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STRATIGRAPHIC UNITS INSIDE HERITAGE BUILDING INFORMATION MODEL: A NOVEL APPROACH FOR THE REPRESENTATION OF BUILDING ARCHAEOLOGY

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ABSTRACT:
The paper discusses the representation of Stratigraphic Units (SUs) and the communication of Building Archaeology analysis in three dimensions within the context of Historic Building Information Modeling (HBIM). The author propose a methodological approach to incorporate 2D Building Archaeology analysis into the HBIM environment, aiming to support experts involved in research and restoration phases. Moving from 2D to 3D graphics in Building Archaeology introduces challenges in describing the third dimension of SUs, particularly regarding thickness and the relationship between different wall layers. In conclusion, the paper suggests the creation of a new category of HBIM called Building Archaeology Informative Modelling (BAIM), which aims to address the specific requirements of representing Building Archaeology in three dimensions.

1. INTRODUCTION

The paper describes the representation of Stratigraphic Units and the communication of Building Archaeology analysis of architectural and archaeological heritage in three dimensions. A methodological approach is proposed to bring 2D Building Archaeology analysis inside the HBIM environment, supporting the experts involved in the research from the knowledge to the restoration phases, considering the increasingly widespread use of BIM for historic buildings.
Building Archaeology studies in the HBIM domain have mainly focused on the virtual reconstruction of ancient buildings (anastylosis) and construction phases. Few studies concern the HBIM representation of Building Archaeology analysis regarding the wall stratigraphy, which is still an open field of research.
Moving from 2D to 3D graphics of Building Archaeology poses some issues due to the need to describe the third dimension of a stratigraphic unit, which is less critical when dealing with traditional 2D drawings. In addition, defining the thickness of the Stratigraphic Units opens some issues: how is the wall stratigraphy? What is the thickness of a wall layer? Do the different layers belong to the same construction phase? Non-destructive analysis might help answer those questions. However, a degree of uncertainty must be considered when dealing with heritage buildings.
Another topic is the communication of information associated with the Stratigraphic Unit (SU), such as direct (on-site observations, geometrical survey) and indirect sources (historical and archival sources).
Furthermore, the information related to the reliability of the 3D model should be taken into account. The transparency of metadata (data that provides information about other data) and paradata (data about the process by which the data were collected) is crucial. In this regard, the London and Seville charters are an essential reference (Denard, 2012).
Then, how to realise the SU in the HBIM software, such as Autodesk Revit, is another challenge, although the Scan-to-BIM workflow is a well-established procedure.
The paper analyses two case studies – St. Francesco church in Arquata del Tronto and Claudius-Anio Novus aqueduct in Rome (Tor Fiscale Park). The first case study shows three different representations of Building Archaeology inside HBIM depending on the level of knowledge of the building and the purpose of the 3D model. The Claudius-Anio Novus aqueduct shows the parameters considered for each modelled SU in the HBIM, opening the discussion about the need for shared criteria and tools for building archaeology representation.
Finally, the paper proposes the definition of a new category of HBIM: Building Archaeology Informative Modelling (BAIM) (Figure 1).

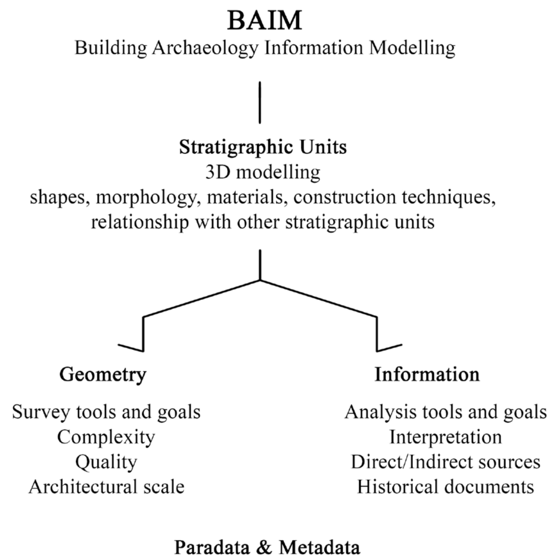

Figure 1 More than in HBIM, information mapping (paradata and metadata) is essential in BAIM as it ensure that data and hypotheses, together with their sources, are available to those who might use the BIM.

2. FROM 2D TO 3D REPRESENTATION: COMPLEXITY, ACCURACY, METADATA, PARADATA

When the stratigraphic units of the 2D drawings are transferred into HBIM objects, together with the geometric data, other significant aspects must be considered, such as materials, construction techniques and chronological data. It is essential to consider the wall's stratigraphy and the interaction between different layers, such as plaster and masonry, when creating the stratigraphic units 3D model. Furthermore, each HBIM object embeds properties and data (e.g. geometries, shapes, areas,

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volume, construction techniques, and chronological and historical information). The analysis becomes more complicated when considering a heritage building, whose materials and construction techniques are not always easy to understand and may require further investigations, such as non-destructive or semi-destructive investigations. Furthermore, the analysis of the materials goes hand in hand with mapping the decay, which opens up other questions, such as whether or not the decay is linked to the materials of the stratigraphic unit.

On the one hand, the issues related to building archaeology within BIM (BAIM) refer to operational issues related to the modelling of complex architectural elements, a topic addressed several times in the specific literature, which is strictly connected to the quality, accuracy and reliability of 3D models. Recently, the Eu commission published a report about the complexity, accuracy and quality of 3D modelling (European Commission, 2022). The report points out the lack of international standards or guidelines for planning, organising, setting up, managing, implementing, using paradata and metadata or evaluating cultural heritage 3D data acquisition results and projects. Furthermore, there is no generally accepted framework for specifying the level of detail and accuracy in cultural heritage digital data acquisition. On the other hand, the issues are related to storing, presenting and communicating the information associated with the models. The possibilities offered by BIM make it possible to associate data with a given entity, in this case, the stratigraphic units, if made up of a parametric object. The information that is usually associated, in addition to the ones purely related to the modelling environment ('constraints' section), concerns structural aspects ('structural' section, i.e. if the object considered is a structural element), dimensions ('dimensions' section: length, area, volume), 'identity data' (image, comments) and construction 'phases' (creation phase, demolition phase). Furthermore, adding fields to the object properties, from descriptions to specific links to other document types, is possible. A topic of great importance for those involved in the creation, management and use of the HBIM model concerns the reliability of the model from the point of view of digital survey, representation (dimensional consistency, materials, construction techniques) and interpretation (information, observations and associated parameters). The model reliability is linked to the concept of 'transparency', which has been in the literature since 2009 thanks to the London Charter. The Charter was integrated in 2012 with the Seville Principles, although referring to the archaeological field, partially foreseen in 2003 when UNESCO adopted the Charter for digital heritage.

The London Charter (Denard 2012), initially conceived by Beacham, Denard and Niccolucci, pertains to computer-based visualisation of Cultural Heritage, i.e. when research linked to a cultural asset uses computer visualisation as a means of data transmission. Referring mainly to three-dimensional reconstructions in archaeology, the 'intellectual transparency' is expressed in the communication, through the model, of the used sources.

The Seville Charter (ICOMOS 2017), on the other hand, refers to 'scientific transparency', i.e. the possibility of making three-dimensional visualisation available and usable to other experts who will be able to confirm or refute the results obtained. Under these principles, the concept of paradata is introduced alongside metadata.

Metadata is 'the set of ancillary data that help to describe an object or a subject in a detailed and complete way'. In the case considered, they could refer to the author of the three-dimensional model and the indirect sources used to construct the model. Paradata is 'ancillary data' that pertains to the process by which the data was collected. In the case of built heritage, they concern the methods of acquisition and survey (direct, laser scanner, photogrammetric). Once these aspects have been defined, the relationship between sources, interpretation and three-dimensional model should be understandable even to those who have not personally dealt with the research, favouring a transparent communication of the results.

3. BUILDING ARCHAEOLOGY ANALYSIS: DIRECT AND INDIRECT DATA SOURCES

Heritage buildings are studied using both direct and indirect sources to gain a comprehensive understanding. Direct sources, or primary sources, offer first-hand information for historical reconstructions. Common direct sources in architectural research include geometrical surveys, on-site inspections, and material/decay analysis. Indirect sources, also known as secondary sources, involve reconstructions from primary or other secondary sources, such as reports and studies of past evidence from scholars. Generally speaking, primary sources provide raw information and first-hand evidence, whereas secondary sources provide second-hand information and commentary from other researchers. However, both contain values and elements of interpretation. Therefore, the distinction between direct and indirect sources is not a matter of 'fact' versus 'interpretation'. In both cases, it is crucial to understand the context in which the information was produced – such as when and where, by whom, for what purpose, and based on what knowledge. Building archaeology is a borderline discipline that involves various factors, such as historical, artistic, cultural, socio-economic values, and material culture, and relies on both direct and indirect sources for a comprehensive understanding of architectural artefacts.

Building archaeology's practical and theoretical foundations were established in Italy approximately at the end of the 1980s. Throughout the 1990s, discussions within the field expanded to include various issues, such as preservation, materials, construction techniques and building types, history of art, historical interpretation, and urban planning (Brogiolo, 2002; Brogiolo, Cagnana, 2012). While the original intention was to encompass various experiences from different research centres and universities across Italy (including Siena, Genova, Venice, Brescia, Rome, and Milan) under the umbrella of building archaeology, there is still a lack of shared tools and practices. However, although building archaeology was initially seen as an ancillary discipline, it has since gained recognition as an indispensable guide for responsible preservation projects.

Building stratigraphy, chrono-typology, archaeometry, dendrochronology, materials analysis, surface finishes, construction techniques, and non-destructive diagnostic investigations are all indispensable tools in building archaeology. Building stratigraphy tool is borrowed from archaeology. It helps interpret the construction phases and elevations of buildings. Positive and negative stratigraphic units represent parts of a building realised or removed in a single constructive action. They are studied to understand the building's transformation and the relationship between its parts. To understand the chronological sequence, the study of mortar joints has a crucial role in exposed masonry facades.

4. BUILDING ARCHEOLOGY INSIDE BIM: A BRIEF STATE OF THE ART

The possibility of orienting the HBIM to the needs of knowledge and preservation practices has led different research centres to develop strategies to transfer material and decay analyses inside informative platforms. At first, geographic information systems, such as GIS, were used, which, unlike

AutoCAD, allow easier quantitative management and better data analysis computation. However, the representation always remained anchored to a two-dimensional image.

Since the operating methods of BIM have expanded to the built heritage, the potential offered by the tool has been oriented in various analyses for maintenance and preservation.

In Italy, the pioneering work on the Basilica of Collemaggio (Brumana et al. 2017) offered the first results of consolidating a practice from decades of experimentation. The Basilica partially collapsed after the earthquake devastated L'Aquila in April 2009 and underwent a complex preservation project. An experience that involved the offices of the local Superintendence, a design support group made up of various research teams from the University of L'Aquila, the Sapienza University of Rome and the Politecnico di Milano, coordinated by ENI, which funded the work, and provided technical skills in the design and construction phase. A preservation project that stood out through the adoption of new innovative technologies for the management of the works to safeguard one of the most important religious buildings in the city. The HBIM model had a fundamental role in managing the different preservation phases. The HBIM was also used to experiment with generating historic architectural elements damaged by the earthquake.

Furthermore, the model was used to manage the construction site, defining hypothesise about the roof of the chevet to be rebuilt since it had partially collapsed. It was also used for the mapping of materials and decay. Furthermore, as an information system managed in a three-dimensional graphic space, BIM is a tool for the historical-critical process of knowledge of the built heritage.

Recently, some research centres aimed at transposing the building archaeology analysis from a two-dimensional to a three-dimensional visualisation using the HBIM. Some studies refer to field archaeological work. Photogrammetric survey is used to create 3D models of stratigraphic units that are removed or demolished during excavation, as demonstrated in the work by Valente et al. (2017). Additionally, the study of archaeological stratigraphy is relevant in the virtual reconstruction of sites and monuments, as Demetrescu (2015) explored.

One of the earliest examples of applying stratigraphic analysis to BIM in the architectural field is the Church of S. Maria di Scarica in the Valle d'Intelvi. The BIM model enables 'volume stratigraphy' representation by grouping elements according to recognised or hypothesised construction phases (Brumana et al., 2013). Furthermore, each stratigraphic element is characterised by the phase it belongs to, which can be viewed in the properties tab. However, the representation was a matter of stratigraphy for macro elements (walls or portions of the building), not the three-dimensional realisation of building archaeology analysis.

The Castel Masegra, located on a rocky hillock overlooking the city of Sondrio, has been the centre of attention since 2012, the date of acquisition of the property by the Municipality, for the design of an overall preservation and rehabilitation plan (Barazzetti et al. 2015). However, even in this case, the BIM aimed to represent the 'volume stratigraphies' identified through the subdivision of the elements constituting the model based on the different construction phases. Furthermore, the BIM model has been a tool for sharing the work, not only for the professionals involved in the project but also for tourists or virtual visitors. Therefore, the study investigated the possibilities of using BIM towards finite element analysis and more playful forms of sharing. In this regard, different applications are compared for utilising the model even remotely.

In 2018, the research group of the Department of Civil Engineering of the University of L'Aquila, coordinated by Stefano Brusaporci (Brusaporci et al. 2018), proposed the BIM based on the building archaeology analysis of the San Vittorino complex near L'Aquila. The church rises in an area of the 4th century. In particular, the study focused on the wall of the old church of San Michele Arcangelo to verify some building construction hypotheses. The first strategy envisaged the creation of a parametric wall for each identified stratigraphic unit, consisting of three layers: external facing, core, and internal facing. In this way, however, the building archaeology concerned only the exterior façade. The second strategy, therefore, envisaged the creation of parametric walls for each stratigraphic unit corresponding to the layers that make up the wall. The result is a parametric wall for the central core and as many walls as the stratigraphic units identified on the external and internal facades. Parameters about description, wall typology, construction phase and state of conservation were then created for each wall. Creating schedules in Autodesk Revit made it possible to extrapolate the information associated with each element in tabular form. Finally, the corresponding construction phase was assigned to each stratigraphic unit; in this way, it is possible to view the construction units for each historical period.

In 2020, the National Research Center (Trizio, Savini 2020) promoted a study about creating an HBIM for the church of S. Francesco in Rocca Calascio, near L'Aquila, a rural building with traces of 16th-century frescoes. The modelling of the stratigraphic units had particular importance. It involved two methods: i) each stratigraphic unit is directly modelled in the parametric software (Autodesk Revit); ii) each stratigraèhic unit is modelled in another software (SketchUp) and then imported in the parametric software. In the first case, each stratigraphic unit was modelled as a parametric family, starting from the point cloud obtained from the laser scanner survey and imported into Revit. In the second case, each stratigraphic unit was modelled in the same project within SketchUp, imported into Revit, recognised as a 'mass', and transformed into a parametric wall. In both cases, the parametric data of each entity was customised and updated with data from the stratigraphic analysis.

Although linked to the volume stratigraphy, the same approach had been employed a year earlier in the elaboration of the Castello di Fossa, an ancient settlement on Monte Circolo. In this case, the modelling occurred directly in Revit by importing the point cloud (Trizio et al. 2019).

In the same year, Diara and Rinaudo published a study on the realisation of HBIM oriented to building archaeology through open-source software, such as FreeCAD, which combines CAD and BIM programs. The program has been implemented on different levels: libraries, material databases and IFC classification (Diara, Rinaudo 2020).

The different studies show the first attempts to move building archaeology into BIM. The growing interest in this issue requires creating discussion tables and setting up shared tools and methods.

5. TOWARDS THE SYSTEMATISATION OF THE PROCESS: TWO CASE STUDIES

The two proposed case studies are significant for the different representative possibilities of building archaeology in BIM (BAIM). Both cases use the Scan-to-BIM process to model the stratigraphic units, integrated with free-form modeling software (such as McNeel Rhinoceros) used to accurately capture the morphology and geometry of each element (Banfi, 2017).

Specifically, the steps that led to the creation of the HBIM model involved four crucial moments:

- survey data acquisition: laser scanner, topographic survey and photogrammetric datasets;
- Scan-to-BIM: the building archaeology analysis was first realised in McNeel Rhinoceros, thanks to interpolating the point clouds to create each stratigraphic unit. The model's reliability concerning the point cloud survey was verified with automatic verification tools (Banfi, 2017) and subsequently imported into Autodesk Revit to proceed with the parameterisation;
- information mapping: association of information, documents, texts, and images to the parametric stratigraphic units of the HBIM model, database extrapolation and implementation of parameters;
- sharing of collected data: transparency of the information embedded in the model.

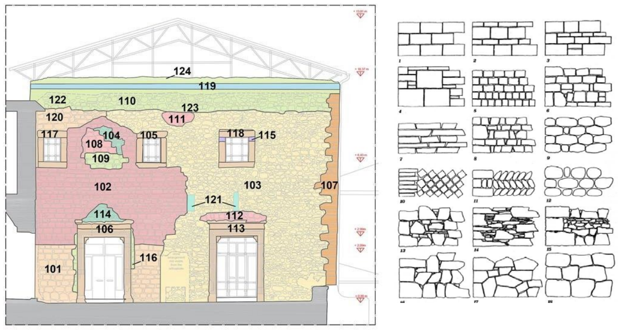
The two case studies show the application of Building Archaeology Information Modelling (BAIM) on an architecture (church of St. Francesco, Arquata del Tronto) and an archaeological site (Claudius-Anio Novus aqueduct, Rome). The differences between the two BAIM are the different features and types of built heritage – a layered building and the ruins of a Roman infrastructure.

Based on the wall stratigraphy, three different representations are offered for the church of St. Francesco. For the Claudius-Anio Novus aqueduct, each stratigraphic unit was modelled as a wall composed of a single layer. In this case, the implementation of the associated parameters had particular importance.

5.1 St. Francesco Church in Arquata del Tronto: BAIM oriented to three different models and representations

The church of St. Francesco in Arquata del Tronto (Ascoli Piceno, Marche) is part of a Franciscan monastery founded in the 13th century along the ancient road via Salaria (Figure 2). Three significant building phases can be identified, from the first church to the addition of a second nave between the 16th and first half of the 17th century. Numerous earthquakes, maintenance, and restorations have led to significant interventions in the building, such as the 20th-century introduction of reinforced concrete structures and roof

Figure 2 The church façade before (top right) and after (top left) the safety works. Bottom: comparison among the orthophotos: May 2019 (left); August 2016 (centre); before the earthquake.



S.U.	DESCRIPTION	LAYOUT	PICTURE	DIRECT SOURCES	INDIRECT SOURCES	MAIN STRATIGRAPHIC RELATIONSHIP
101	Coursed ashlar Ashlar masonry built of **sandstones** having the same height within each course, but each course varying in height.			• Thin joints mortar construction, flat-joint repointing. • Level beds are not aligned on the two sides of the door. • Stones dimension (height): from 14 cm to 30 cm.		101 is broken by 116 102 leans on 101 103 leans on 101
102	Coursed ashlar Ashlar masonry built of **travertine** stones having the same height within each course, but each course varying in height.			• Thin joints mortar construction, flat-joint repointing. • Level beds are not aligned on the two sides of the door, but they are aligned above the lintel. • The stone arrangement on the external surface of the facade and the inspection of the internal surface suggest that the masonry section is a wall faced with cut stone and rubble masonry fill (*muratura a sacco*). • Stones dimension (height): from 14 cm to 30 cm.		102 leans on 101 SSS 102 is bind to 105, 117
103	Coursed rubble Rubble wall (**sandstones, travertine**) having approximately level beds and brought at intervals to continuos level courses.			• Thick joints mortar construction, flat-joint repointing. • Level beds are alligned with the quoins at a certain height. • The wall correspond to the ennlargement of the church occurred around the 16th century.		SSS 103 is bind to 105, 107, 113, 115 103 leans on 102, 116
119	Reinforced concrete beam			• The reinforced concrete beam was placed to strenghten the roof and the walls during the 1930s restoration.	• Archive document: ASAP, Prefettura, Culto, II versamento, b. 25.	

Figure 3 Building Archaeology 2D representation (top left) depending on the different construction techniques (top right). First draft of the database (bottom).

replacement. However, the earthquake of August-October 2016 and heavy snowfall in January 2017 caused significant damage to the church, resulting in the collapse of the roof, wooden carved ceiling, and part of the walls.

The preliminary analysis (Banfi et al. 2022a) of St. Francesco church involved an examination of the façade through building archaeology. The façade has been shaped by a long history of construction, extensions, and renovations carried out in response to various events, including earthquakes.

The building archaeology analysis posed various challenges, largely due to the lack of documentary materials supporting the study and the difficulty of interpreting the texture of the façade's walls. Certain sections of the façade, such as those above the two doors and the quoins, were covered with fibre-reinforced mortar to reinforce the wall, along with metal structural elements installed during the safety measures implemented after the 2016 earthquake. In May and June of 2019, a laser scanner and total station survey were carried out. Moreover, the façade's current condition was documented through photogrammetry. The drawing of the façade was created using both the TLS and orthophoto restitutions. Old photographs were rectified for areas of the masonry covered with fibre-reinforced mortar. However, the fibre-reinforced mortar presented an obstacle in studying the materials and texture of the façade. Furthermore, the repointed mortar joints made it difficult to observe the stratigraphical relationship among the units.

As a result, the building archaeology was based on identifying different stratigraphic masonry units named after numbers based on the stones' type, size, shape, and arrangement. The goal was to understand the wall-structural continuities, making assumptions regarding the chronological relationship between the identified stratigraphic units. Figure 3 shows the identified stratigraphic units.

Visualising the stratigraphic units in 3D has three representations, which do not correspond to three levels of detail (from least to most detailed). The three representations (Figure 4) can be considered as different hypotheses and uses of the 3D model, as they helped to manage the uncertainty data following the granularisation of the model.

In each case, the stratigraphic unit has specific information and related data, including details about the wall texture, texture layout drawing, pictures, and description of direct and indirect sources. The purpose of having 'direct and indirect sources' boxes is to indicate the origin of the observations from building archaeology analysis and their level of reliability. Furthermore, BAIM helps to interpret the relationship between building components, construction phases and 'structural discontinuities'.

In case 1, each stratigraphic unit includes several layers. Case 1 provides a first masonry structure, which could subsequently be detailed with the modelling of the single layers. It is a method that could be used when the stratigraphy of the wall is not known, but it is not suitable when each layer belongs to a different construction phase. In case 2, each hypothetical wall layer has its own 'consistency' and thickness. In this way, the wall is made of several layers. Case 2 could be used when different stratigraphic units belong to the same wall or additions are made with different materials whose thickness is not the same as the main wall. Therefore, each layer of the wall has its own area, volume, and physical features (chronology, description). In case 3, each stone that makes the stratigraphic unit is identified and modelled. This representation could be helpful to characterise each construction element by adding specific properties. For example, it could be used for a detailed decay analysis. However, the representation of the decay is a separate topic since the resulting mapping does not always correspond to the subdivision of the stratigraphic units. For example, biological colonisation can involve different materials belonging to different stratigraphic units. Therefore, in such cases, the decay mapping should be represented as an additional wall layer superimposed on the identified ones.

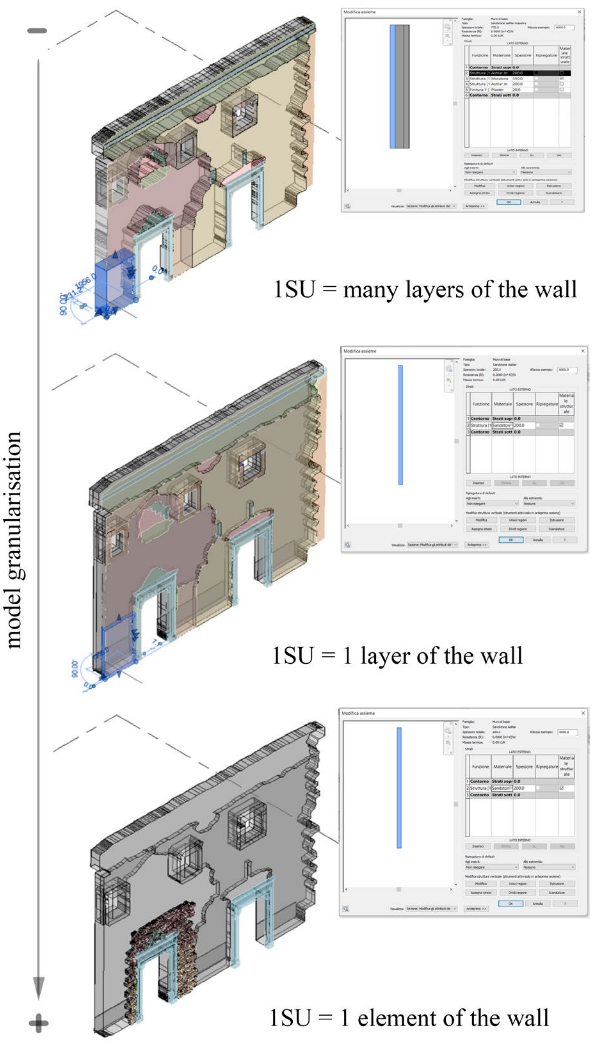


Figure 2 The three types of Stratigraphic Unit representation regarding the St. Francesco church. They correspond to a different granularisation of the model, which does not necessary correspond with an increasing level of knowledge. Model granularisation is related to more knowledge on a geometrical level but not on a knowledge base. For example, each ashlar stone is modelled; however, one can still not know the stratigraphical relationship with the masonry.

5.2 Claudius-Anio Novus aqueduct in Rome: implementing the parameters to be addressed

The Claudius aqueduct was built starting in 38 AD under the empire of Caligula and expanded with the addition of the Anio Novus *speco* (water channel) almost jointly at the beginning of the construction. The aqueduct was inaugurated by Emperor Claudius in 52 AD. The stretch of the aqueduct considered pertains to the Torre del Fiscale Park in Rome and consists of seven portions. These are mainly the reinforcement structures of the aqueduct arches since what can be observed in most sections are not the *opus quadratum* pillars, but the opus latericium structures, probably realised in the Hadrianic period to fix structural problems (Figure 5). In June 2021 an extensive survey campaign was carried out to document the aqueduct and the park, including laser scanner, total station and terrestrial and aerial photogrammetry (Banfi et al. 2022b).

The challenge represented by the Claudio aqueduct was first to

Figure 3 Sections A-G of Claudius-Anio Novus aqueduct in Tor Fiscale Park, Rome.

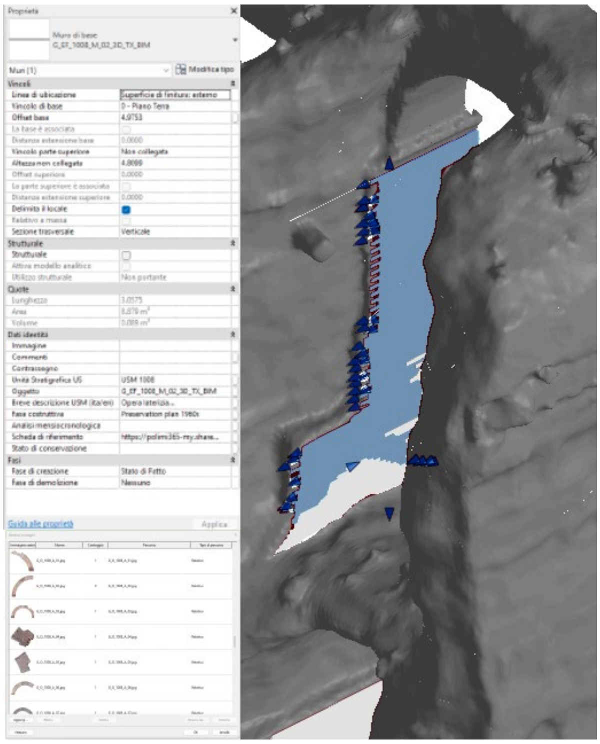


Figure 6 Stratigraphic units and *opus caementicium* in BIM environment (Autodesk Revit).

model elements characterised by unique morphological features (such as the *opus caementicium*), second to define the parameters to be implemented for the preservation project and the diagnostic investigation.

Opus latericium (brick work) construction technique is characterised by coarse-laid brickwork used to face a core of *opus caementicium*. For this reason, the opus caementicium was modelled as a single stratigraphic unit. Wall-BIM objects were created for each stratigraphic unit as the facing of the *opus caementicium*. Although more or less large areas of reconstruction of the *opus caementicium* can be observed, the brick facings have been replaced the most during the restorations that occurred over the centuries. It was therefore decided to direct the stratigraphic analysis towards identifying the various brick facings (Figure 6). Then, the parameters referring to the identified stratigraphic units were implemented.

Specifically, the parameters implemented for each modelled object-stratigraphic unit, referred to in the 'Identity data' section, concern (Figure 7):

- Stratigraphic unit: the stratigraphic unit relating to the parametric object (e.g. USM 1002);
- Object: each parametric element is uniquely identified by a code which consists of a first letter corresponding to the stretch of the aqueduct (A, B, C, D, E, F, G, H), by a second letter indicative of the orientation of the stratigraphic unit (N = North, S = South, W = West, E = East), by the number relating to the stratigraphic unit (from 1000 to 1012), a further letter indicating the type of stratigraphic unit (M = masonry, S = Surface), a progressive number to differentiate similar elements. Finally, three acronyms: 3D, TX (texture) and BIM which, indicate the actual parameterisation and texturing in Revit of the object (e.g. G_O_1002_M_01_3D_TX_BIM);
- Brief description of the stratigraphic unit in Italian and English;
- Construction phase (if known or hypothesised);
- Mensiochronological analysis (for brick facings and stone ashlars if available);
- Reference file: link to the external repository where the files in PDF format referring to the individual stratigraphic units are kept;
- State of conservation: brief description of the current state of conservation and links to reference files.

Furthermore, the orthomosaics relating to each stratigraphic unit have been uploaded in the 'image' section so that they can be viewed and made accessible as documents that can be consulted separately. The data can be exported as an Excel spreadsheet, making them available and modifiable by the subjects involved. At the same time, Excel can be used as a base grid for the definition of an accurate database which can subsequently be connected to the BIM. A database that can also consider future diagnostic investigations that will need to be carried out. Mortar characterisation investigations are currently being carried out for each stratigraphic unit identified in the BAIM.

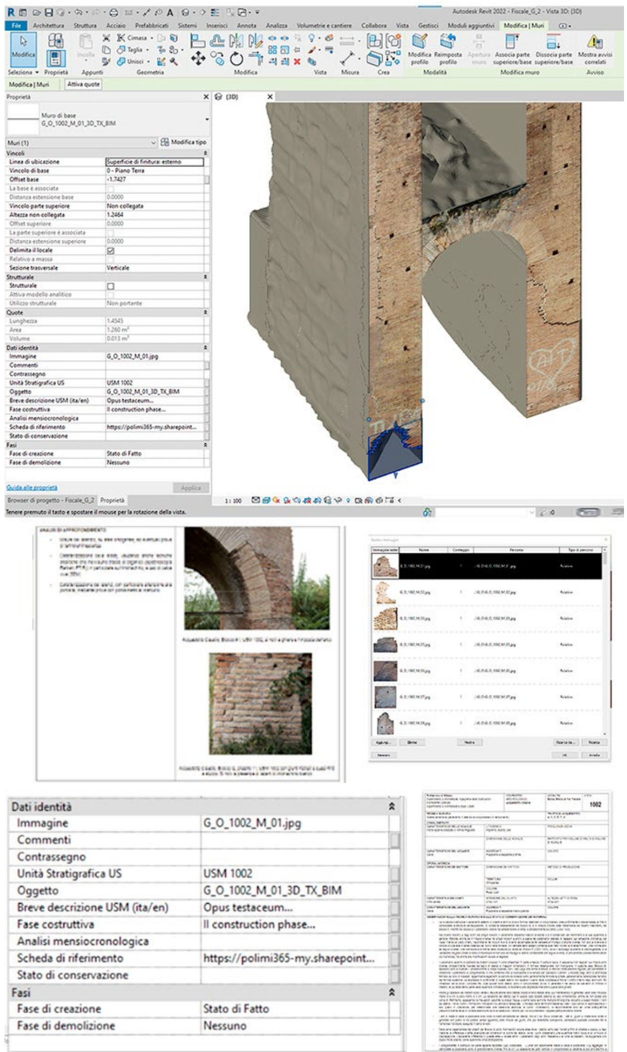


Figure 7 Implemented parameters for each stratigraphic unit and associated links (descriptions, construction phases, materials analysis and dimensions, documents, spreadsheets, orthophotos, images).

6. DISCUSSION AND FUTURE DEVELOPMENTS

The two case studies show some of the application possibilities of the BAIM. In the first case, the three representations adapt to different levels of knowledge and project needs. The second shows the parameters that can be implemented when dealing with archaeological structures. Since there are no standardised methods or tools for the 2D representation of building archaeology, exploring and developing them for 3D representation is required.
For instance, the survey and model parameters could be incorporated in the examined cases, despite verifying the accuracy of each stratigraphic unit's models in Rhinoceros. The parameter could be implemented by inserting 'survey methodologies' and 'degree of accuracy' descriptions. In the first case, it could be added if the survey tools took (laser scanner, photogrammetry or direct measurements). In the second, the quantification (in mm) of the accuracy of the modelled object with respect to the point cloud or the metric scale at which the survey was carried out. In the case of interoperability modelling, the Grade of Generation and Grade of Accuracy (Banfi, 2017) could also be entered. LoDs (Level of Detail) could be inserted in a survey and modelling process based on detail levels.
Another topic concerns the construction phases of the stratigraphic units, which can be inserted in Revit as a simple description or visualised through the graphic settings as colour thresholds. Also, the stratigraphic relationship between one unit and another is inserted as a description field. However, one could instead hypothesise more sophisticated ways to visualise it.
Furthermore, in the case of BAIM for preservation intervention, it is necessary to understand who should create the model and take care of the subsequent management, not only in the design and construction phases but also in the following phases and once the intervention is finished. If the company in charge of the preservation works has skilled personnel, then it can provide the client with this type of service: building the model and depositing the information that settles hand in hand with the progress of the works. However, once the tender contract has been completed, the client should hire personnel capable of continuing to update the model over time, to monitor and record the activities.
This issue is related to managing the knowledge stratified over time, i.e., sharing, archiving and returning a great deal of data deriving from a multiplicity of contributions. Shared use, even later in time, means connecting BIM models to data sharing environments (Common Data Environment), i.e. virtual environments, such as clouds and servers, to which all the actors involved in the intervention can entrust their work and files, organised and structured in order to trace the progress of the activities, identifying roles and responsibilities and providing up-to-date and complete information.

7. CONCLUSIONS

In the general framework of research on built heritage, the paradigm shift from traditional to more advanced digital tools defines the latter as collectors of many processes: from visualisation to the three-dimensional re-proposition of constructive hypotheses, from building archaeology to preservation project, from the collection of analyses and diagnostic investigations to the development of databases. Digital tools, such as BIM, are flexible tools that adapt to research and can also support the transmission of the collected data.
It is always necessary to balance survey resources, modelling possibilities, stakeholder needs, and expected outputs to design a useful BAIM for the project.
In the case of an HBIM model oriented to building archaeology, it is necessary to evaluate the need for such detailed and specialised modelling. For example, the model's granularisation could follow the preservation works' requirements, which need the differentiation of the elements based on the material and decay analysis and to make work computation. It could then be a practice not widespread on the whole structure subject to intervention or a phase after initial modelling for architectural elements.
These considerations should be included in a broader perspective of managing digital tools in the work practice of architects and restorers in line with the digital transformation in Europe (EU BIM Task Group, 2017). For example, using HBIM models for heritage preservation in Italy has evolved as a practice developed over previous decades and influenced by the regulatory requirements imposed since 2016 for public building works. (UNI 113377-2017, DM312/21). Therefore, it is increasingly frequent to make use of new technologies and methodologies based on the digitisation of the building process, also for the built heritage (Gasparoli et al. 2018; Raimondi, Attico 2021). However, the widespread use of HBIM still requires cultural change, operational process revision, internal skill updates, and innovative IT solutions to make procedures as flexible as possible and systems.

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