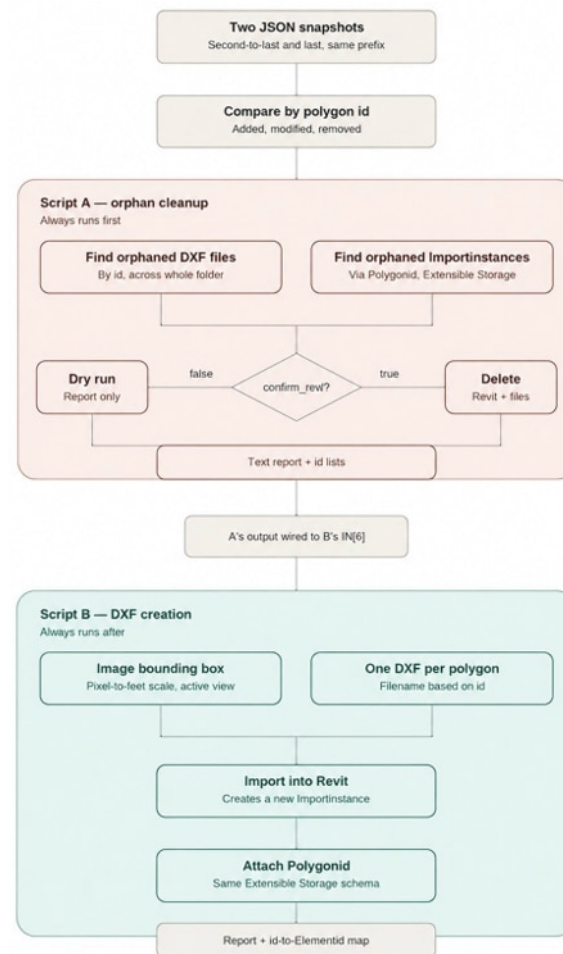


Figure 3. Operational diagram of the differential synchronization between SMAT and the Autodesk Revit environment through Dynamo scripts.

4. Real Case Study Application

The experimentation was carried out on a real case study, in continuity with previous research work [23]. The object of the study is the Oratory of San Giovanni Battista in Bussana Vecchia, within the municipality of Sanremo, in the province of Imperia, Italy. The building is currently, in 2025–2026, undergoing a restoration intervention in the execution phase. The works are supervised by the Segretariato Regionale del Ministero della Cultura per la Liguria (now the Soprintendenza Archeologia Belle Arti e Paesaggio per la città metropolitana di Genova e la provincia di La Spezia), which also developed the architectural project in 2024.

The building, constructed in the seventeenth century, is made of structural split-stone masonry, and has a rectangular single-hall layout with a semi-circular apse and a small tower. In the eighteenth century, the building was modified to accommodate an organ on the inner façade, supported by a large masonry arch. New side doors and windows were also opened. The interior decoration was also modified, with the insertion of canvas paintings on the walls and the repainting of the apse and two lateral niches. Before the start of the works, the oratory had no roof. The barrel vault with lunettes and the overlying roof had almost completely collapsed because of the damage caused by the 1887 earthquake. The earthquake caused the collapse of numerous buildings in Bussana, which was abandoned and rebuilt in the lower area, where Bussana Nuova still stands today. The oratory remained in such a severe state of structural instability that, in the first half of the twentieth century, the vault collapsed (Figure 4). The prolonged exposure of

the masonry wall crowns and interiors to atmospheric agents affected both the remaining structures and the finishes, including plasterwork and stucco decoration. The building, unused for more than a century, showed major structural problems and a widespread poor state of conservation of materials and construction elements. From a structural point of view, the preliminary analyses had identified widespread critical issues, including deep cracks in the masonry, an initial overturning mechanism of the facade, and instability of the wall tops.

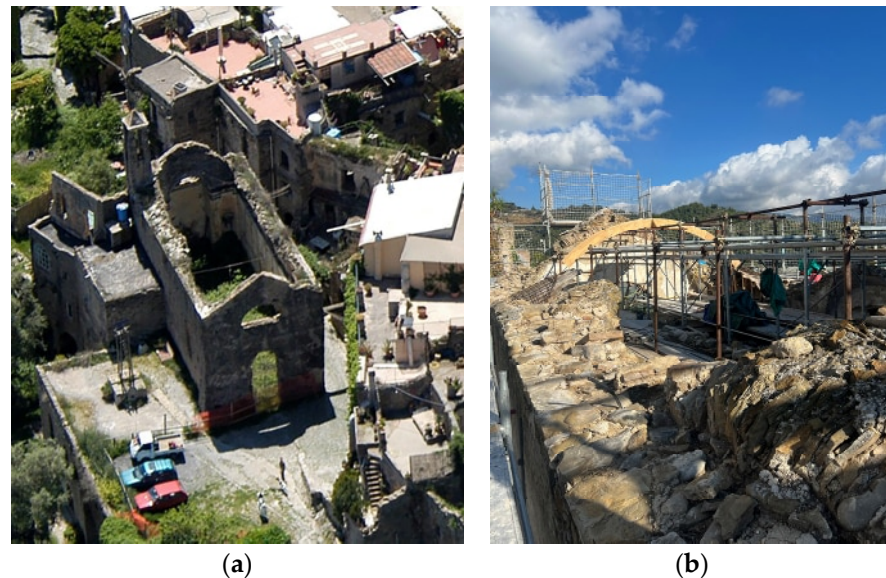


Figure 4. Oratory S. Giovanni Battista—Bussana Vecchia, Sanremo, Imperia—Italy (a) aerial view before the beginning of the design phase—Modus srl (June 2022); (b) view from the scaffolding installed during the site works (November 2025).

The project, developed by the Segretariato Regionale in collaboration with the University of Genoa, Department of Architecture and Design (DAD), with Prof. S.F. Musso and Prof. R. Vecchiattini as scientific coordinators, and the Department of Civil, Chemical and Environmental Engineering (DICCA), with Prof. S. Lagomarsino as scientific coordinator, aimed to reduce vulnerability, restore the oratory, and restore its space to use for the cultural life of the local community. The main objectives included the consolidation and seismic improvement in the building, also through the reconstruction of the roof, to ensure greater stability of the structure and make its use possible. The project was designed by NG Studio Associato di Architettura e Ingegneria. The project also included the restoration of the surfaces, aimed at preserving the surviving parts and maintaining the historic image of the ruin.

The knowledge framework preliminary to the project was developed through different investigation activities, aimed at documenting the geometric, structural, historical-archaeological, material and conservation aspects of the oratory. The building survey was carried out by Modus S.r.l., which conducted a digital survey campaign using tLS and SfM, with topographic control. The combination of the two survey techniques was used to integrate, as far as possible, the geometric data of the upper parts of the building, which were not directly accessible. The photographic campaign carried out using a drone (DJI MAVIC 3T—SZ DJI Technology Co., Ltd., Shenzhen, China) proved valuable, although not exhaustive. Indeed, the presence of obstructions inside the oratory, invasive vegetation on part of the surfaces, and a metal hoop around the dangerously deformed small tower limited the readability of some portions. These areas were not fully documented and, consequently, were only partially considered in the subsequent knowledge analyses.

From a structural point of view, the investigations concerned the analysis and diagnosis of structural damage, also in relation to past structural consolidation interventions, the safety assessment with respect to the seismic risk of the area, and the evaluation of possible static criticalities. About the architectural and conservation aspects, the activities included the historical–archaeological study and analysis of the building, as well as the preparation of maps of materials and decay phenomena (Figure 5), developed according to the terminology of the UNI 11182:2006 standard [22].



Figure 5. Map of the decay phenomena present on an internal wall of the oratory (elaboration by DAD, University of Genoa; scientific coordinators: R. Vecchiattini and S.F. Musso).

The set of activities formed the knowledge base for the definition of the final/executive design, according to the previous structure of design levels, now redefined by Article 41 of Legislative Decree 36/2023 [1], which organizes the design process into the technical-economic feasibility project and the executive project.

At the beginning of the worksite phase, the first operations involving the removal of obstructions and disinfestation revealed a more complete and partly different situation compared with that documented during the design phase. Some areas, previously characterized by poor visibility, finally became readable, making it necessary to update documents, graphic drawings and, in some cases, even certain design choices. The installation of scaffolding also allowed a closer reading of the upper parts of the building and of the wall tops, enabling a better understanding of the state of conservation of materials and elements. It should also be considered that, in restoration practice, the design phase and the worksite phase are rarely close in time. Several years may pass before a project receives funding and can be implemented on site. During this period, conditions may change, making the updating process an essential step.

The experimentation is positioned precisely within this transition, after the start of the worksite phase, when it becomes necessary to verify and update certain data for the adaptation of the project. The coexistence of structural, material and conservation issues make the case study suitable for testing the management of multiple types of information in the transition between executive design and worksite (Figure 6). This contribution presents only the results related to the verification and updating of the state of conservation.



Figure 6. Oratory S. Giovanni Battista—Bussana Vecchia, Sanremo (Imperia—Italy): (a) interior view before the site works (Matilde Ridella—January 2023); (b) interior view during the first removal operations (Matilde Ridella—October 2024).

5. Results and Discussion

The experimentation starts from the HBIM model developed during a previous phase of research on the Oratory of San Giovanni Battista in Bussana Vecchia, aimed at assessing the use of this technology in support of the restoration project, also in relation to the progressive mandatory adoption of digital information management methods and tools for construction in the design and execution of public works, as provided for by Article 43 of Legislative Decree 36/2023 (Table 1). The choice of the case study is related both to continuity with the previous phase of the research and to its representativeness of a typical condition of historic architectural heritage, due to the coexistence of different decay phenomena and the architectural complexity of the building, despite its relatively limited size (Figure 4). In the previous phase, the model had been developed from data acquired through TLS surveying and SfM photogrammetry, with the support of graphical documentation related to the mapping of materials and decay phenomena (Figure 7).

The research had analyzed and compared different approaches to the geometric and semantic modelling of architectural elements, considering knowledge-related, material, and conservation aspects, as well as the surface restoration interventions envisaged by the project. Decay phenomena had been modelled using generic in-place families, selected because of the greater flexibility they offered in geometric modelling and in associating semantic information compared with other methods available in the software. During the previous experimentation, other solutions had also been evaluated, including the use of the Divide Surface/Paint Surface commands, representation through filled regions, and the use of adaptive geometric models. However, these approaches had shown greater limitations in terms of geometric accuracy, processing speed, and the possibility of semantic enrichment. The use of in-place families had nevertheless highlighted some critical issues related to processing time, the complexity of element management, and the consequent reduction in

software performance. The present research adopted this model as an operational basis (Figure 7), shifting the focus from the design phase to the initial stage of the construction site, during which the new accessibility conditions made it possible to verify, integrate, and update the information previously acquired.

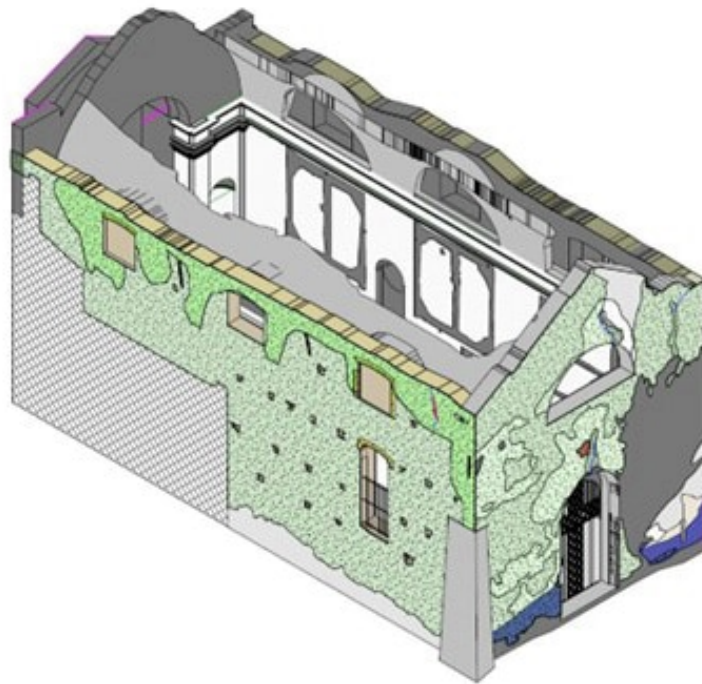


Figure 7. View of the 3D model within the Autodesk Revit Software (elaboration by Margherita Valentini—July 2023).

Starting from this need, an initial experimentation with SMAT was carried out, aimed at defining a workflow for the on-site updating of decay phenomenon maps and their subsequent reintegration into the two-dimensional views of the HBIM model, without modifying the three-dimensional geometry of the model.

Using the orthophotos associated with the elevations and sections of the existing model as reference (Figure 8), the observations made on site were recorded in SMAT using polygons and polylines and associated with the corresponding entries in the decay pattern schedule (Figure 9). The traced geometries can be corrected and updated through union and subtraction operations, while different phenomena can also be represented in overlapping form on the same portion of the surface (Figure 10).

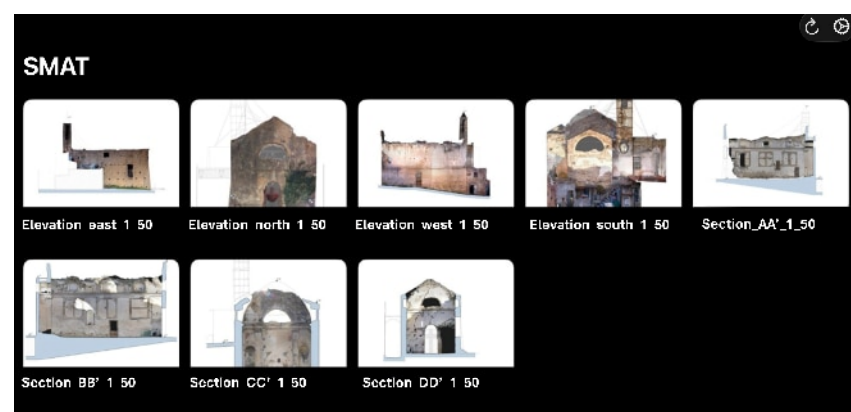


Figure 8. Initial screen of the SMAT application, showing the available drawings for selection and loading.

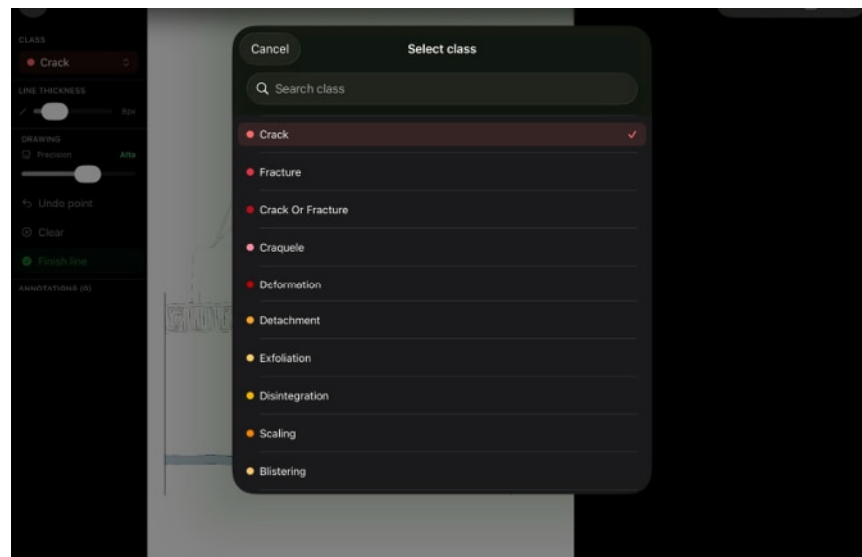


Figure 9. SMAT interface for selecting the decay phenomena class during on-site annotation.

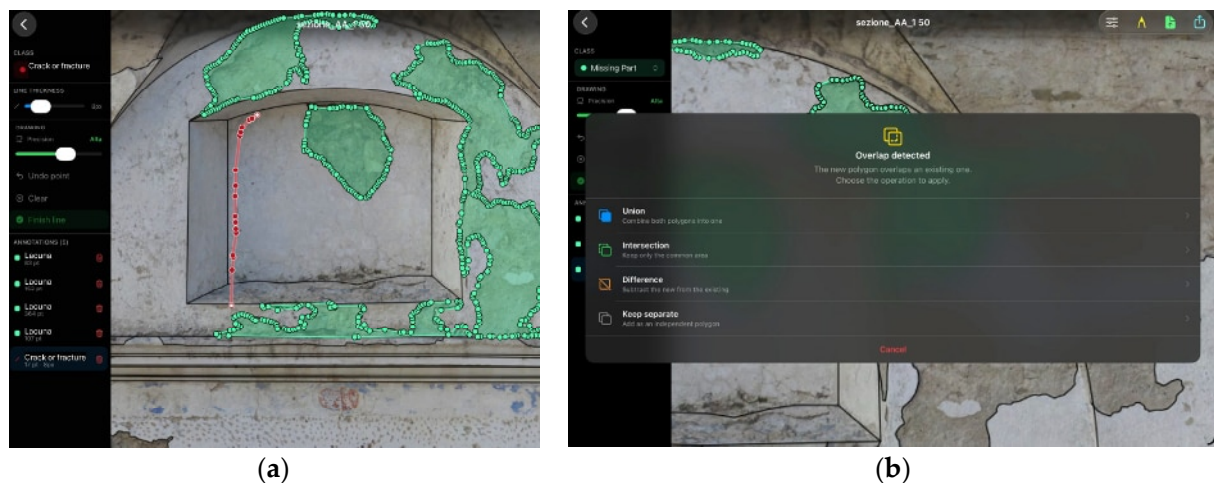


Figure 10. SMAT interface for managing overlapping decay annotations: (a) visualization and editing of annotated geometries; (b) selection of Boolean operations for overlapping geometries.

The annotations produced in SMAT were reintegrated into the corresponding two-dimensional views of the HBIM model. In addition to the geometric representation and classification of the decay phenomenon, the collected information was organized in a structured form, also including temporal data and information relating to the technician responsible for the annotation. During the experimentation, the persistence and transfer of the annotation data were functionally verified. Annotations saved in SMAT were subsequently reloaded while preserving their geometry, associated decay class, and *UUID*. The identifier remained unchanged following both geometric and semantic modifications. The corresponding DXF representations were generated from the structured JSON data and subsequently imported into the intended Revit views, where their correspondence with the reference orthophoto was qualitatively checked in terms of position and scale. The persistence of the annotation identifier throughout the information-transfer process provides the basis for managing subsequent annotation updates within the HBIM environment.

The workflow also allows the reference orthophoto to be replaced while maintaining the same insertion point, thereby updating the graphical basis for further annotation activities.

The differential synchronization procedure was functionally verified for unchanged, added, modified, and deleted annotations, including both geometric and semantic modifi-

cations. The corresponding annotation states were correctly identified while preserving the *UUID–PolygonId* correspondence. In this way, the updating of decay phenomenon maps is not based on the simple superimposition of successive drawings but allows obsolete representations to be identified and removed before importing new or modified ones. Deleted and replaced representations were removed following operator verification, and no missing, duplicated, incorrectly classified, or incorrectly linked annotations were observed during the tested transfer operations. The workflow therefore maintains the correspondence between the annotation produced in SMAT, the related DXF representation, and the corresponding element imported into Autodesk Revit. However, the procedure is not fully automated since the removal of the identified elements remains subject to operator confirmation.

A first strength emerging from the experimentation concerns the continuity between the direct observation of architectural surfaces and the existing information model. Neither the creation of a new HBIM model nor its direct modification by the operator carrying out the on-site annotations is required. The activity is performed using a mobile device, with already available orthophotos, elevations, and sections serving as graphical references.

The combined availability of structured data in JSON format and exports in DXF also maintains compatibility both with the information workflow based on the HBIM model and with the two-dimensional processing methods typical of the CAD environment. The two formats perform different functions: JSON preserves the information structure, identifiers, and changes to the annotations, whereas DXF enables their graphical transfer into the two-dimensional views of the model.

Overall, the experimentation highlights the possibility of managing updates to the state of conservation as modifications to previously acquired information, while maintaining the link between the data collected in situ, its structured organization, and its corresponding representation within the HBIM environment.

The experimentation nevertheless highlighted some limitations. The geometries imported into Autodesk Revit do not constitute native three-dimensional parametric objects semantically linked to the architectural elements of the HBIM model. They remain graphical-information elements associated with two-dimensional views and, therefore, do not replace the three-dimensional modelling of decay phenomena, nor do they automatically enrich the corresponding architectural elements with new parametric information.

A further limitation concerns curved and irregular architectural surfaces. In these cases, annotation on the orthophoto does not automatically guarantee geometric correspondence with the actual development of the surface. This aspect affects the potential metric use of decay phenomenon maps, particularly when they are used as a basis for defining conservation interventions and for the economic quantification of the related works.

The differential synchronization mechanism presents some limitations related to the current logic for comparing successive snapshots. The cleaning script compares the two most recent JSON versions, assuming that they correspond to consecutive annotation sessions; any discontinuity in the synchronization sequence may therefore affect the correct identification of the elements to be updated or removed. In addition, in its current configuration, the workflow is designed for use by a single operator at a time and does not support concurrent modifications to the same dataset. Checking snapshot continuity and the possible extension to collaborative multi-operator workflows are therefore identified as potential future developments. A further limitation concerns the identity of imported elements across updates. Because modified geometries are handled through deletion of the existing Import Instance followed by creation of a new one, rather than in-place editing, each Import Instance receives a new Revit *ElementId* whenever the corresponding annotation is edited, even though its *PolygonId*—and therefore its link to the source annotation—is preserved

through the Extensible Storage schema. Although annotation identity is preserved through the *PolygonId*, references that depend directly on the previous Revit *ElementId* may not be preserved when the corresponding Import Instance is replaced. This limitation results from the delete-and-recreate strategy adopted to avoid duplicate or overlapping elements (Section 3.2). Preserving the identity of the Revit element across geometry updates, for example by modifying the existing element in place where permitted by the Revit API, is identified as a possible future development.

The experimentation also did not include a quantitative comparison between SMAT and manual or traditional procedures in terms of execution time, geometric accuracy, and annotation errors. The results therefore document an initial operational feasibility of the workflow, but do not constitute a quantitative validation of its efficiency or accuracy. A comparative assessment would require a dedicated experimental protocol based on comparable annotation tasks, repeated by different operators, and evaluated using predefined quantitative indicators.

6. Conclusions

In interventions on historic built heritage, the beginning of the worksite phase constitutes a moment in which the information acquired during the design phase can be verified, integrated, and updated. This need mainly depends on the level of knowledge reached during the design phase, which is in turn influenced by the complexity of the building, the accessibility limits of the asset, and the availability of economic, human and time resources. The new accessibility conditions, determined by the installation of temporary works and by the first operational activities, such as the clearance of rooms or the removal and dismantling of elements, can offer new possibilities for observation and make readable portions that were previously not documentable or only partially analyzed. In this sense, the worksite can allow a refinement of the knowledge of the asset. The comparison between the data produced during the design phase and the conditions observable on the asset during the worksite phase therefore makes it possible to refine, integrate or modify the knowledge framework, with possible effects on operational choices and, consequently, on the economic framework. These updates may concern geometric data, material aspects, archaeological and construction-related information, as well as the state of conservation of the asset.

This research specifically investigates the on-site updating of data related to decay phenomena through the testing of an initial SMAT prototype, developed to support the in-situ revision of the corresponding maps and the transformation of observations concerning the state of conservation into structured, traceable data that can be reintegrated into the two-dimensional views of an HBIM model. The experimentation carried out on the Oratory of San Giovanni Battista in Bussana Vecchia made it possible to test this procedure in a real case study, starting from an HBIM model already developed during a previous phase of the research [23]. The main contribution therefore does not concern the construction of a new information model of the building, but rather the extension of the information flow from the design phase to the initial phase of the worksite through a tool aimed at updating data recorded directly on the asset. The SMAT application enables the decay phenomena present on the asset to be annotated on reference orthophotos using vector geometries, associating each annotation with the detected phenomenon, temporal data, and information concerning the surveying technician.

The experimentation showed that correspondence can be maintained between the observations recorded on site, the structured annotation data, and their representation within the HBIM environment. Subsequent updates can be managed by distinguishing unchanged geometries from those that have been added, modified, or deleted, rather than

by simply superimposing new maps onto previous versions. Compared with conventional CAD-based workflows for updating decay maps, in which revisions are generally managed through the modification or replacement of graphical documentation, the proposed procedure introduces a persistent identification mechanism that makes it possible to recognize and manage changes to individual annotations across successive sessions.

The methodological contribution of the workflow presented here lies specifically in closing this gap for the on-site phase: the identifier chain described above (*UUID*, *JSON record*, *PolygonId*) allows the system to recognize the same annotation across sessions and to update only what has changed, while keeping the on-site observation and its technician traceable from the field annotation to its corresponding graphical representation within the HBIM environment. This makes it possible to track changes in the documentation concerning the state of conservation during the transition from the design phase to the worksite phase. The use of a commonly available device, such as a tablet, and of an interface based on established graphic documents may facilitate the updating of data produced on site. This aspect is relevant in a process involving actors with different skills, responsibilities, and operational tools. At the current stage, the workflow is designed for sequential use by a single operator at a time; the management of concurrent multi-operator editing remains a possible future development. This aspect becomes even more important in the context of the progressive mandatory adoption of digital information management methods and tools in public procurement [1,2]. The experimentation therefore highlights the need to develop HBIM procedures that are not only structured and interoperable, but also compatible with the current operational conditions of interventions on the built heritage, at least within the Italian context.

The current prototype configuration of SMAT still presents several limitations related to the two-dimensional nature of the geometries reintegrated into the model, the representation of curved or irregular surfaces, and the absence of quantitative performance validation. The geometries imported into Autodesk Revit remain graphic and informational elements associated with two-dimensional views and do not constitute native three-dimensional parametric objects linked to the architectural elements of the HBIM model. Moreover, the use of orthophotos does not automatically ensure geometric correspondence with the actual development of complex surfaces.

Overall, the research does not resolve all the critical issues associated with the representation and modelling of decay phenomena within the HBIM process but proposes an initial assessment of the operational feasibility of a workflow intended to support information continuity between the executive design and worksite phases. The value of the method lies in the possibility of complementing the HBIM model with a rapid tool for the in situ updating of decay maps, with the potential to limit the intermediate steps between direct observation, graphic representation, and data reintegration.

Future developments may concern greater automation of the connection between the mobile application and the BIM environment, the extension of the system to the management of complex three-dimensional surfaces, the generation of BIM information elements directly from annotations produced on site, and greater data interoperability, including through open formats such as IFC. A further development may concern the assessment of the integration between LiDAR surveys carried out using mobile devices and SMAT, considering both the updating of orthographic references through geometric data and co-registered RGB images and the possibility of extending annotation directly to three-dimensional point clouds.

These developments should nevertheless maintain ease of use as a central requirement, so that the updating of information concerning the state of conservation can be effectively

integrated into the operational conditions of interventions on the built heritage and used by professionals with different skills and functions.

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References

1. Repubblica Italiana. *Decreto Legislativo 31 Marzo 2023, n. 36. Codice dei Contratti Pubblici*; Serie Generale No. 77, Suppl. Ordinario No. 12, 31 marzo 2023; Gazzetta Ufficiale della Repubblica Italiana: Rome, Italy, 2023.
2. Repubblica Italiana. *Decreto Legislativo 31 Dicembre 2024, n. 209. Disposizioni Integrative e Correttive al Codice dei Contratti Pubblici, di cui al Decreto Legislativo 31 Marzo 2023, n. 36*; Serie Generale No. 305, Suppl. Ordinario No. 45, 31 dicembre 2024; Gazzetta Ufficiale della Repubblica Italiana: Rome, Italy, 2023.
3. Murphy, M.; McGovern, E.; Pavía, S. Historic Building Information Modelling (HBIM). *Struct. Surv.* **2009**, *27*, 311–327. [\[CrossRef\]](#)
4. Murphy, M.; McGovern, E.; Pavia, S. Historic Building Information Modelling—Adding Intelligence to Laser and Image Based Surveys of European Classical Architecture. *ISPRS J. Photogramm. Remote Sens.* **2013**, *76*, 89–102. [\[CrossRef\]](#)
5. Moyano, J.; Carreño, E.; Nieto-Julián, J.E.; Gil-Arizona, I.; Bruno, S. Systematic Approach to Generate Historical Building Information Modelling (HBIM) in Architectural Restoration Project. *Autom. Constr.* **2022**, *143*, 104551. [\[CrossRef\]](#)
6. Banfi, F.; Previtali, M. Human–Computer Interaction Based on Scan-to-BIM Models, Digital Photogrammetry, Visual Programming Language and eXtended Reality (XR). *Appl. Sci.* **2021**, *11*, 6109. [\[CrossRef\]](#)
7. Diara, F.; Rinaudo, F. IFC Classification for FOSS HBIM: Open Issues and a Schema Proposal for Cultural Heritage Assets. *Appl. Sci.* **2020**, *10*, 8320. [\[CrossRef\]](#)
8. Argasiński, K.; Tomczak, A. Enhancing Semantic Interoperability of Heritage BIM-Based Asset Preservation. *Heritage* **2025**, *8*, 410. [\[CrossRef\]](#)
9. Pocobelli, D.P.; Boehm, J.; Bryan, P.; Still, J.; Grau-Bové, J. BIM for Heritage Science: A Review. *Herit. Sci.* **2018**, *6*, 30. [\[CrossRef\]](#)
10. Zanni, T.; Sbrogiò, L.; Zanchetta, C.; Valluzzi, M.R. OpenHBIM Framework for Material Deterioration Assessment and Prioritization of Interventions in Historical Buildings. *Digit. Appl. Archaeol. Cult. Herit.* **2025**, *37*, e00428. [\[CrossRef\]](#)
11. Adami, A.; Scala, B.; Treccani, D.; Dufour, N.; Papandrea, K. Hbim approach for heritage protection: First experiences for dedicated training. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2023**, *XLVIII-M-2–2023*, 11–18. [\[CrossRef\]](#)
12. Parente, M.; Ottoni, F. HBIM Tra Aspettative e Realtà: Limiti e Frontiere Dell’utilizzo Dei Modelli Informativi per La Conoscenza e Il Restauro (Anche Strutturale). In Proceedings of the Restauro dell’Architettura, Naples, Italy, 15–16 July 2023.
13. Antón, D.; Mayoral-Valsera, J.; Simón-Vallejo, M.D.; Parrilla-Giráldez, R.; Cortés-Sánchez, M. Built-in Smartphone LiDAR for Archaeological and Speleological Research. *J. Archaeol. Sci.* **2025**, *181*, 106330. [\[CrossRef\]](#)

14. Kędzierski, P.; Jagoda, M.; Tysiąc, P.; Katzer, J. An Example of Using Low-Cost LiDAR Technology for 3D Modeling and Assessment of Degradation of Heritage Structures and Buildings. *Materials* **2024**, *17*, 5445. [[CrossRef](#)] [[PubMed](#)]
15. Asadpour, A. Documenting Historic Tileworks Using Smartphone-Based Photogrammetry. *Mersin Photogramm. J.* **2021**, *3*, 15–20. [[CrossRef](#)]
16. Hurst, S.; Franklin, L.; Johnson, E. Assessment of Apple’s Object Capture Photogrammetry API for Rapidly Creating Research Quality Cultural Heritage 3D Models. *PLoS ONE* **2024**, *19*, e0314560. [[CrossRef](#)] [[PubMed](#)]
17. Abergel, V.; Manuel, A.; Pamart, A.; Cao, I.; De Luca, L. Aioli: A Reality-Based 3D Annotation Cloud Platform for the Collaborative Documentation of Cultural Heritage Artefacts. *Digit. Appl. Archaeol. Cult. Herit.* **2023**, *30*, e00285. [[CrossRef](#)]
18. Arese, P.; Roussel, R.; De Luca, L. Establishing a Dialogue Between Textual Sources and 3D-Spatialised Annotations: A First Experiment Within Notre-Dame’s Scientific Data Corpus. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2025**, XLVIII-M-9–2025, 49–56. [[CrossRef](#)]
19. Ponchio, F.; Callieri, M.; Dellepiane, M.; Scopigno, R. Effective Annotations Over 3D Models. *Comput. Graph. Forum* **2019**, *39*, 89–105. [[CrossRef](#)]
20. Bekele, M.; Pierdicca, R.; Frontoni, E.; Malinverni, E.; Gain, J. A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage. *J. Comput. Cult. Herit.* **2018**, *11*, 1–36. [[CrossRef](#)]
21. Abergel, V.; Jacquot, K.; Luca, L.D.; Veron, P. Towards a SLAM-Based Augmented Reality Application for the 3D Annotation of Rock Art. *Int. J. Virtual Real.* **2019**, *19*, 17–26. [[CrossRef](#)]
22. UNI 11182:2006; Beni Culturali—Materiali Lapidei Naturali Ed Artificiali—Descrizione Della Forma di Alterazione—Termini e Definizioni. Ente Nazionale Italiano di Unificazione: Milan, Italy, 2006.
23. Valentini, M.; Battini, C.; Vecchiattini, R. HBIM to Support the Executive Design of a Restoration. Critical Issues Related to Geometric and Semantic Modeling. *SCIRES-IT-Sci. Res. Inf. Technol.* **2023**, *13*, 125–136. [[CrossRef](#)]

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