HBIM for Planned Conservation: A New Approach to Information Management

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HBIM (Historical Building Information System) represents a very promising tool for the management of Cultural Heritage, both for daily operations and for the planned preservation of the asset itself. However, it requires a specific effort to adapt tried and tested tools and methods for new construction to existing Cultural Heritage buildings. First of all, the starting point of the process (new construction projects versus surveys of existing buildings) changes, and consequently the requirements for geometric and informative modelling change.

Especially in the field of Cultural Heritage, an in-depth and reasoned design of such (geometric and informative) models is necessary, to respond properly to the needs identified in the processes for planned conservation. To this end, an appropriate semantic classification of the building elements must be carried out prior to modelling, taking into account both documentation and geometric description requirements.

The aim here is to propose a system for managing the information component of the model that takes its cue from the internal logic of BIM (Building Information System) Authoring (Autodesk Revit©) software and takes into account the operating practices of professionals in the conservation sector. In particular, a system which no longer takes into account the traditional two-dimensional classification of elements, but which directly affects three-dimensional technological elements is proposed.

This is the case of the remains of the convent of S. Maria, near Lake Garda, where the geometric modelling was structured according to this new model of management of information content. In this way it was possible to give a complete description of the reality of the building (and its surroundings), making it more usable and readable by the operators.

Key words:
HBIM, Semantic Classification, Information Modelling.

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INTRODUCTION

While the “Building Information System” (BIM) approach has been adopted over a long period in the construction field (generally its conception is attributed to Charles Eastman in [Eastman et al. 1974]), its application to Cultural Heritage is much more recent. The concept of a “Historical Building Information System” (HBIM) has been suggested by [Murphy et al. 2009] as “a new system of modelling historic structures”. Many definitions have been given, as is evident from the diverse literature developed around this theme a recent review in López Facundo et al. [2008]. Leaving out these numerous and varied discussions, it is more relevant, for this paper, to define the role of HBIM. Firstly, it is necessary to clarify that it is not a tangible instrument, but rather a system, an approach (borrowed from the new construction sector) built to optimize the process of knowledge, analysis, design, conservation and management of an historical building. The extensive research that is developing around this approach is due (first of all) to the need shared at all levels of preserving historical Heritage. Its universally recognized value, both artistically and as evidence of the past, leads to the search for the most suitable systems for its conservation and management. On the other hand, it is a widely shared opinion that historical buildings are too

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complex for current commercial tools, which necessarily show several shortcomings in operational terms. Moreover, the transition from surveyed data to 3D model (usually a parametric one) is a very difficult process, because still mostly manual and not capable of allowing a complete and exact description of the object detected. It therefore becomes an operation, as well as subjective, also very time-consuming.

There are also further difficulties, related as always to Cultural Heritage and its uniqueness. In the BIM environment, the model consists of two entities: the graphic one (simply described as “geometric") and the informative one (with all the information related to the geometry) [Bruno 2018]. The merge of these two entities constitutes the core of HBIM systems. Moreover, linking information to different entities is a behavior which underlines another concept of BIM approach: the object-based modelling. Such an approach considers the building not as a single artefact, but rather as the sum of objects, all different from each other (at least in principle, especially in the context of “as-built” Heritage). This concept brings up a greatly discussed research theme: the necessity, indeed, to identify suitable procedures to break down a complex reality into more basic elements; elements linked together but equipped independently with their own meaning and role. In this paper, we talk about semantic decomposition or classification, just to underline the need for a meaningful reduction into such fundamental parts [De Luca 2011].

Finally, when dealing with the theme of informative and geometric models, it is necessary to remember that the concept of HBIM itself is not related to a single activity or field of use, but to a variety of application which coexist in a shared environment. This means that there are many coexistent models inside the HBIM, each with their own characteristics and ontologies, identified and described by the specialized operators who will make use the model. In this article, the semantic decomposition and the subsequent classification is thought, in fact, for an activity of planned conservation, one always necessary within the built Heritage, with its own ontologies and needs [Acierno et al. 2017].

PLANNED CONSERVATION AND HBIM

‘Planned conservation’ is a cultural heritage management process, introduced over fifteen years ago, that determined an important shift in the safeguard of these assets.

Punctual restoration work, undertaken when damage already happened or after years of abandon, widely proved its flaws, not only financially, but mainly because of the consequent loss of historical and documental matter, which is the underlying reason for conservation.

The heart of the matter called ‘planned conservation’ is the will to look after a specific asset in the long run, so to monitor undergoing changes, and avoid critic situations, anticipating them with continuous inspections of the complex historical organism. It is not restoration, conservation, maintenance or monitoring work, but more of a complex and well-structured strategy comprehensive of all those activities in a wider perspective, plus a day-to-day attentive care activity. The aim of this policy is to go beyond downright treatment of architectural, structural or artistic aspects, to include systems usage, user exploitation, interaction with the local environment and the territory and whatever else might be related to the edifice.

To better understand this renewed attitude towards built environment, it is necessary to go back to the reasons of the shift from ‘maintenance’ to ‘planned conservation’.

‘Maintenance’ is the whole of repeated repairs keeping the built-up in working order. Performing these tasks might cause the risk of losing historical matter (replaced by more recent material), by the hands of experts in traditional constructive techniques, capable of reproducing what was there without evidence of it. Therefore, the assets would gradually lose both the historical matter and the proof of its replacement. ‘Planned conservation’ takes in consideration not only the technical issues, but also the remarks of many experts in different fields, all interacting with the built fabric. Economists, jurists, sociologists, are all called for action in the development of a strategic program of accountability, that goes from looking for financial resources (to guarantee interventions) to the correct exploitation of the asset, which is intended as cultural wealth for the society involved.

The interaction of the conservation field with other spheres cannot elude contact with the newest technologies. The imposing system that needs to be implemented requires the sharing and comparison of information generated during the process of governance of the asset by all its actors.

Because of this demand, from the years around 2000, a number of technologically innovative systems have been developed, which have tried to determine a strategy of systematization for the large amount of data produced during the phases of knowledge of the asset. Digital experiments that exploited the potential of GIS tools applied to 2D CAD processing, have been promoted [Coccoli and Scala 2006]. Within these systems the geometries identifying each technological component, georeferenced properly, were linked to databases of the information items, to then be connected to the centroid or to the graphic area, representing a portion of the building.

These experiments did not have much following and have left room to other systems more suited to the characteristics of historic built edifices. Once established that data collected made reference to tangible objects, the first action taken was to develop a method of unambiguous recognition of the same technological element. From 2004, in continuity with the activity of the "Carta del Rischio" (risk evaluation plan), a fairly complex nomenclature was developed, whose valuable aspect (among others) was the unequivocal nature of the identification of the object to which data were reported.

Two of these management systems are still available.

“SIRCoP” is a database produced by Lombardy Region (Italy), in which the professional can progressively insert data (coming both from the knowledge phases and from the site) into various digital formats, thus archiving them in a systematic and orderly manner, so as to prepare and update the conservation plan, that remains articulated in the regulation predicted terms. The evolution of this software has been “PlaNet Beni Architettonici” [Della Torre 2014], that overcomes the limits of interoperability highlighted in the previous system.

The key point of these experiments has always been the correct nomenclature of the technological elements, referred to the first elaboration proposed in 2004 [Della Torre 2003; Benatti 2014]. This classification breaks down the building according to *Technological Elements Classes* (such as “Foundations”, “Vertical Structures”, “Horizontal Structures”, “Openings”, “Roofs”, “Covering”, “Ornaments”, etc.) and *Constructive Elements Subclasses* (as “Load bearing walls”, “Pillars”, “Windows”, “Doors”, “Floor”, “Vault”, etc.). With this method, each element is identified by a proper class and subclass, whose initials are used to compose an alphanumeric string that codes the objects. Particularly, the string is composed as follows:

Class + Subclass Initials:

- A numeric code with reference to the level and the room, to locate the objects inside the building: the rooms are marked with three numbers, where the first one indicates the level, while the following two identify progressively the room (e.g. 105 = room 05 at level 1);
- A progressive number which distinguishes elements of the same class and subclass that are located in the same room;

Examples of codes are provided in the table below (Table 1), with particular reference to openings (windows and doors), elements with vertical development (such as walls and stairs) and elements with horizontal development (such as floors and roofs). As shown in the following table, the numeric part of the code is slightly different according to the typology of elements. In particular, elements that are located in a room such as openings or ornaments) show the number of the level and of the room where they are; vertical elements are considered from base to top indicating only the number of the floors they connect; finally, horizontal elements refer only to the rooms on which they extend (104-107 = covers rooms 104 and 107), therefore the number of the floor is associated indirectly because already present in the coding of the room.

Table 1. Example of currently used classification, applied to windows, walls and floors

	Class	Sub-Class	Position inside the building			Progressive Number	Complete code
			Level	Room		On room	
Window	INe	Fi	0	01	_	1	INeFi001_1
						On building	
Wall	SV	Mp	0-3		_	1	SVMp0-3_1
						Always = 1	
Floor	SO	So		104-107	_	1	SOSo104-107_1

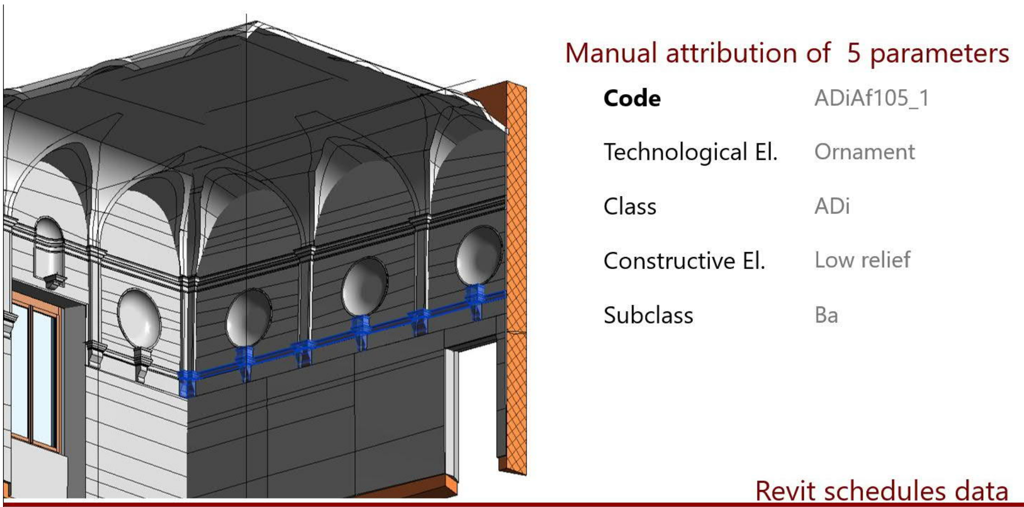
Even though this classification was conceived before BIM development, the need of breaking down the building according to technological elements suites well the BIM logic too. Each BIM model is generally defined by a “Work Breakdown Structure” (WBS), which identifies all the elements of the building in a logical way, in order to make them univocally recognizable. Each BIM-approach software solution applies a particular classification system to code elements in the model: for instance, Autodesk Revit uses a progressive “identification number” (ID), Graphisoft ArchiCAD developed a string code (“Globally Unique Identifier” (GUID)) which identifies the library objects and tracks their revised versions, and so on.

In historical buildings the need of a unique identification is even more binding because of the different and peculiar characteristics that each element presents: different geometric features, different damages and pathologies, historical stratification and so on. For this reason, an attempt to combine the BIM logic with the semantic classification currently adopted in Italy in the field of Cultural Heritage, has been made and tested on a real case study represented by the Apartment of Troia in Mantua, as described in the following paragraph. The test was made using Autodesk Revit©, but with some implementation can be extended to other BIM-approach software solutions.

Case study: the apartment of Troia in Mantua (Italy)

The “apartment of Troia” (sited in the Palazzo Ducale, Mantova) was designed by Giulio Romano between 1536 and 1539; it is an interesting case in the research about HBIM, being an elaborate existing architecture, built with very heterogeneous elements. The modelling of the Apartment [Adami et al. 2017] began, as it often happens in a HBIM environment, from point clouds obtained by means of a laser scanner. The point clouds were registered according to a topographic framework and colored with panoramic images acquired from the same position of the laser scan. For the modelling, the software Autodesk Revit© was used, to investigate the possibility of using a commercial software for non-standard architectural elements (such as for different kinds of vault and several decorative elements).

Each object of the model has been classified and then modelled according to the rules of planned conservation; the data foreseen by this approach have thus been entered into the software. For this purpose, five new parameters have been set in Revit©, by which to classify the elements. As shown in Fig. 1, these parameters refer to: the technological element name, its initials (class), the constructive element name, its initials (subclass) and the entire string code. Fig. 1 illustrates only an example of classification made on the molding that runs along the room perimeter; but all the elements that compose the model have been classified according to this methodology.



PD_ADiAf107_48	ADiAf107_48	ADi	Apparato Decorativo Interno	Af	Affresco	107_48	
PD_ADiAf107_49	ADiAf107_49	ADi	Apparato Decorativo Interno	Af	Affresco	107_49	
PD_ADiBa105_1	ADiBa105_1	ADi	Apparato Decorativo Interno	Ba	Bassorilievo	105_1	PD_Gess
PD_ADiBa105_2	ADiBa105_2	ADi	Apparato Decorativo Interno	Ba	Bassorilievo	105_2	PD_Gess
PD_ADiBa105_3	ADiBa105_3	ADi	Apparato Decorativo Interno	Ba	Bassorilievo	105_3	PD_Gess
PD_ADiBa105_4	ADiBa105_4	ADi	Apparato Decorativo Interno	Ba	Bassorilievo	105_4	PD_Gess
PD_ADiBa105_5	ADiBa105_5	ADi	Apparato Decorativo Interno	Ba	Bassorilievo	105_5	PD_Gess

Fig. 1. Example of classification made on the Apartment of Troia case study (the initials of class and subclass parameters refer to Italian words)

The parameters set for the classification, can be collected in schedules and used to query the model and filter the items according to their attributes.

The test made on this case study highlighted some limits and cons of this methodology. First of all, it is a manual process: the operator has to insert manually all five parameters for each item, which is time-consuming and increases the possibility of error. Also, with this method, the codes could be duplicated, making the elements not univocally recognizable.

In addition, such classification is suited to the traditional way of representing architecture (e.g. by 2D drawings of plans, elevations and cross sections) and, so, it follows a different logic from the BIM one. While in the BIM approach each architectural element is considered as a 3D object, the traditional methodology describes elements by their 2D views. This classification can be thus considered a 2D one, since it does not consider the elements as a whole in their 3D shape but exploits the different 2D views to give different pieces of information. For instance, information about the inner structure of a wall is provided in the plans, but information about its surface is marked in the elevations, using even different classifications of the same element. For example, the same wall can be classified as "Vertical Structure – Load Bearing Wall" in plan and as "Exterior cladding" in elevation, since the plan shows the structure, while the elevation shows the cladding (Fig. 2). This leads to mismatching in the database and makes difficult to retrace all the data referred to the same element.

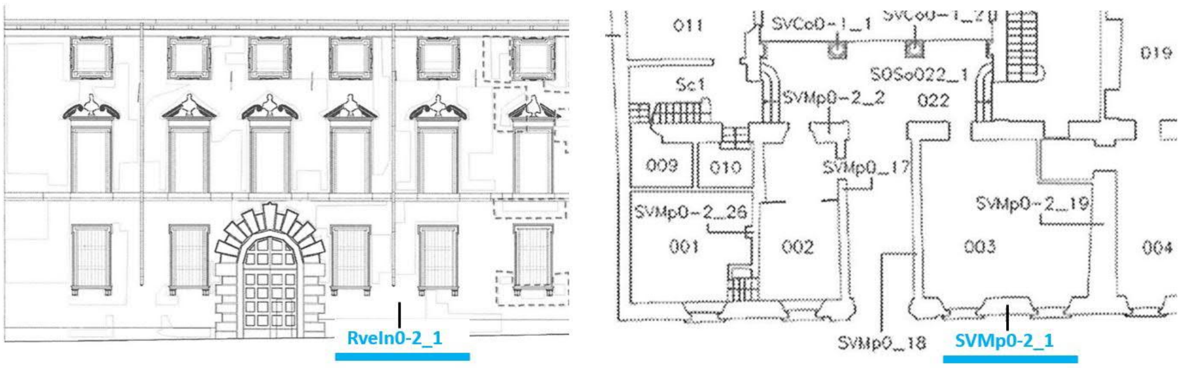


Fig. 2. Example of different classification of the same wall between elevation (Exterior cladding - RveIn) on the left. And plan (load bearing wall - SVMp) on the right

These limitations make the procedure described above not particularly suitable for BIM approach. Therefore, a new method, that integrates the classification currently used for planned conservation and the way of conceiving an architectural building typical of BIM, has been developed as well, and described in the next paragraph.

A NEW APPROACH TO CLASSIFICATION

The proposed classification method

The set up proposal wants to overcome the aforementioned limitations, providing a system able to translate the traditional classification system into a BIM environment. In particular, an automatic way of classification has been developed, to ensures time saving, error reduction and in particular to avoid element duplication.

BIM-approach software solutions are generally referred to a database, and therefore adopt a precise coding system to uniquely identify the elements. Each element is marked by a unique and progressive code (number or string), automatically generated by the system when modelled. In addition, objects are carefully categorized (e.g. divided into walls, doors, floors, connections, etc.) and given well-defined topological relationships with other elements (proximity, constraint, dependency, etc.). All these data are automatically associated to the BIM element, according to its positioning within the model and the specifics of the object itself.

For instance, Revit© classifies the objects according to:

Categories → *Families* → *Types* → *Instances*

(Door) → (double-leaf door) → (double-leaf door 120x210 cm) → (double-leaf door 120x210, no 1)

The *Category* represents the class of technological elements, e.g. foundations, walls, floors, etc. The *Family* is a group of elements with a set of common properties, called parameters, and a related to graphical representation. The *Type* represents a variation of parameters within the same family. The different elements belonging to a family can have different values for some or for all the parameters, but their set, such as names and functions, is the same. These variations within a family are called *Family Types* or *Types*. The *Instance* represents the single object placed in the model. When the user creates an element in a project with a specific *Family* and *Family Type*, an instance of the element is created. Each *Instance* is associated with the specific location parameters within the model and has a unique ID.

It was then assumed to make changes to the coding elements proposed [Della Torre 2003], to better adapt it to the organization of data in BIM, and take advantage of automation allowed by the software, in order to reduce errors such as duplications or omissions. The classification complies with the rules of planned conservation and, in addition, is tailored for BIM approach.

In particular, it considers the architectural elements as 3D objects and does not distinguish between plan and elevation. The object remains the same, it is unique, its classification is unique too and the same applies to both plans and elevations. To give information about the inner structure and the surface finishing of an element (such as a wall) BIM programs usually allows to define object stratigraphy and to associate information to each layer, avoiding the need of using different views to visualize such information.

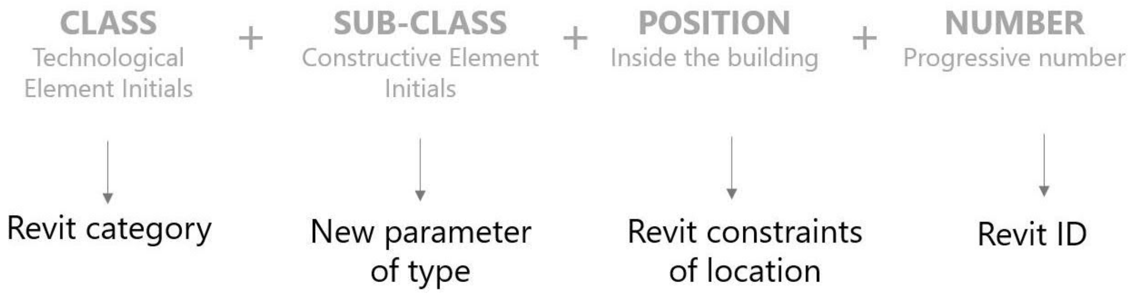


Fig. 3. Traditional and new classification comparison

Thus, using for instance Autodesk Revit©, the traditional classification system is translated as follows (Fig. 3): The *Technological Elements Classes* correspond to the *Categories* of constructive elements provided by Revit; the *Constructive Elements Subclasses* are associated to a new parameter of type which is assigned to each family. The user has to compile this value only once, and after it gets automatically associated with the element when modelled. Its position inside the building is calculated exploiting the topological relationship and the constraints given by Revit. For most of the elements it is possible to refer to the *Level* on which they are located. For elements that may extend over several floors (such as walls, stairs, pillars), the location can be defined using the base and the top-level constraints, while for furniture items, generic models, doors and windows (which are not strictly referred to a specific level) the location is provided using the number of the associated *Room*. Revit assigns a progressive number to each *Room* and the corresponding level, making the spatial identification completely defined. Finally, the unique identifier by which Revit indexes every element in the model ensures that the objects are uniquely identified.

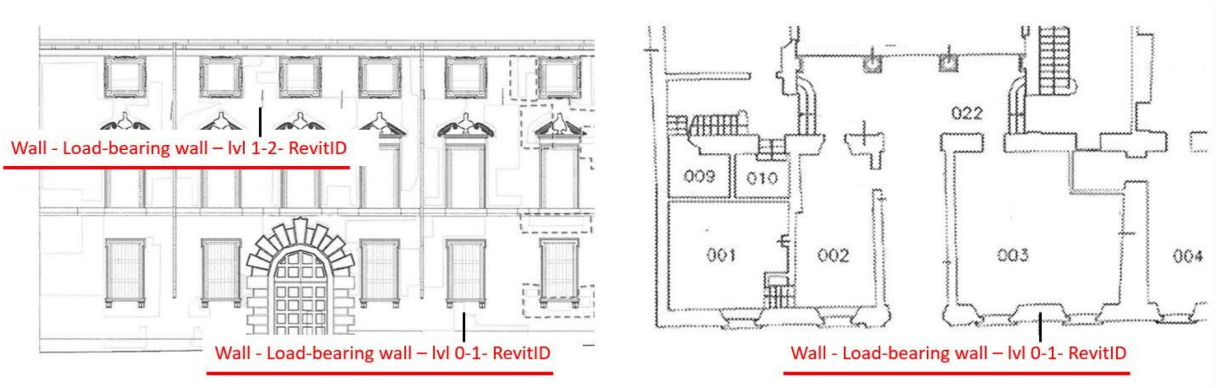


Fig. 4. New proposed classification comparison with the former (see Fig.1)

All these data are automatically associated to each BIM element; they can be collected in schedules and also used to analyze the building. In addition, since each element is unequivocally identified, it is possible to link further information, (simple files or full databases) containing descriptive data or information useful to preserve the object, as shown in the following paragraphs.

Case study: Convent of S. Maria in Castiglione delle Stiviere, Mantua (Italy)

Although a BIM model was not the main goal of the work, the investigation of this conventual complex consisted in an internal and external survey of its spaces, inclusive of the geometry necessary for the construction of a well-rounded model. What is left of a once larger structure now includes a two-stories building that covers a 600 square meters surface and a much smaller rustic building. The point-cloud resulting from the survey was then imported into the BIM environment, more precisely Autodesk Revit©. The import operation happened, thanks to a translation of the cloud in an Autodesk Recap© format file (same as in the Apartment of Troia case study). In that environment, the cloud is visible as any other object within the software; more importantly, it can be cut with section planes when needed. The point cloud object stayed the main reference for the modelling and the model check.

This case study explores classification difficulties that the apartment of Troia did not highlight: shared walls, floors and ceiling between rooms. The first modelling phase was that of defining walls for this complex; as expected, sizes, thicknesses and typologies vary constantly across the building construction. But with the creation of enough 'types' from the beginning, it was possible to reach their definition through the program's system families. However, a choice had been made ahead: since the first and second floor share the same load bearing walls, therefore the same layout as well, the models replicates this behavior, and a single wall has been drawn for both levels. The same logic was applied to the roof (that was not split for the different rooms it covers), and the floors/ceilings. What follows is that (in addition to the classification described beforehand) when interrogated, the system reads the same components instead of creating information replicas.

As far as the classification is concerned, for each element the Class is determined automatically on the basis of the category of the object modelled. In this case study, the main categories used were Wall, Floor, Roof, Column, Structural Framing, Stair, Door and Window. The Subclass was instead assigned during the creation of the families. Therefore, for each family, in addition to the geometric and stratigraphic definition, a new parameter of type containing the Subclass was created.

For instance, Walls were sub-classified in "Load-bearing wall", "Dividing wall" and "Curtain wall"; the Floors were divided in "Floor", "Vault" and "Balcony" and the Roofs were broken down in "Roofing" and "Structure" and so on, as shown in the figure below (Fig. 5).

Current classification				Proposed classification		Location inside the building						
Technological Elements Classes		*Constructive Elements Subclasses*		*Revit category*	*Parameter of type*	*level*	*room*	*Top constraint/ level*	*Base constraint/ level*	*From room*	*To room*	*Reference level elvation*
SV	Vertical structure	Mp	Load bearing wall	Wall	Load bearing wall			X	X			
		Md	Dividing wall	Wall	Dividing wall			X	X			
		Pi	Pillar	Structural column	Pillar			X	X			
		Co	Column	Structural column	Column			X	X			
		Mt	Curtain wall	Wall	Curtain wall			X	X			
SO	Horizontal Structures	So	Floor	Floor	Floor	X						
		Vo	Vault	Floor or ceiling	Vault	X						
		Cu	Dome	Floor or ceiling	Dome	X						
		Ba	Balcony	Floor	Balcony	X						
		Bl	Gallery	Floor	Gallery	X						
		Te	Terrace	Floor	Terrace	X						
CP	Roofs	Mc	Roofing	Roof	Roofing				X			
		St	Structure	Roof or structural frame	Structure							X
		Gr	Gutter	Roof	Gutter				X			
CV	Connections	Ra	Ramp	Ramp	Ramp			X	X			
		Sc	Stair	Stair	Stair			X	X			
INe	Exterior openings	Fi	Window	Window	Exterior openings	X				X	X	
		Po	Door	Door	Exterior openings	X				X	X	
INi	Interior openings	Po	Door	Door	Interior openings	X				X	X	

Fig. 5. Classification used in the Santa Maria case study

To each element, the precise location inside the building is automatically attached, making reference to the levels and/or to base and top constraints as explained in Fig. 5.

All these data can be easily retraced in schedules and used to query the model. (Fig. 6)

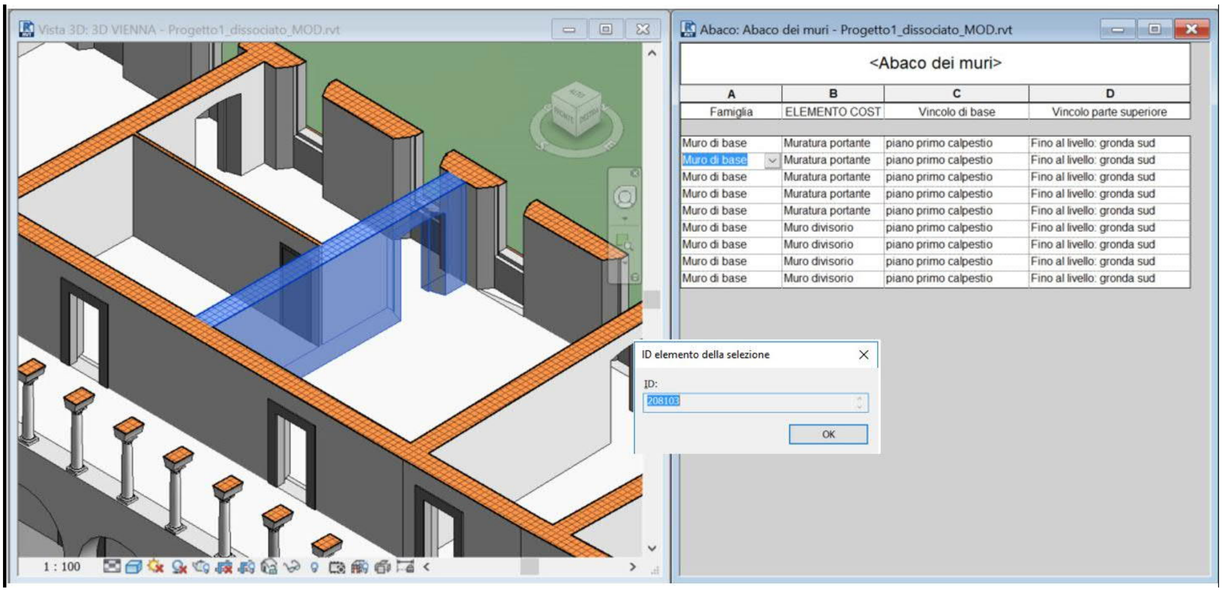


Fig. 6. Selected wall with the linked schedule

INFORMATION MANAGEMENT IN HBIM

The test carried on in the Cavallerizza courtyard at Palazzo Ducale (Mantova), was set up to reach different study levels within the model, according to the data available for input. More specifically, starting from the survey point cloud, a first “generic” model has been developed, to which to link topographic survey data, current and historical cartography and information derived from the “Carta del Rischio”.

Later, a second level of analysis, called “architectural”, determined the definition of the technological component as the smallest item for attaching both historical information (previous investigations, descriptive reports, photographs, graphic schemes, and so on) and planned conservation generated data (surveys, monitoring, small interventions) part of a complex care-program for the building. During the last elaboration phase, the "detailed" one, the aforesaid component was broken up, and eventually the information regarding the planned conservation project plan were added. Such layout of the model, has allowed us to provide the correct graphic and organizational depth in relation to available information, avoiding redundancy or lack of support.

Link with external database

As mentioned previously, another way of associating information to the model can be done by linking the model to an external relational database containing all the data needed for planned conservation activities. The adoption of databases for structuring and managing data related to historical buildings ensures a better organization and retrieval of information, and a resulting overall consistency.

To document a cultural asset, the available data sources are many. Survey data (geometric, material, decay, structural or monitoring data) are principally used, in addition to which, photographic images, archival data, historical documents, reports etc. can be useful. Generally, these data have an articulated structure, with complicated and multiple relationships, therefore a proper layout of the database can improve the correct and exhaustive description of the building. Although BIM programs allow new parameters to link all the desired information to the elements (texts, number, files, images and so on), this imposes some limitations and does not provide as much flexibility and organization as traditional relational databases do [Bruno and Roncella 2019]. Such limitations are often binding, and a considerable interest is arising in the development of solutions to link BIM and external databases, allowing easier data management.

In this case study, according to a methodology tested in previous research works [Bruno and Roncella 2019], a specific database has been structured to host all the descriptive data about the building, in order to manage the planned conservation activities. In summary, such data can be grouped into building identification and descriptive data, risk factors, owners' details, morphological and descriptive characteristics of each element, information about surveying, pathologies and conservation activities.

The link between the BIM model and the database is ensured by the ID which univocally identifies each object into the BIM model: each element of the model finds a unique equivalent in the database to which to link information. The application works with Revit as a plug-in: each Revit project is associated with a database, which is accessed when the project is opened. Directly in the Revit environment, it is therefore possible to view/enter all the information related to the model and directly access the database. In order to simplify the interaction with the database, graphical user interfaces have been implemented, to make data entry and editing easy and intuitive for the user. An information dialog box opens when the user selects the item (as shown in Fig. 7).

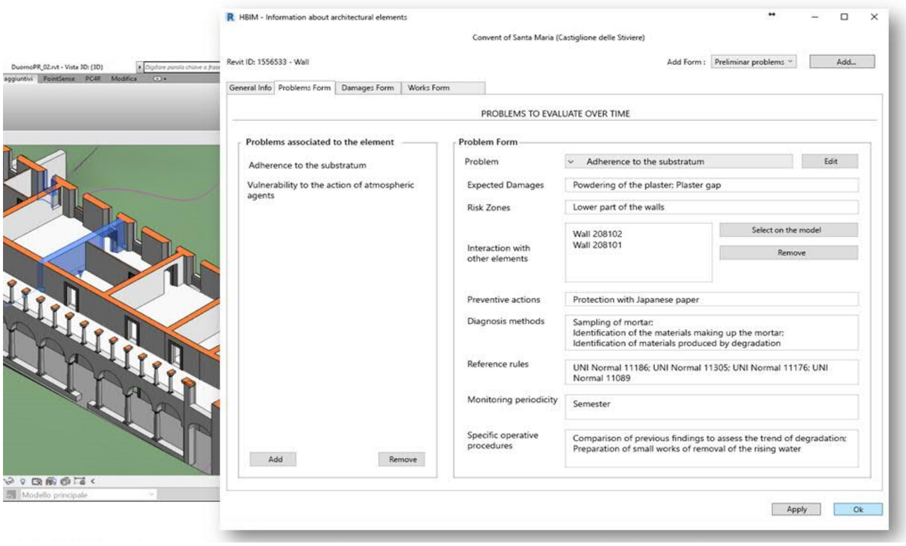


Fig. 7. Example of access to database inside Revit environment. The form refers to the evaluation of the pathologies that can affect the object

CONCLUSIONS

In this paper, a new classification method has been suggested, trying to overcome the limitations of the traditional 2D approach and to fully exploit the potential of BIM-authoring solutions. The possibility to have the same component linking the interior and the exterior of the building with its inner structure is a very reliable approach for those who work in the Cultural Heritage field, for the knowledge, design and also management of the asset.

The tests conducted on the convent of Santa Maria and on the Cavallerizza courtyard, very different both in terms of architecture and in terms of project goals, have demonstrated the sensitivity of this method. They also highlighted, of course, the difficulties in proposing a unique and standardized system, which is hard to combine with the uniqueness of Cultural Heritage; but it confirmed the possibility of using guidelines to implement, in detail, each individual complex case.

Nevertheless, we should never forget the desiderata of the specialized operators who intervene in the various BIM processes. It is necessary, in fact, to define with great precision the ontologies that each discipline needs to implement in the BIM, so as to verify or design the semantic decomposition, not only in accordance with the characteristics of the building, but also with the desiderata of the operators. The proposal described in the paper is based on experiences of planned conservation on the “as-built” heritage. However, there are many other specific sectors where this classification could take on different rules (dictated by different operators) such as structural design, plant design, energy evaluation, etc.

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