Virtual Archaeology Review, **12**(24): 49-65, 2021
https://doi.org/10.4995/var.2021.13661

Received: May 8, 2020
Accepted: October 28, 2020

HBIM APPROACH TO IMPLEMENT THE HISTORICAL AND CONSTRUCTIVE KNOWLEDGE. THE CASE OF THE REAL COLEGIATA OF SAN ISIDORO (LEÓN, SPAIN)

PROCEDIMIENTO HBIM PARA IMPLEMENTAR EL CONOCIMIENTO HISTÓRICO-CONSTRUCTIVO. EL CASO DE LA REAL COLEGIATA DE SAN ISIDORO (LEÓN, ESPAÑA)

Arianna Santoni[a], Rafael Martín-Talaverano[b]*, Ramona Quattrini[a], José Ignacio Murillo-Fragero[c]

[a] Department of Civil and Building Engineering and Architecture, Polytechnic University of Marche; Via Brecce Bianche, Italy. ariannasantoni03@gmail.com, r.quattrini@univpm.it

[b] Departamento de Ideación Gráfica Arquitectónica, Polythecnic University of Madrid, Calle Ramiro de Maeztu, 7, 28040 Madrid, Spain. r.martin@upm.es

[d] Urbe pro Orbe Patrimonio Cultural, Calle Segovia 5E, 28005 Madrid, Spain. jimurillo@urbeproorbe.com

Highlights:

- A comparison of modelling strategies applied to historical buildings taking into consideration their singularities and estimation of required times and benefits.
- The division and taxonomy of the model to incorporate both the temporal sequence and the constructive aspects, allowing enrichment of the HBIM model with customized parameters.
- The development of queries generated in Dynamo to allow customized and combined searches of data, optimizing the use of the database.

Abstract:

The development of Historic Building Information Modelling (HBIM) focuses (among other uses) on the adaptation of the BIM methodology to the historical building's features, as well as on increasing geometric accuracy and on model data enrichment. Regarding the first issue, it can be underlined, on the one hand, that historical buildings are the result of a sequence of transformations that take place throughout their whole history; they cannot be considered as unitary objects that have been created in a single moment. Therefore, they have a temporal sequence which can be understood as the essence of their evolving nature. On the other hand, historical architecture has different construction materials and techniques, with other kinds of features and pathological processes that are quite different from those of contemporary buildings. In this line, this study proposes a new workflow that allows outlining new criteria that include both the temporal sequence and the constructive features of historical buildings. For this purpose, the case study of the Real Colegiata of San Isidoro in León (Spain) has been considered. In order to create the model, several modelling strategies have been used to compare both the results and the time spent in this task. Then, the model has been divided into several parts, both in terms of constructive criteria and temporal stratification, and thus, the database and the implemented information have been organized following such essential aspects of the historical building. Finally, to provide an advanced and more efficient use of the information, customized queries have been created using Dynamo, allowing searching with combined criteria and the isolation and visualization of the resulting elements. This could be helpful for both research and conservation and management activities.

Keywords: historical architecture; archaeology of architecture; historic building information modelling (HBIM); 3D reconstruction, level of knowledge (LOK), visual programming language (VPL)

Resumen:

El desarrollo del modelado de información de edificios históricos (HBIM) se ha centrado, entre otros aspectos, en la adaptación de la metodología BIM a las características específicas de la arquitectura histórica, en el aumento de la precisión geométrica y en el enriquecimiento de los datos relacionados con el modelo. En referencia al primer aspecto, podemos destacar que los edificios históricos se caracterizan por ser el producto de una secuencia de transformaciones que tienen lugar a lo largo de su historia, de modo que no pueden concebirse como objetos unitarios creados en un

*Corresponding author: Rafael Martín-Talaverano, r.martin@upm.es

momento determinado, sino que incorporan una secuencia temporal que forma parte de su esencia evolutiva. Por otro lado, a diferencia de las edificaciones actuales, la arquitectura histórica emplea técnicas y materiales constructivos distintos con características y patología diferentes. En esta línea, el presente estudio tiene como objetivo proponer un nuevo método de trabajo que permita incorporar la secuencia temporal y las características constructivas de los edificios históricos, centrándose en el caso de la Real Colegiata de San Isidoro, en León (España). Para ello, se han analizado y comparado varias estrategias de modelado, atendiendo fundamentalmente a los resultados obtenidos y al tiempo empleado en cada una de ellas. Posteriormente, el modelo se ha dividido en varias partes, teniendo en cuenta las características constructivas y la estratificación temporal y, de este modo, tanto la base de datos como la información implementada se han organizado en base a estos aspectos esenciales del edificio histórico. Finalmente, con la intención de permitir un uso avanzado y más eficiente de la información, se ha creado un sistema de consultas personalizadas con Dynamo, lo que permite la búsqueda basada en criterios combinados y la identificación y visualización de los elementos resultantes, lo cual podrá ser útil para las labores de investigación y de conservación.

Palabras clave: arquitectura histórica; arqueología de la arquitectura; modelado de información de edificios históricos (HBIM); reconstrucción 3D, nivel de conocimiento (LOK), lenguaje de programación visual (VPL)

1. Introduction

1.1. BIM and historical architecture (state of art)

The use of BIM (Building Information Modeling) methodology has allowed in the last years the improvement of several work processes related to the design, construction and management of buildings. Given that the main feature of BIM is the association of digital data to geometrical elements, it is possible to obtain a unified and easily accessible and manageable information system organized around the 3D model of the building.

Arising from the possibilities of BIM methodology, many types of research have taken into consideration its application within the frame of cultural heritage. For this reason, several authors have analysed the positive effects that BIM could carry on this area and, as an initial result, the HBIM concept (where H could refer both to historic and heritage) has been created (Murphy, McGovern, & Pavia, 2009) and became more and more paradigmatic (Simeone, Cursi, Toldo, & Carrara, 2014). For a clear overview of trends and advancements in HBIM field, literature reviews and comparative studies are available (Volk, Stengel, & Schultmann, 2014), highlighting how HBIM experts are trying to obtain tools for projects of reconstruction, documentation, management, or maintenance of CH (López, Lerones, Llamas, Gómez-García-Bermejo & Zalama, 2018). They currently show that there are important challenges and opportunities in HBIM, mainly when BIM platforms are applied before starting an architectural heritage restoration project. The hurdles preventing the feasibility of widespread HBIM approach are the interoperability within domains, the complexity of the data enrichment and the time-consuming modelling schemes. In the last years, the main aspect focused by authors is the last one: how to reduce the modelling phase in effective workflows (Biagini, Capone, Donato, & Facchini, 2016) and how to automatically transform point clouds into a parametric

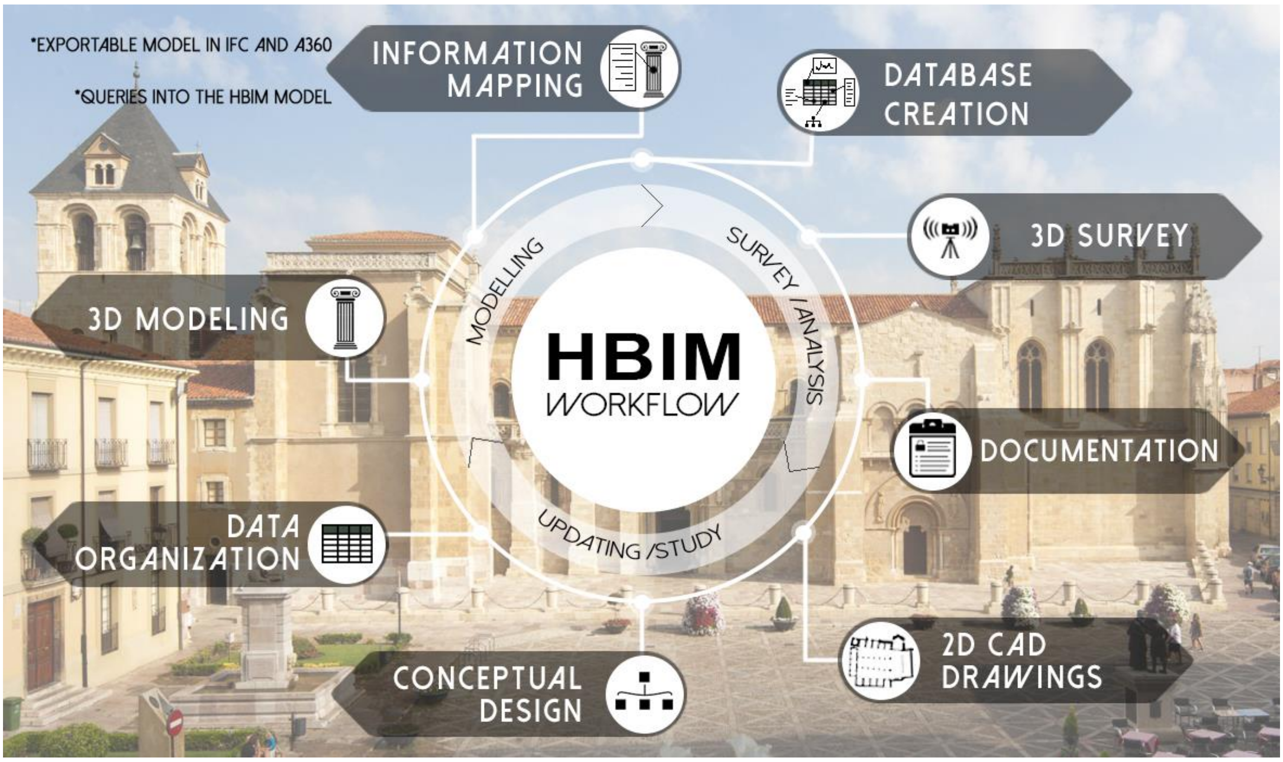


Figure 1: HBIM process.

object with Scan-to-BIM, including deep learning approaches (Malinverni et al., 2019). Other authors deal with the creation of shape recognition algorithms to automate the parametric reconstruction of entire buildings (Macher, Landes, & Grussenmeyer, 2017) or the optimization/classification of different ways of modelling historical buildings as well as the definition of the level of accuracy and geometry (Banfi, Brumana, & Stanga, 2019). Moreover, others prefer to work outside the BIM authoring environments in order to interoperate or to perform data management optimization but allowing specific queries among heterogeneous data (Gargaro, Giudice, & Ruffino, 2019). Very robust approaches show frameworks for integrating different expertise, advanced methodologies for integrated data capturing, semantic modelling in BIM environment and the development of a platform to collect, archive and share semantically enriched models (Maietti et al., 2019).

Besides, in our opinion, the aspects worthwhile to investigate are the adaptation of BIM methodology to the specific features of historical architecture, the level of knowledge that is possible to incorporate in an HBIM and the available semantical structures for historical heritage. Some authors focus primarily on the historical building analysis and on the generation of knowledge that should be incorporated in a digital replica, considering geometric accuracy as a characteristic of the model that may evolve according to its level of knowledge and development (Castellano-Román & Pinto-Puerto, 2019). Interesting studies highlight the potential of HBIM parametric intelligence and semantic structuring (Apollonio, Gaiani, & Sun, 2016). Moreover, others deal with the development of a specific library of historical architectural elements with the definition of aware Historical Building Object Model (HBOM) (Santagati & Lo Turco, 2016).

The level of knowledge could be incorporated via BIM environments or connecting external databases (Achille et al., 2020), in both cases, the data ontology and its semantical structuring are the keys for contents retrieval (Quattrini, Pierdicca, & Morbidoni, 2017). The importance of building up robust and compliant taxonomies for the management of several types of data with complex contents is well known (Adami, Fassi, Fregonese, & Piana, 2018).

The present work is developed in continuity with previous ones, in which the model is oriented to implement digital information in parametric objects focused on the interoperability of data enrichment and the semantic structures (Quattrini, Pierdicca, Morbidoni & Malinverni, 2017). Works addressing similar issues would enlarge the possibilities offered by management tools and could be exploited by different professionals in the cultural heritage domain.

1.2. Justification, objectives and methodology of the research

Although several pieces of research have approached the analysis of the BIM methodology applied to historical buildings, there are still some lacks when considering their specific features: on the one hand, the materials and construction techniques and, in the other, the temporal dimension.

Regarding the constructive issue, it must be pointed out that historical buildings include materials and construction techniques which were typical from the historical periods in which they were raised and transformed. Although some materials are still used in our time, the constructive techniques are unlike, that is, the difference does not only rely on the material but also in how such a material is used. Besides this, in most cases, no standardized elements were used, and there was not a catalogue of predefined materials, so that each element, with few exceptions, should be considered as unique. Thus, the singular constructive features of the historical architecture are quite different from those of the contemporary one and they must be considered when creating a model.

In addition, the temporal dimension must be taken into account, given that historical buildings are the product of a set of constructions and destructions that take place throughout the whole life of the building. Thus, the building is the reflection of a transformation sequence which includes a group of constructions, spaces and uses that have existed -and, in some cases, they have also disappeared- in certain moments of its history. Then, as far as the historical building is being used, its sequence will continue.

We consider that it is essential to include both the constructive issues and the transformation sequence when developing an HBIM model, given that those features involve both the 3D model creation, and the design and setting of an information system ontology. Accordingly, the transformation sequence offers, perhaps, the most adequate organization for the structure of such a database, allowing a coherent relationship of the information with the nature of the historical building. However, it is an issue that is worth to study with rigour.

Besides this, another key aspect for the adequate implementation of BIM methodology within the frame of cultural heritage is its feasibility, that is, a positive balance between the extra costs of developing a BIM model of a historical building and the benefits obtained. Regarding the use of BIM methodology in current works, it has been demonstrated the various benefits derived from it (López et al., 2018); for instance, a significant reduction of costs can be obtained during the execution works. However, it is not still clear in which terms can be assured the feasibility when dealing with historical buildings, given that it does not seem that the use of a BIM model provides economic benefits. Considering this, we are convinced that the feasibility keys of BIM methodology applied to cultural heritage objects are still to be analysed.

According to the above-mentioned aspects, this research has aimed to analyse the most appropriate strategy to properly implement the specific features of historical buildings in a BIM model within a context of feasibility, minimizing the costs and boosting the advantages in the management of the information. Thus, three main objectives can be pointed out: firstly, to study several modelling strategies in order to create a model, considering both the constructive singularities and the transformation sequence. Secondly, to analyse which is the best way to customize the information system; and, thirdly, which is the cost in terms of time, in order to analyse the feasibility key issues.

To reach such objectives, a case study has been developed: The Real Colegiata of San Isidoro in León, and a model has been created using a standard BIM application (Autodesk Revit). To do this, several criteria have been considered, such as the level of accuracy, the level of detail and the level of division according to its temporal sequence. Such temporal sequence has been obtained thanks to the methodology of the so-called archaeology of architecture, which offers the basis for the identification, division and setting of the temporal relationships of the different parts of the building (Caballero, 2010). Then, several modelling strategies have been tested in certain parts of the model in order to obtain and compare results in terms of quality and the corresponding times of execution. Besides this, the standard database included in Revit has been customized to adapt it to the required information system structure. Finally, a data search system has been developed with Dynamo, based on customized queries with combined criteria.

1.3. The case study of San Isidoro (León)

The Real Colegiata of San Isidoro, located in the city of León (Spain), is one of the most important historic buildings in the city and it comprises a group of constructions and spaces (Fig. 2). Its long and complex transformation sequence throughout its life (from the Roman Age until today) has been one of the main criteria for its selection as a case study. Several restoration and refurbishment works have been developed, and they have required various studies made by architects, archaeologists and historians to reach a proper level of knowledge of the building. Thus, another reason for the selection of this case study is the need for organisation and management of such data.

The building that we can see today is the result of a sequence of transformations that dates back to Roman times when the city wall was built. Over this structure, in the 11th century, a first church was built under the reign of Fernando I and Sancha, ca. 1063 (Utrero-Agudo & Murillo-Fragero, 2017). From this initial construction, today remains the west end of the basilica and some spaces organized in two levels between this occidental façade and the Roman wall, namely the Royal Pantheon in and the Cámara de Doña Sancha over it.

The currently existing basilica is, however, the enlargement of the first church, which was almost replaced during the second half of the 11th and the 12th centuries by a bigger one, consecrated in 1149, under the reign of Alfonso VII (Utrero-Agudo & Murillo-Fragero, 2014). It has nave and side aisles divided into six bays, and a transept and a tripartite east end.

After the temple was finished, several transformations took place. In the late Middle Ages, some buildings were erected next to the existing one: a courtyard in the southern atrium, a chapter house in the north façade of the transept and an upper platform in the west end of the nave. In the 16th century, the central apse was rebuilt by Juan de Badajoz el Viejo who provided a deeper and higher space covered with late-Gothic star vaults, and also Juan de Badajoz el Mozo was the responsible for building the library, which is attached to the south façade of the basilica. Afterwards, in the 18th century, the façade of the cloister adjacent to the basilica was built and later, a second cloister was erected in the north part of the whole complex. During the 19th century, not many works were carried out, but fire damaged the building in 1811, and this fact caused various restoration actions. Nowadays, a refurbishment of the museum is being carried on.

2. Methods and workflow of the research

2.1. Modelling

The modelling process has been based on a 3D survey which has been developed in several stages, carried on combining Terrestrial Laser Scanning (TLS) and digital photogrammetry, both supported by various control points measured with a total station. Such points have allowed the integration of all the data sets in a coherent metrical

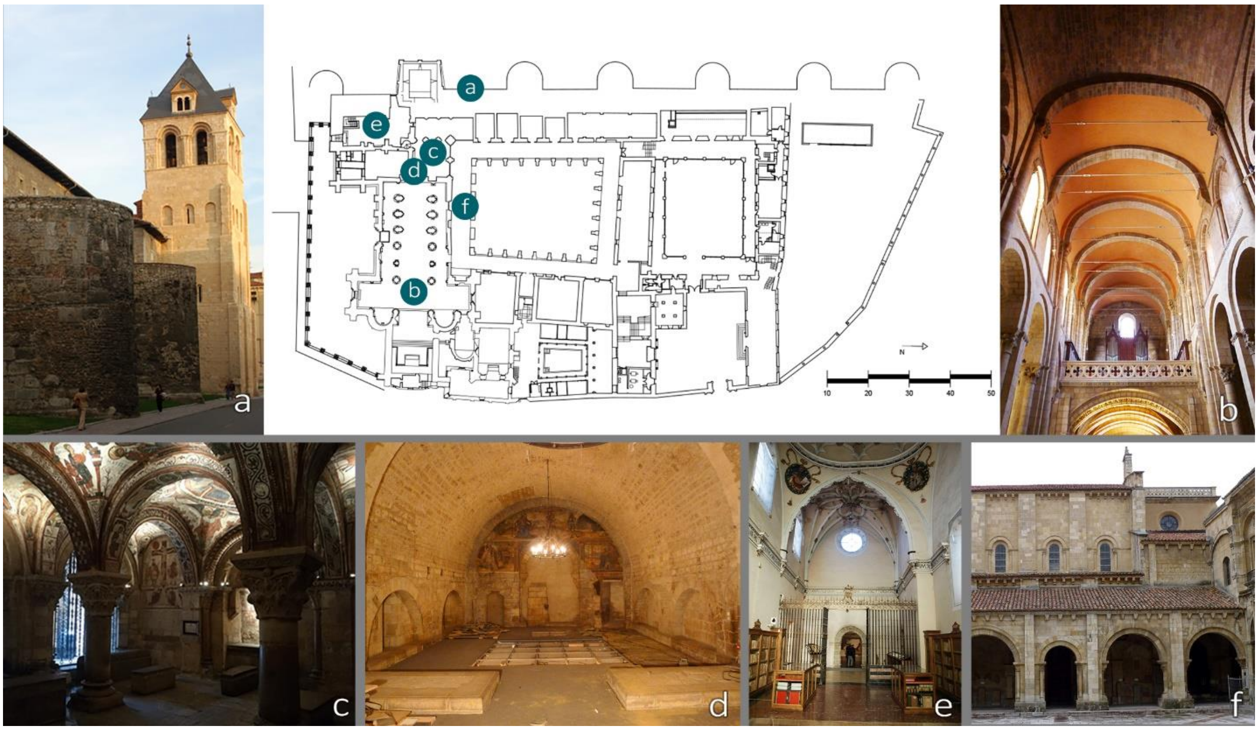


Figure 2: Plan and views of the Real Colegiata of San Isidoro: a) Roman Wall and tower; b) Basilica; c) Pantheon (ground floor); d) Camara de Doña Sancha (upper floor); e) Library (upper floor); f) Cloister.

basis, providing an overall maximum deviation of 3 cm. As a result, dense cloud points and triangular meshes were obtained, and they have provided the geometrical basis for the modelling process.

The advantages of such not invasive method on the buildings and the high precision of the results, consisting of a discrete model (point clouds), are well known (Nespeca, 2018); (Quattrini et al., 2015); (Lerma, Navarro, Cabrelles, & Villaverde, 2010). The geometry of the model is one of the most studied aspects of the recent works in the HBIM research field. In particular, several researchers are performing robust methods to obtain an accurate model of historical elements like vaults, arches, columns, damaged walls, walls with variable sections, historical decorations taking into account various precision degrees and comparing several grades of geometry and/or information (Banfi, Brumana & Stanga, 2019; Santagati & Lo Turco, 2016).

Table 1: Survey Data with Topcon GLS 2000 laser scanner and JRC 3D Reconstructor software.

Survey technique	*Building*	*Number of captures*
Maximum error: 4mm	External captures	12
	Internal captures	
	Lower Floor:	
	Basilica	17
	Pantheon	13
	Cloister	20
	Hall	9
	Upper Floors:	
	Library	3
	Camara D.Sancha	3
	Tower	4
	Corridors	11
Photogrammetrical survey: Olympus E-510 Maximum error: 3cm	External façades	319
	Pantheon	493
	Cloister	2.800
Topographic control points		53

Besides the geometrical issues, one main purpose of our research has been to implement the historical sequence by dividing the model into the different historical phases, constructive activities and stratigraphic units derived from the archaeology of the architecture's method (Caballero, 2010) and integrating the associated information. Thanks to several studies promoted by the Regional Government of Castilla y León (Utrero-Agudo & Murillo-Fragero, 2014; Utrero-Agudo & Murillo-Fragero, 2017) it has been possible to outline the historical and constructive sequence of San Isidoro. The above-mentioned analyses divide the historical sequence of the building into six main periods, and each one of them is subdivided into constructive activities and stratigraphic units (Fig. 3). This

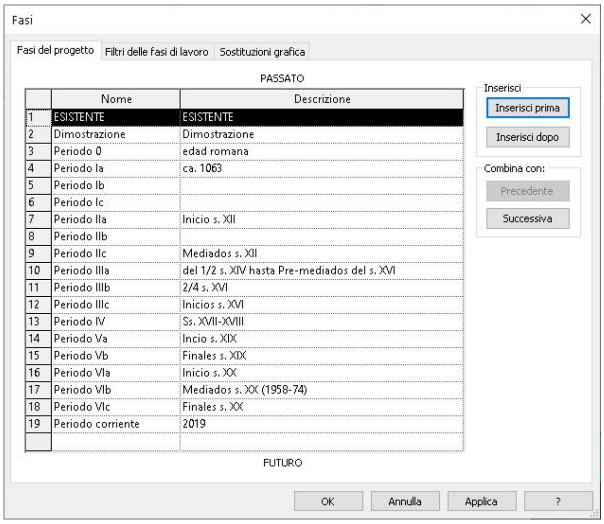


Figure 3: Historical phases implemented in Revit, according to (Murillo-Fragero & Utrero-Agudo, 2014).

analysis is recorded in a database consisting of 2D drawings, stratigraphic matrix, pictures, historical documents and tables (Fig. 4).

The modelling work mainly consisted of using two methods for different parts of the buildings: a) Modelling with Autodesk Revit® 2018 families (generation of new geometrical elements with the support of the metric data obtained in the survey); b) Modelling with other programs to transform the meshes from the point cloud obtained in the survey into NURBS. The first approach has been used to create walls, arches, regular vaults, roofs and floors. They were modelled with the help of 2D computer-aided design (CAD) drawings like plans and sections, which were also used to divide the object into different parts associated with different stratigraphic units (Fig. 5a). The imported point clouds have served as a rigorous reference system in order to control the development of the model.

The creation of more detailed and complex objects, such as columns or irregular vaults, was carried out via external families, able to build high quality and precise elements starting from the point clouds (Fig. 5b). To obtain a higher accuracy of the model compliant with TLS data source, some attempts were developed to transform the mesh obtained from the point cloud into a non-uniform rational B-spline (NURBS) model. This format allows us to add all parameters in the HBIM environment: this is a mandatory requirement to carry out the intelligent model. The tests were done concerning the central groin vault of the Pantheon.

According to other authors (Banfi, 2017), two Grade of Generation (GOG 9 and 10) are defined describing the modelling process directly from the point cloud using the NURBS model. In our case, however, the modelling process has started not with the point cloud, but with the triangular mesh generated from such point cloud. Within the first approach (GOG 9), the workflow foresees transforming the point cloud into a mesh that was imported into the Rhinoceros program to extract many plane sections (wireframe) used to rebuild the four parts of the vault in a NURBS model (Fig. 6). This process took a lot of time, resulting in a surface with high accuracy but lacking solid characteristics, so this method was discarded.

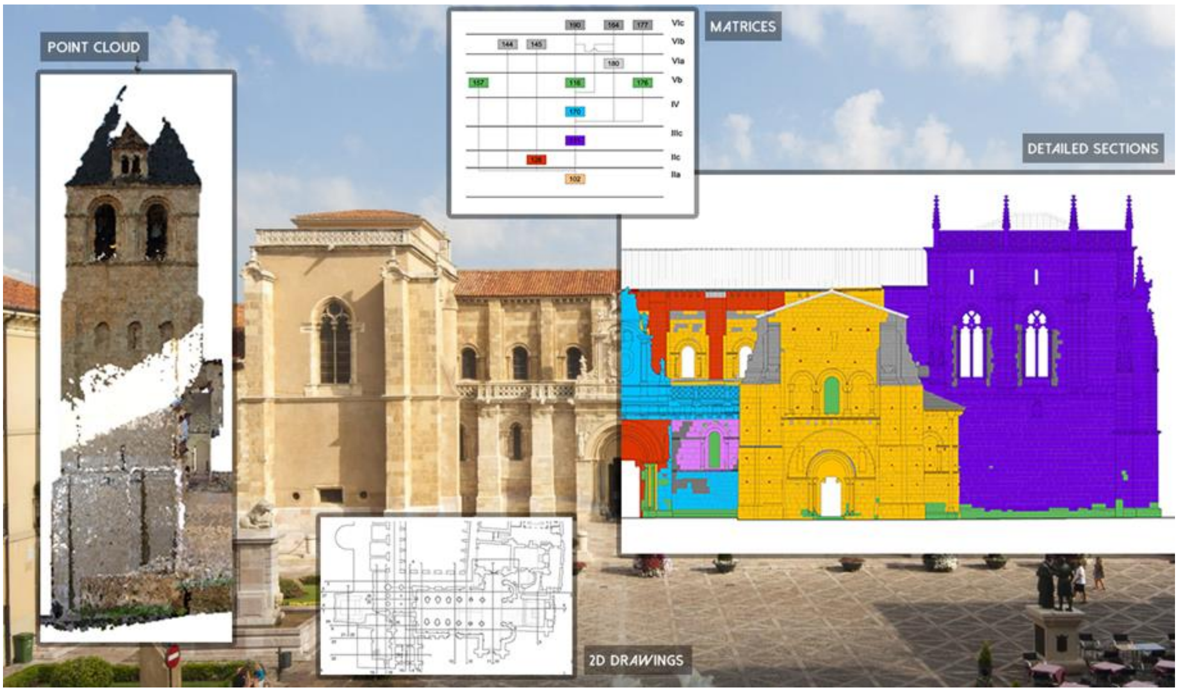
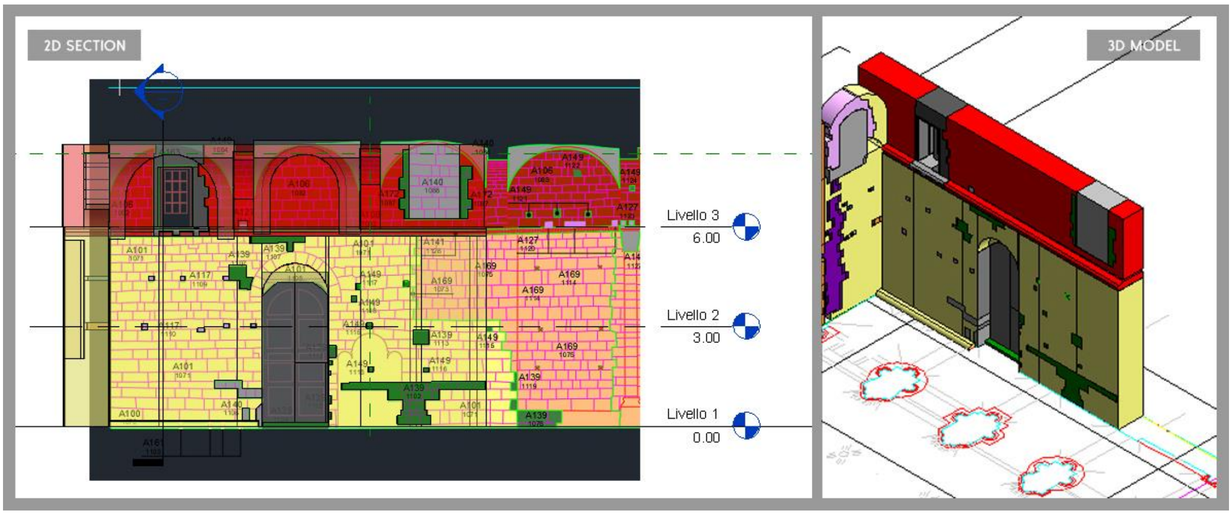
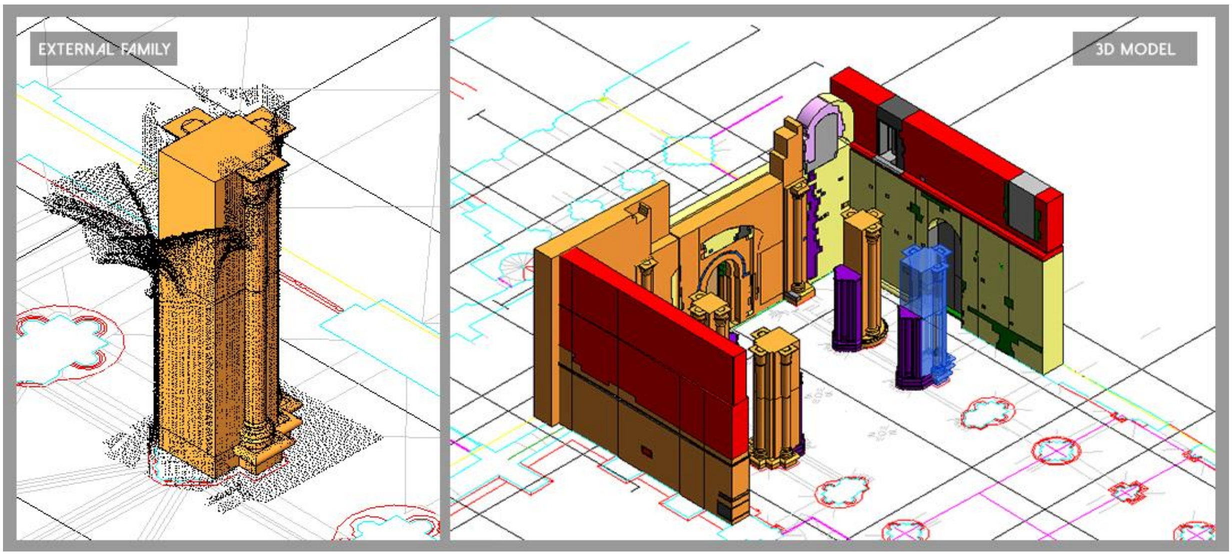


Figure 4: Surveys and data for analysis.



(a)



(b)

Figure 5: Church elements designed by 2D drawings and point cloud in internal (a) or external (b) Revit families.

Figure 6: The GOG 9 workflow from mesh to HBIM object.

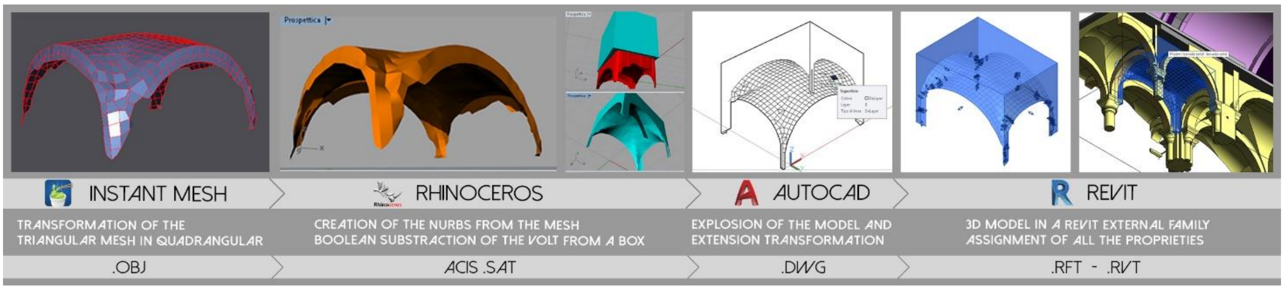


Figure 7: The GOG 10 workflow from mesh to parametric HBIM object.

The GOG 10 model overtook the first attempt, allowing us to obtain a parametric, precise and lightweight object using the Instant Mesh program, which transforms a triangular collection of meshes in quadrangular ones, easier to use. The point cloud was converted into a mesh, decimated, and then transformed into a parametric element. Thus, the .OBJ mesh file has been imported in the Rhinoceros environment, which can convert the meshes in NURBS, allowing several modelling and editing operations. Given that the processed point cloud represents internal spaces, the obtained solid represents the intrados of the vault: the solid of the vault was obtained with a simple box modified thanks to a Boolean subtraction. The final solid was exported in ACIS .SAT extension, then in AutoCAD, it was saved in .DWG extension to be imported in an external Revit family. All the material and stratigraphic properties have been then assigned to the imported family in the HBIM model (Fig. 7). We are aware that this object does not represent the actual constructive configuration of the vault, given that between the intrados side of the vault and the upper floor there is not a solid mass, but masonry layers and wooden structures; however, the presented approach for the creation of this element was useful to test the modelling process itself and to obtain the searched results in terms of accuracy and work time.

The proposed workflow to obtain a GOG 10 model is considered the most effective strategy for the research purpose: a cost-benefit analysis of these strategies of modelling is provided in the third chapter (Discussion).

2.2. HBIM taxonomy division and data enrichment: the creation of an intelligent model

As described in recent studies (Quattrini et al., 2017; Utrero-Agudo, Murillo-Fragero, & Martín-Talaverano, 2016) the HBIM model is intended as a digital database that organizes and preserves a complete set of interdisciplinary information. In an HBIM-oriented approach, the model has both geometric and non-geometric data, consisting of information collected and related to various disciplines: historical documents, monitoring data, structural information, conservation or restoration status and so on. This approach can be achieved by connecting the 3D model with a set of digital data representing a multitude of information from different fields, which helps to reconstruct the building as a whole.

In the case study of San Isidoro, in addition to the relevant data, the main analysis focuses on the methodology of the archaeology of architecture that provides information from each stratigraphic unit (detailed typological description, relationship with other units and interpretation). The criteria consist of three main divisions of the model: a) main historical phases; b) constructive activities; c) stratigraphic units. The main objective of the work was to integrate all the analysis and knowledge in the HBIM model in order to assess the creation of new forms of semantically aware models, exploiting the currently available tools. According to other HBIM studies (Castellano-Román & Pinto-Puerto, 2019) the definition of an asset modelling strategy is much more decisive in the construction of an HBIM model than the geometric accuracy. A high-resolution point cloud, or a model of high metric accuracy, can offer a real picture of reality, but not necessarily a high level of knowledge of the building.

For the case of San Isidoro, the temporal organization and division oriented the basic structure of the model in close relationship with its information system. Thus, the developed analysis allowed reaching a deep level of knowledge, both about the temporal sequence and the constructive configuration of the buildings. It has been fundamental to divide the model to properly implement the data and organize the information system (Martín-Talaverano, Murillo-Fragero, & Utrero-Agudo, 2021). The various historical phases identified during the archaeological research were implemented in Revit thanks to the parameter that highlights the creation and the destruction phase for each object of the model. Each element was then enriched by these two parameters based on the colour division shown on previous 2D CAD sections. Therefore, this first step of modelling results in a taxonomy according to the historical phases defined during the analysis.

The idea was to model the elements based on the point cloud that shows the actual situation, so for the elements still present today the destruction phase is “no one”. Following the 2D sections, the historical phase was assigned to each HBIM object. A reconstructive hypothesis was also modelled referring to the first phase when the church was smaller. A reliable geometrical configuration is built up, and then a destructive phase has been assigned in the second period, so it is not visible in the today phase. The user can browse the model in different phases by the properties of the view (Fig. 8).

The division criteria include two further steps: the division into constructive activities, which consists of different stratigraphic units. In this way, all the hierarchical levels of the semantic structure are carried out. The assignment of all stratigraphic data was obtained using the so-called “shared parameters”, namely “historical phase”, “activity ID”, “stratigraphic unit ID”. Moreover, other four parameters were created, describing the elements in contact with the selected one. Therefore, those parameters are “previous to activity”, “back to activity”,

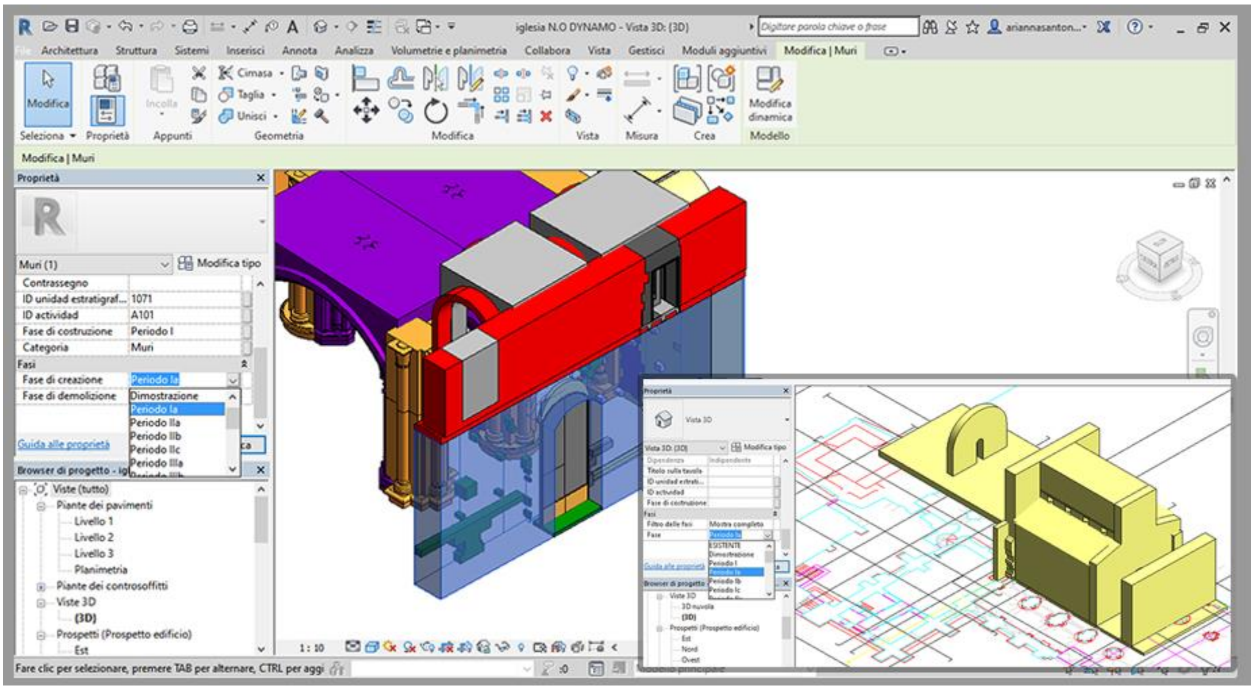


Figure 8: Assignment of the phase to each element and visualization of the model in different phases.

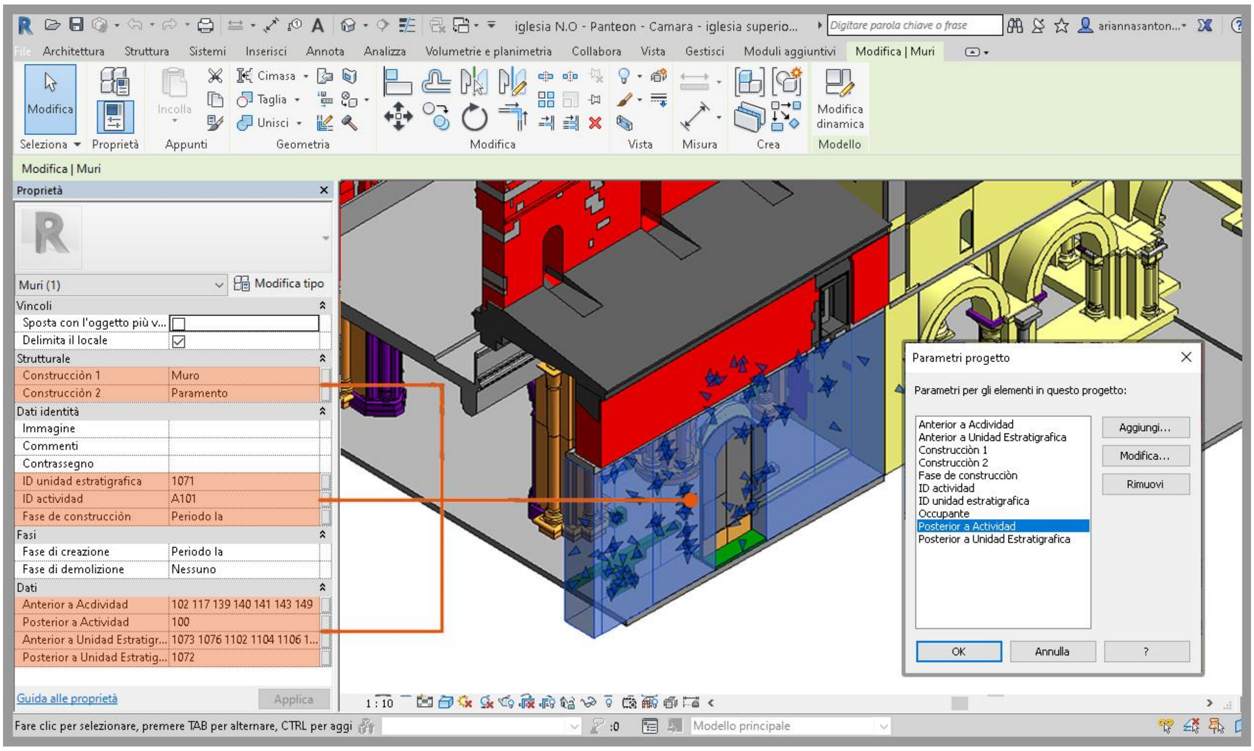


Figure 9: Properties panel of a generic wall with new parameters describing stratigraphy and construction.

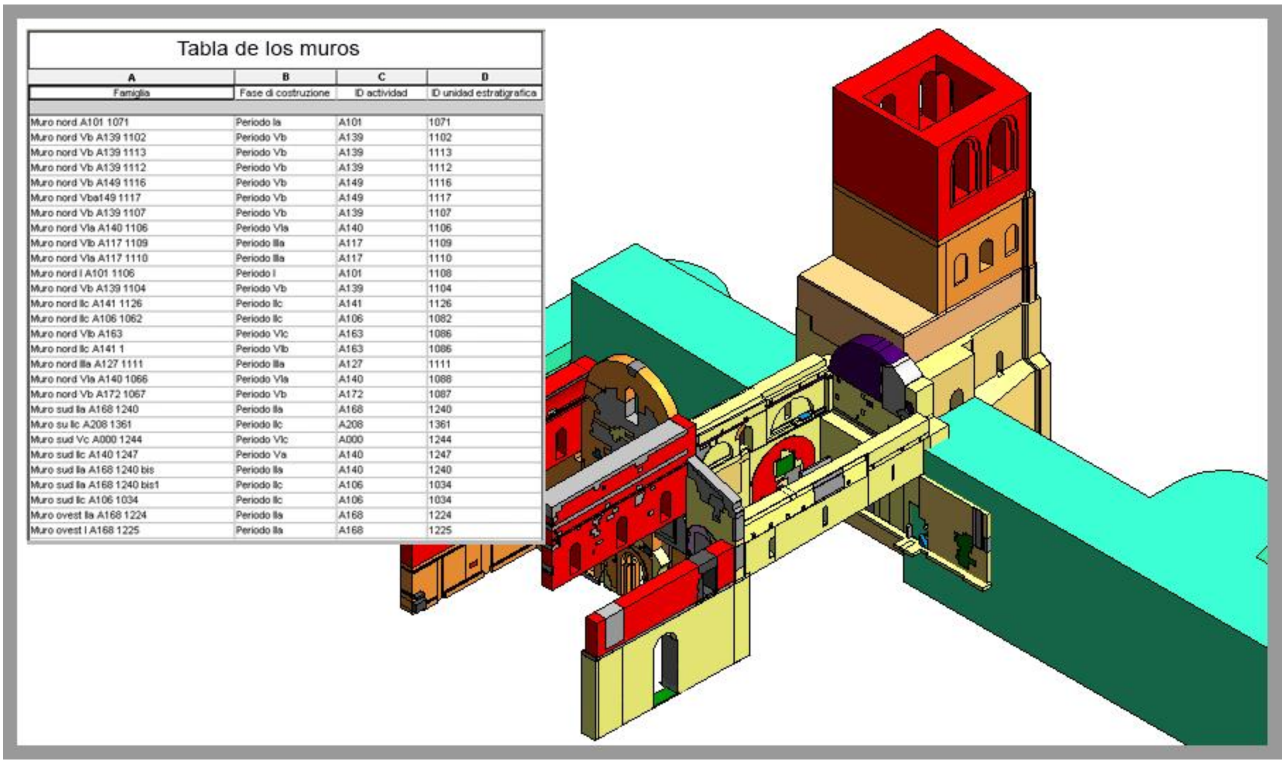


Tabla de los muros

A	B	C	D
Famiglia	Fase di costruzione	ID actividad	ID unidad estratigrafica
Muro nord A101 1071	Periodo Ia	A101	1071
Muro nord Vb A139 1102	Periodo Vb	A139	1102
Muro nord Vb A139 1113	Periodo Vb	A139	1113
Muro nord Vb A139 1112	Periodo Vb	A139	1112
Muro nord Vb A149 1116	Periodo Vb	A149	1116
Muro nord Vba149 1117	Periodo Vb	A149	1117
Muro nord Vb A139 1107	Periodo Vb	A139	1107
Muro nord VIa A140 1106	Periodo VIa	A140	1106
Muro nord VIb A117 1109	Periodo IIIa	A117	1109
Muro nord VIa A117 1110	Periodo IIIa	A117	1110
Muro nord I A101 1106	Periodo I	A101	1108
Muro nord Vb A139 1104	Periodo Vb	A139	1104
Muro nord IIc A141 1126	Periodo IIc	A141	1126
Muro nord IIc A106 1062	Periodo IIc	A106	1082
Muro nord VIb A163	Periodo VIc	A163	1086
Muro nord IIc A141 1	Periodo VIb	A163	1086
Muro nord IIIa A127 1111	Periodo IIIa	A127	1111
Muro nord VIa A140 1066	Periodo VIa	A140	1088
Muro nord Vb A172 1067	Periodo Vb	A172	1087
Muro sud IIa A168 1240	Periodo IIa	A168	1240
Muro su IIc A208 1361	Periodo IIc	A208	1361
Muro sud Vc A000 1244	Periodo VIc	A000	1244
Muro sud IIc A140 1247	Periodo Va	A140	1247
Muro sud IIa A168 1240 bis	Periodo IIa	A140	1240
Muro sud IIa A168 1240 bis1	Periodo IIc	A106	1034
Muro sud IIc A106 1034	Periodo IIc	A106	1034
Muro ovest IIa A168 1224	Periodo IIa	A168	1224
Muro ovest I A168 1225	Periodo IIa	A168	1225

Figure 10: Walls tables showing the principal stratigraphic parameters.

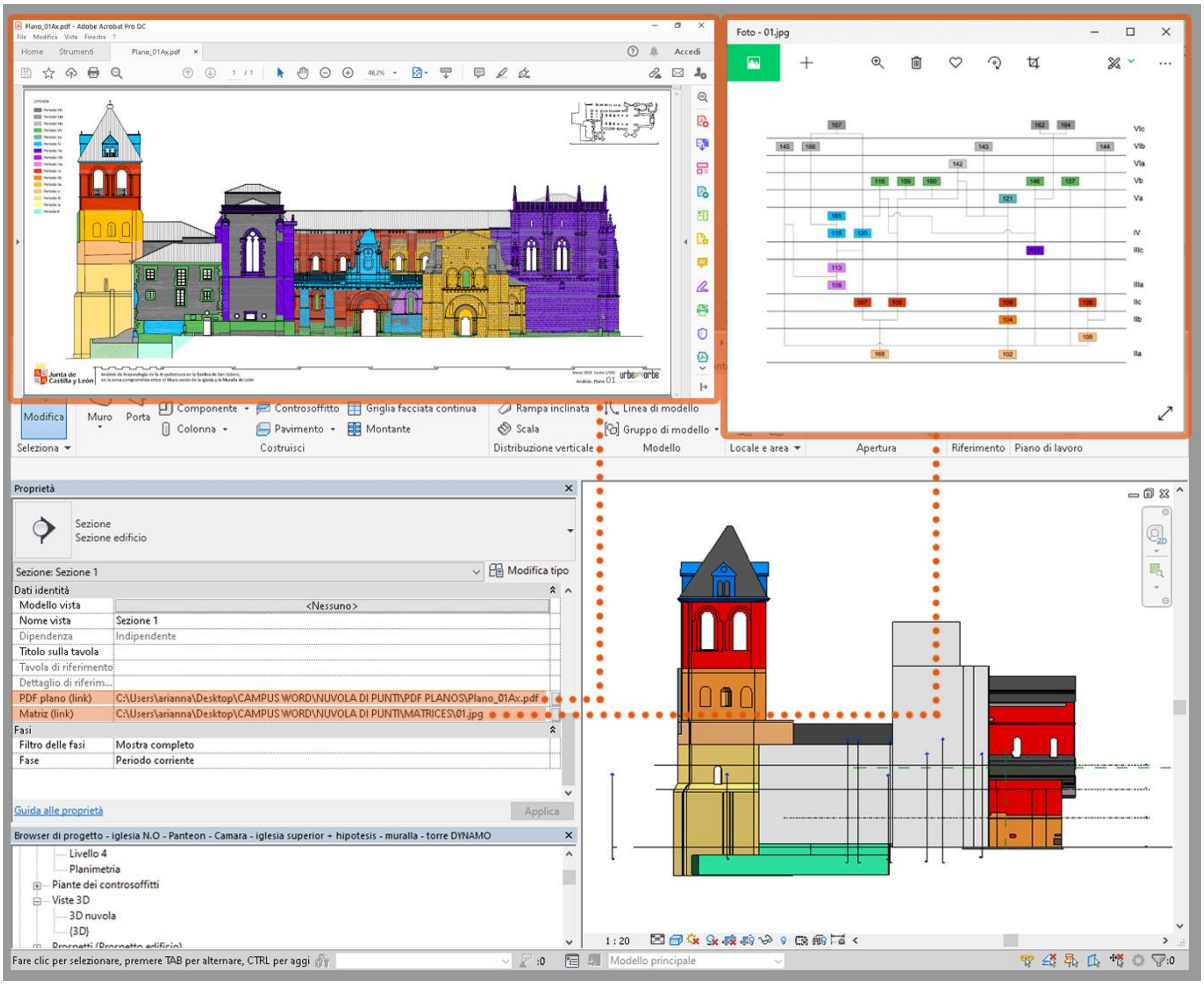


Figure 11: URL of external files opened in a simple click from the HBIM mode: PDF section and JPG matrix.

"previous to stratigraphic unit", "back to stratigraphic unit". The last analysed aspect was the constructive one, allowing to manage using the proprieties panel the family division and a deeper division in structural parts for each wall, roof, column or floor (Fig. 9).

A good way to manage the huge quantity of elements on the HBIM model is by creating tables divided into families. Those tables must show and collect all needed parameters, which could be selected in Revit. In this case, the most important ones were the stratigraphic parameters, so that each table for each family shows "historical phase", "activity ID" and "stratigraphic unit ID" (Fig. 10).

In order to enrich the HBIM model and to connect all the drawings elaborated during the analysis phase, an easy and efficient method is to use the parameters which represent an external link: it is sufficient to get to an URL describing the folders where the selected file is allocated and to take care when the model and the connected sources have to be moved.

The most important files produced during the analysis and used for the HBIM model creation are the PDF sections, which describe the different stratigraphic units, activity, and historical phases. So those drawings were connected to the corresponding sections into the model. Other connected data were the stratigraphic matrix: JPG diagrams showing the temporal relation between the stratigraphic units (Fig. 11). Those two external files were connected to the family "views", so a file is joint to the views of the property panel.

The general database created in Access was connected to the 3D view given that it constitutes the general visualization of the entire HBIM model. Within the frame of our research, several degrees of division, and thus different levels of knowledge have been implemented in the model of San Isidoro according to various taxonomy levels as it is explained below.

The matrix in Fig. 12 represents the approach to two principal aspects: the construction (represented in the vertical direction) and the temporal evolution of the building (represented in the horizontal direction). From the lowest degree of division (in the upper-left corner) to its maximum (in the lower-right corner), the complexity of the model increases in relationship with a deeper knowledge of the building. The various degrees are symbolized with different colours, and they concern different levels of division, knowledge and data enrichment in a model or a part of it.

TAXONOMY KNOWLEDGE AND LEVEL OF DIVISION		TEMPORAL EVOLUTION			
		NO DIVISION	DIVISION INTO HISTORICAL PHASES	DIVISION INTO ACTIVITY	DIVISION INTO STRATIGRAPHIC UNITS
CONSTRUCTION	NO DIVISION				
	DIVISION INTO BUILDING ZONE				
	DIVISION INTO CONSTRUCTIVE ELEMENT				
	DIVISION INTO CONSTRUCTIVE MATERIALS				

Figure 12: Taxonomy performed for the whole model in HBIM.

The lowest level corresponds to a state of no division (that is, no knowledge, no data enrichment), represented with a grey colour. Once the model has any data (any kind of constructive or temporal knowledge), a grade of colour is assigned. Following the horizontal axis, the temporal information is deeper, and a higher degree of division is applied to the model: historical phases, constructive activities and stratigraphic units. Similarly, following the vertical axis, the constructive division increases: the first division of the building is in building zones (Quattrini et al., 2017; Bruno & Roncella, 2019), then constructive elements are identified (walls, roofs, vaults, columns, etc.) and, at least, constructive materials are defined (bricks, stones, plasters, etc.). Then, a more subdivided taxonomy represents a deeper constructive and temporal knowledge of the building. The boxes of the matrix with no colour represent an impossible correspondence between levels of division and knowledge.

The knowledge of a complex building, such as San Isidoro, may not be homogeneous as well as it can be extended during different research phases. Some parts may present a more accurate analysis than others, but the evolving study allows us to fill in the gaps continuously. For this reason, some parts of the San Isidoro church have been developed and implemented in a more precise way than others. The research deals with highlighting the possibilities of the method regarding a significant part of the building, allowing to apply these ideas in other parts or other buildings. The areas with more available data are the west part of the church and the Pantheon together with the Camara de Doña Sancha. The tower, the library and the Roman wall have been developed with a less detailed level in terms of geometry as well as of data implementation. The cloister has not been included in the model because investigations are still in progress (Fig. 13). This case study has demonstrated one of the main characteristics of the HBIM methodology, that is, the possibility to progressively enrich the model by managing it through several levels of knowledge.

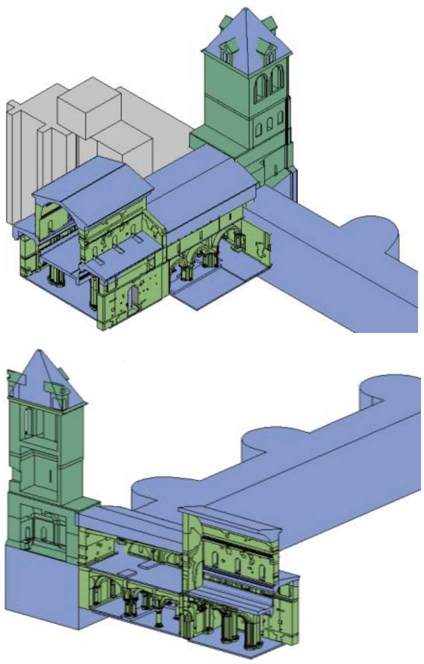


Figure 13: The HBIM model with the taxonomy representation.

2.3. Database advanced use: queries into the HBIM model

The research aimed to enable new forms of contents retrieval in HBIM, highlighting that a workflow based on common software permits to search and to find out a specific object into a Revit model. For this purpose, a current trend is represented by VPL (Visual Programming Languages). A visual programming tool aims to be accessible to both non-programmers and programmers alike. It gives users the ability to visually script behaviour, to define custom pieces of logic, and to script using various textual programming languages. It is possible to use the algorithms for a wide array of applications (from processing data to generating geometry) all in real-time and without writing a lick of code. Autodesk has implemented the graphical programming interface called Dynamo as an add-on for Revit. This platform enables designers to explore visual programming, solve problems, and make their own tools[1].

In HBIM literature, the VPL tools have demonstrated to be robust to generate geometries (Paris & Wahbeh, 2016) (Tomalini & Lo Turco, 2019) or to define ontological structure of virtual museums (Lo Turco, Calvano, & Giovannini, 2019). The present work tries to enable new applications according to the concept of division in levels of knowledge and its easy management. A specific goal is to select and isolate elements with specific assigned parameters, in particular, the stratigraphic parameters assigned during the analysis phase. In this case, Dynamo was used to create queries with new parameters (stratigraphic parameters from the archaeology of the architecture methodology) starting from two additional packages in Dynamo, called “Data-shape” ad “Archi-lab_Grimshaw”.

Those two specific Dynamo elements allowed creating a user interface to select the objects from the model and isolate them from the chosen view. First of all, it was important to choose the parameter to visualize and introduce the list of codes which respond to this parameter. The inserted twice codes and empty codes were removed from the list because similar bugs affected the running. The list was inserted into a Dynamo node that created a drop and down window, connected to the principal window visualized with some optional commands (the description, the search logo, a cancel button text, etc.). All these options are connected in a Dynamo element called “UI.MultipleInputForm ++”. Using this element, it was possible to create a function that implemented the parameter with the list and allowed to visualize the elements with the chosen code in an isolated view.

Once the visual programming has been implemented[2], the program was opened into the HBIM model, on the Dynamo player, to search the specific elements with a specific “activity ID” of “stratigraphic unit ID” or “constructive phase”. The window opened by the Dynamo program allows users to select an ID from a list with all the IDs entered during the creation of the HBIM model. Once the specific ID is selected, the program isolates the elements in a specific 3D view (Fig. 14).

The research has been also focused on developing cross queries combining several parameters. The two fundamental aspects of the HBIM model of San Isidoro have been the temporal and the constructive parameters: the first ones consisted of a) historical phase, b) constructive activity ID and c) stratigraphic unit ID; the second ones consisted of a) constructive parameter 1, which divides the element into the main families (walls, roofs, columns and floors) and b) constructive parameter 2, which divides each item into some subfamilies.

A first approach to carry on the query is a two-step one. For instance, the user may start with the “activity ID” query, and the 3D model isolates only the elements associated with this specific code. Then, into the isolated 3D view, it is possible to run the algorithm regarding the construction parameters, which allows selecting from a list about the constructive categories belonging to that specific activity ID.

A different way to isolate a constructive category belonging to a specific activity is with another Dynamo algorithm which searches elements using two parameters in a single-step method. In this case, it is possible to select an activity and a constructive category that belongs to it (Fig. 15). On the contrary, if a category not belonging to the selected activity is required, the isolated view will show nothing. It is possible to combine more parameters too, but it is necessary to know the relationship between the parameters or the results will be no one (Fig. 16).

3. Discussion

According to the feasibility of HBIM approach, the time spent to build the model itself and the time required for the implementation of the information should be mentioned. After the proper definition of modelling and taxonomy criteria, according to the level of knowledge and the objectives of the HBIM model, the time spent in comparison with the obtained accuracies has been analysed. The parts with the maximum grade of constructive and temporal division are the west end of the church, the Pantheon and the Camara de Doña Sancha. In Fig. 17, a comparison of the spent time for creating and dividing the different parts of the model is presented, considering that the operator and the computer was the same. This kind of data gives an order of magnitude and are mainly meaningful if compared with the division and level of knowledge (Fig.12 and 13).

The two parallel workflows for modelling the central vault of the Pantheon have been compared. The first one, according to (Banfi, 2017) has a GOG 9; in this case, several plane sections have been used from the mesh to build the NURBS and to obtain the parametric model. This process took about 3 h, but the final model is a simple surface, it has not all solid parameters like the materials or the volumes, so it can be useless for the HBIM model. The second method is identified with a GOG 10 and consists of directly transforming the accurate mesh into NURBS to obtain the parametric element for the HBIM model. This process took only an hour and its high geometric accuracy can be ascertained thanks to the client software Cloud Compare, using the point clouds as reference. This second model (GOG 10) has been compared to the model designed with the new Revit objects. This classic process took about 20 minutes but had twice the standard deviation in Cloud Compare (Fig. 18).

[1] https://www.dynamoprimer.com/en/08_Dynamo-for-Revit/8-1_The-Revit-Connection.html
[2] https://www3.dicca.unige.it/~cbattini/up/script/ui_query_cb.dyn

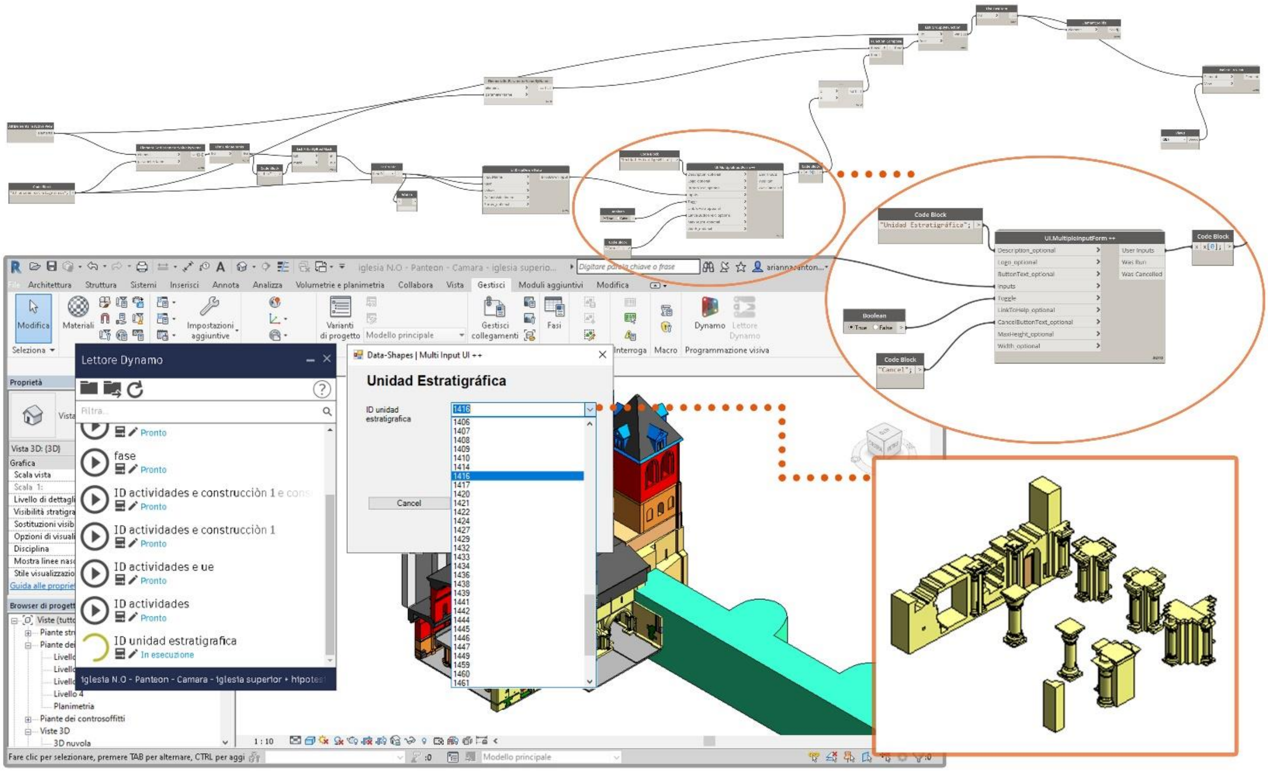


Figure 14: Isolation of elements who has a specific “Stratigraphic unit ID”.

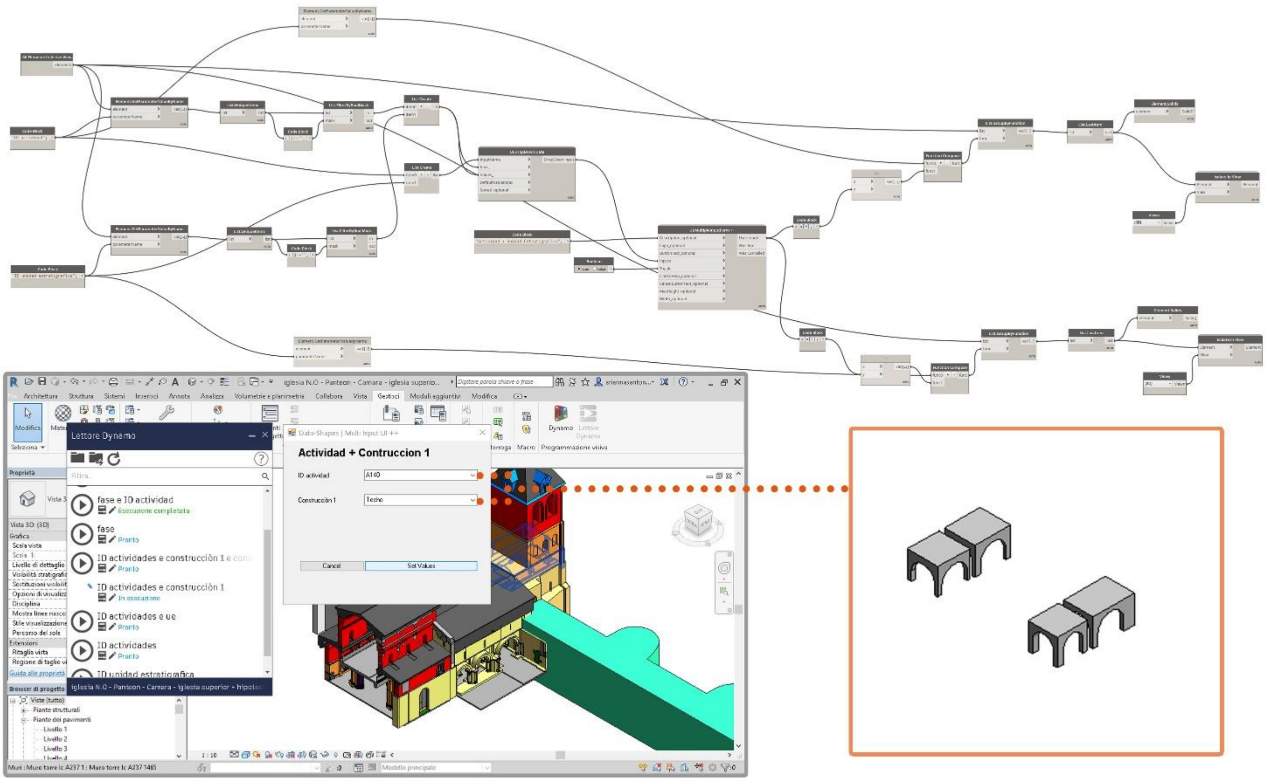


Figure 15: Isolation of elements with a specific “Activity ID” and a specific “construction category” belonging to that activity.

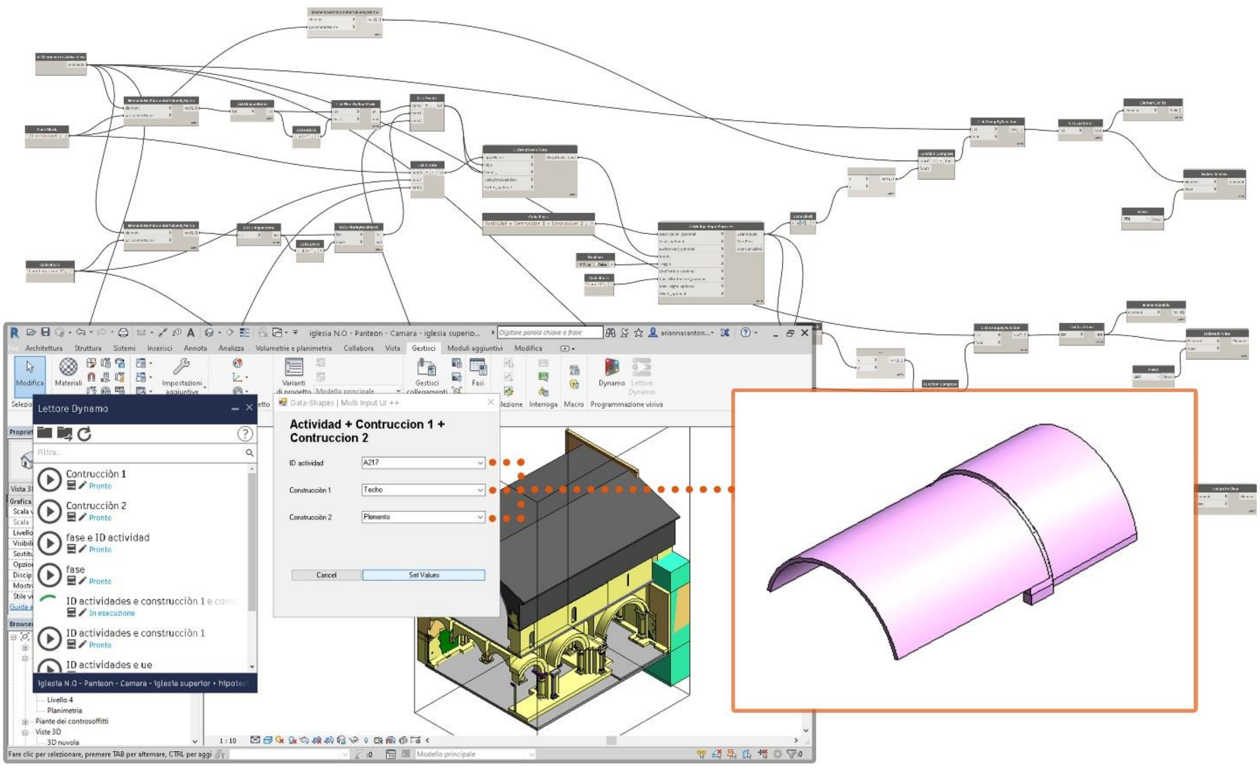


Figure 16: Isolation elements with specific "Activity ID" and two different constructive parameters.

BUILDING	FEATURES	TIME
CHURCH	Two levels Groin vaults More architectural style Four complex column Many stratigraphic units	60 HOURS
PANTHEON	One level Many columns Groin vaults and arches Few stratigraphic units	30 HOURS
CAMARA DE DONA SANCHA	One level Only 3 arches Only a barrel vault Few stratigraphic units	20 HOURS
TOWER	Two different level of precision: Lower part is simpler Upper levels divided in greater detail	10 HOURS
ROMAN WALL	Modelled only with the external shape and only with the main phase	1 HOUR
LIBRARY	Modelled only with the external shape without phases or stratigraphic division	1 HOUR

Figure 17: Time spent to create each part of the model.

A further purpose of this research was to analyse an easy-to-use way of visualization of the model for specialized users and stakeholders regarding the analysis, conservation and management of cultural heritage, trying to show the entire research process carried on the building. This issue has already been addressed in several international documents such as the London Charter, which pursues a more efficient and transparent methodology to visualize cultural heritage objects in order to allow the user to understand the asset and learn all the research processes developed in this regard. Addressing this goal, the management of HBIM aims to reduce the loss of information.

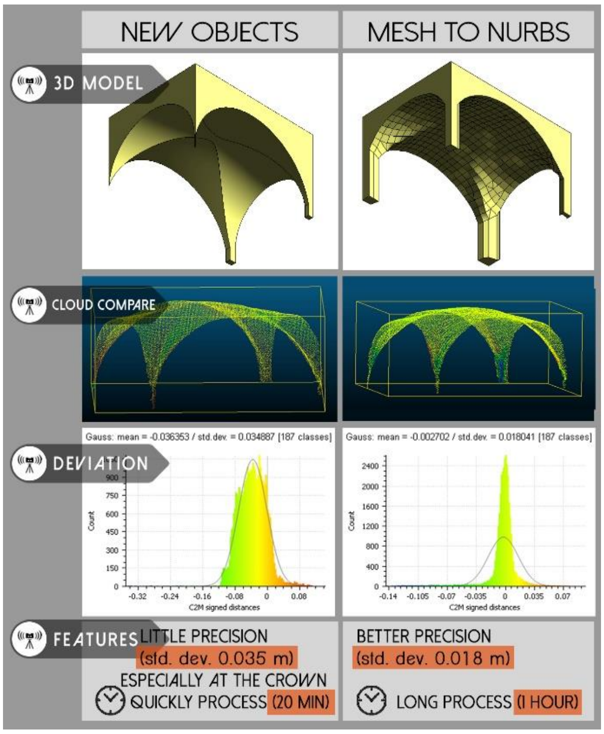


Figure 18: Comparison of the two different modelling methods.

The interoperability is possible thanks to the IFC (Industry Foundation Classes) format which allows the designer to continue working with familiar tools (Fig. 19a) and, at the same time, allows the use of all the data contained in the project in other software platforms used by other users. (Fig. 19b). The sharing of project information can also count on the many possibilities: a market-based solution is Autodesk A360. It is directly connected to BIM projects generated in Autodesk Revit. Once saved in DWF format,

Figure 19: a) Complete model in Revit; b) Visualization of the HBIM model in a client software for IFC; c) 3D sectioned view of the model in the A360 for PC; d) Proprieties of the model and phases in A360 for PC; e) App A360 for mobile.

it allows access to different parts of the model (Fig. 19c). In the present work, two folders containing the two models have been uploaded, the current one and the one assumed for the first period. Once the files have been uploaded, they can be easily viewed either directly from desktop applications or mobile phone (Fig. 19d, e). Also, freeware is available in order to ensure a complete interchange of IFC compliant information and to demonstrate to local authorities usability of HBIM approaches.

4. Conclusions

4.1. Main achievement

The research described in this article has dealt with the creation of an HBIM model taking into consideration the specific features of historical buildings, especially the constructive and temporal issues. Thus, a high complexity model has been created analysing the modelling strategies and reaching a high level of division (constructive elements and stratigraphic units). In relationship with the information management, a new knowledge-based taxonomy and data enrichment for HBIM environment has been developed, enabling to incorporate knowledge about temporal sequences and constructive aspects. Besides this, a system for customized queries to the information system via VPL has been created; given that both the model and the information system have been divided following the constructive configuration and the temporal sequence forming an integrated database, such customized queries allow a more efficient way to obtain advanced data. Both information structures can be thus compared and interrelated, providing a deeper knowledge and a more coherent and global vision of the historical building.

Additionally, the time spent with each modelling strategy has been considered; without the aim of providing absolute data (this aspect depends on various conditions), it shows the required time relationship between several approaches developed by the same person and with the same resources. This could give an idea in order to select the most appropriate modelling strategy in terms of feasibility.

4.2. Future works

This work has been focused both on the enrichment of the model with constructive and stratigraphic data and the creation of queries to search and isolate elements considering the main parameters. This method can be developed in the future with new cross searches considering new parameters with more information. For instance, the archaeology of the architecture methodology describes two kinds of stratigraphic units: elements resulted from constructions or additions, which correspond to positive stratigraphic units; and elements caused by destructions or subtractions, which are negative stratigraphic units. The current research shows a way to visualize the positive actions, but it does not represent the negative ones, so it would be important to study a method to show them. Besides this, another important parameter that should be somehow included in the HBIM model is that regarding the level of evidence of hypothetical or non-existing elements. Thus, the reliability of the information could be available. In this line, some authors have proposed the scale of archaeological evidence (Aparicio Resco & Figueiredo, 2017), which could serve as a guide for the implementation of such data.

The method applied of the division into construction phases has also been used by other authors (Marchetti, Redi, Savini, Trizio, & Giannangeli, 2017), (Brusaporci, Ruggeri, Maiezza, & Tata, 2018). They already obtained interesting thematic VR developments and analysis of collapse mechanisms, but the portability of these ontologies and interoperability issues are promising topics.

Recently, the semantic web approaches to cultural heritage have developed stable and shared processes for the representation of particular aspects such as the cataloguing of heritage or damage to monuments. In particular, two models have developed in this sense, CRMba and CRMsci, oriented to constructed archaeology and scientific investigation processes (Felicetti, Murano, Ronzino, & Niccolucci, 2015; Simeone, Cursi, & Acierno, 2019). The present work has dealt with the application of already consolidated ontologies in the BIM environment. Further research works could compare them with the above-mentioned emerging ontologies and even expand them. For a faster automated implementation between the BIM database and the information ontologies, it would be possible to conceive a specific platform defined as BIM Semantic Bridge that works to reconstruct the taxonomies of the classes of both sides so that control and value transfer operations could be performed in both directions. All these new aspects could be then implemented in an open and accessible HBIM platform, compliant also with the recent guidelines about Level of Detail (LOD) and Level of Information Needed (LOIN) (Uni Committee, 2017; Iso Committee, 2019) to enrich the knowledge of our cultural heritage.

Acknowledgements

This research has been developed within the framework of the CampusWorld programme of the Università Politecnica delle Marche (Italy). The research is also partially framed in CIVITAS, Strategic research project of UNIVPM. The authors would like to thank the helpful collaboration of both the staff of the Museo de San Isidoro, as well as of the Servicio de Restauración of the Dirección General de Patrimonio Cultural of the Junta de Castilla y León for providing the access and some data of the analyzed building.

References

Achille, C., Fassi, F., Mandelli, A., Perfetti, L., Rechichi, F., & Teruggi, S. (2020). From a traditional to a digital site: 2008–2019. The history of Milan Cathedral Survey. In B. Daniotti, M. Gianinetto, & S. Della Torre (Eds.), *Digital Transformation of the Design, Construction and Management Processes of the Built Environment* (pp. 331–341). Springer, Cham. https://doi.org/10.1007/978-3-030-33570-0_30

Adami, A., Fassi, F., Fregonese, L., & Piana, M. (2018). Image-based techniques for the survey of mosaics in the St Mark's Basilica in Venice. *Virtual Archaeology Review*, *9*(19), 1–20, https://doi.org/10.4995/var.2018.9087

Aparicio Resco, P., & Figueiredo, C. (2017). El grado de evidencia histórico-arqueológica de las reconstrucciones virtuales: Hacia una escala de representación gráfica - The level of historical-archaeological evidence of virtual reconstructions: Towards a scale of graphical representation. *Otras Arqueologías*, *1*. https://doi.org/10.23914/otarq.v0i1.96

Apollonio, F. I., Gaiani, M., & Sun, Z. (2016). A reality integrated BIM for architectural heritage conservation. *Handbook of Research on Emerging Technologies for Architectural and Archaeological Heritage* (pp. 31–65). IGI Global, Hershey. https://doi.org/10.4018/978-1-5225-0675-1.ch002

Banfi, F. (2017). BIM orientation: Grades of generation and information for different type of analysis and management process. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W5,* 57–64. https://doi.org/10.5194/isprs-archives-XLII-2-W5-57-2017

Banfi, F., Brumana, R., & Stanga, C. (2019). Extended reality and informative models for the architectural heritage: from scan-to-BIM process to virtual and augmented reality. *Virtual Archaeology Review*, *10*(21), 14–30. https://doi.org/10.4995/var.2019.11923

Biagini, C., Capone, P., Donato, V., & Facchini, N. (2016). Towards the BIM implementation for historical building restoration sites. *Automation in Construction*, *71*, 74–86. https://doi.org/10.1016/J.AUTCON.2016.03.003

Bruno, N., & Roncella, R. (2019). HBIM for conservation: A new proposal for information modeling. *Remote Sensing, 11(15)*. https://doi.org/10.3390/rs11151751

Brusaporci, S., Ruggeri, G., Maiezza, P., & Tata, A. (2018). AHBIM per l'analisi stratigrafica dell'architettura storica. *Restauro Archeologico, 26*(1), 112–131. https://doi.org/10.13128/RA-23463

Caballero, L. (2010). Experiencia metodológica en Arqueología de la Arquitectura de un grupo de investigación. Instituto de Historia. CSIC. Madrid. In C. Martín Morales & E. De Vega (Eds.), *Arqueología aplicada al estudio e intervención de edificios históricos. Últimas tendencias metodológicas,* (pp. 103–120). Madrid: Ministerio de Cultura.

Castellano-Román, M., & Pinto-Puerto, F. (2019). Dimensions and levels of knowledge in heritage building information modelling, HBIM: The model of the Charterhouse of Jerez (Cádiz, Spain). *Digital Applications in Archaeology and Cultural Heritage*, *14*, e00110. https://doi.org/10.1016/j.daach.2019.e00110

Felicetti, A., Murano, F., Ronzino, P., & Niccolucci, F. (2015). CIDOC CRM and epigraphy: A hermeneutic challenge. *CEUR Workshop Proceedings*, *1656*, (pp. 55–68). CEUR-WS.

Gargaro, S., Giudice, M. Del, & Ruffino, P. A. (2019). Towards a multi-functional HBIM model. *SCIRES-IT - SCIentific RESearch and Information Technology*, *8*(2), 49–58. https://doi.org/10.2423/I22394303V8N2P49

ISO Committee. (2019). *UNI EN ISO 19650-1:2019 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling*.

Lerma, J. L., Navarro, S., Cabrelles, M., & Villaverde, V. (2010). Terrestrial laser scanning and close range photogrammetry for 3D archaeological documentation: the Upper Palaeolithic Cave of Parpalló as a case study. *Journal of Archaeological Science*, *37*(3), 499–507. https://doi.org/10.1016/j.jas.2009.10.011

Lo Turco, M., Calvano, M., & Giovannini, E. C. (2019). Data modeling for museum collections. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *42*(2/W9), 433–440. https://doi.org/10.5194/isprs-archives-XLII-2-W9-433-2019

López, F. J., Lerones, P. M., Llamas, J., Gómez-García-Bermejo, J., & Zalama, E. (2018). A review of heritage building information modeling (H-BIM). *Multimodal Technologies and Interaction, 2*(2), 21. https://doi.org/10.3390/mti2020021

Macher, H., Landes, T., & Grussenmeyer, P. (2017). From point clouds to building information models: 3D semi-automatic reconstruction of indoors of existing buildings. *Applied Sciences*, *7*(10), 1030. https://doi.org/10.3390/app7101030

Maietti, F., Di Giulio, R., Medici, M., Ferrari, F., Piaia, E., & Brunoro, S. (2019). Accessing and understanding heritage buildings through ICT. The INCEPTION methodology applied to the Istituto degli Innocenti. *International Journal of Architectural Heritage*, 1–10. https://doi.org/10.1080/15583058.2019.1683780

Malinverni, E. S., Pierdicca, R., Paolanti, M., Martini, M., Morbidoni, C., Matrone, F., & Lingua, A. (2019). Deep learning for semantic segmentation of 3D point cloud. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-2/W15*, 735–742. https://doi.org/10.5194/isprs-archives-XLII-2-W15-735-2019

Marchetti, A., Redi, F., Savini, F., Trizio, I., & Giannangeli, A. (2017). La chiesa di San Cipriano a Castelvecchio Calvisio (AQ) nella Baronia di Carapelle: documentazione speditiva e analisi stratigrafica 3D del manufatto. *Archeologia Dell'Architettura», XXII*, *2017*, 239–253.

Martín-Talaverano, R., Murillo-Fragero, J. I., & Utrero-Agudo, M. (2021). Reflexiones y criterios relativos a la creación de modelos BIM de edificios históricos. *Arqueología de la Arquitectura*, *18*.

Murphy, M., McGovern, E., & Pavia, S. (2009). Historic building information modelling (HBIM). *Structural Survey*, *27*(4), 311–327. https://doi.org/10.4018/978-1-4666-8379-2.ch007

Nespeca, R. (2018). Towards a 3D digital model for management and fruition of Ducal Palace at Urbino. An integrated survey with mobile mapping. *SCIRES-IT - SCIentific RESearch and Information Technology*, *8*(2), 1–14. https://doi.org/10.2423/I22394303V8N2P1

Paris, L., & Wahbeh, W. (2016). Survey and representation of the parametric geometries in HBIM Rilievo e rappresentazione delle geometrie parametriche per l 'HBIM. *DISEGNARECON*, *9*(16).

Quattrini, R., Malinverni, E. S., Clini, P., Nespeca, R., & Orlietti, E. (2015). From TLS to HBIM. High quality semantically-aware 3D modeling of complex architecture. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-5/W4,* 367–374. https://doi.org/10.5194/isprsarchives-XL-5-W4-367-2015

Quattrini, R., Pierdicca, R., & Morbidoni, C. (2017). Knowledge-based data enrichment for HBIM: Exploring high-quality models using the semantic-web. *Journal of Cultural Heritage, 28,* 129-139. https://doi.org/10.1016/j.culher.2017.05.004

Quattrini, R., Pierdicca, R., Morbidoni, C., & Malinverni, E. S. (2017). Conservation-oriented HBIM. The BIMexplorer web tool. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *42*(5W1). https://doi.org/10.5194/isprs-Archives-XLII-5-W1-275-2017

Santagati, C., & Lo Turco, M. (2016). From structure from motion to historical building information modeling: populating a semantic-aware library of architectural elements. *Journal of Electronic Imaging*, *26*(1), 011007. https://doi.org/10.1117/1.JEI.26.1.011007

Simeone, D., Cursi, S., & Acierno, M. (2019). BIM semantic-enrichment for built heritage representation. *Automation in Construction*, *97*, 122–137. https://doi.org/10.1016/j.autcon.2018.11.004

Simeone, D., Cursi, S., Toldo, I., & Carrara, G. (2014). B (H) IM - Built Heritage Information Modelling. Extending BIM approach to historical and archaeological heritage representation. *ECAADe*, *1*, (pp.613–622).

Tomalini, A., & Lo Turco, M. (2019). Parametric heritage. The digital reconstruction of P.L. Nervi's Palazzo del Lavoro in the 3Dmodelling age. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *42*(2/W15), 1149–1155. https://doi.org/10.5194/isprs-archives-XLII-2-W15-1149-2019

UNI Committee. (2017). *UNI 11337-5:2017 Titolo : Edilizia e opere di ingegneria civile – Gestione digitale dei processi informativi delle costruzioni – Parte 5: Flussi informativi nei processi digitalizzati* (pp. 1–24).

Utrero-Agudo, M. A., & Murillo-Fragero, J. I. (2017). Arqueología de la Basílica de San Isidoro de León. In M. A. Utrero Agudo, E. Álvarez Areces, J. M. Baltuille Martín, & J. I. Murillo Fragero (Eds.), *La Real Colegiata de San Isidoro de León. Diez siglos de construcción y reconstrucción en piedra* (pp. 25–166). Madrid: Instituto Geológico y Minero de España.

Utrero-Agudo, M. A., Murillo-Fragero, J. I., & Martín-Talaverano, R. (2016). Virtual models for archaeological research and 2.0 dissemination: The early medieval church of San Cebrián de Mazote (Spain). *SCIRES-IT - SCIentific RESearch and Information Technology*, *6*(2), 93–108. https://doi.org/10.2423/I22394303V6N2P93

Utrero-Agudo, M., & Murillo-Fragero, J. I. (2014). San Isidoro de León. Construcción y reconstrucción de una basílica románica. *Arqueologia de la Arquitectura*, *11*. https://doi.org/10.3989/arq.arqt.2014.011

Volk, R., Stengel, J., & Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings—Literature review and future needs. *Automation in Construction*, *38*, 109–127. https://doi.org/10.1016/j.autcon.2013.10.023