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

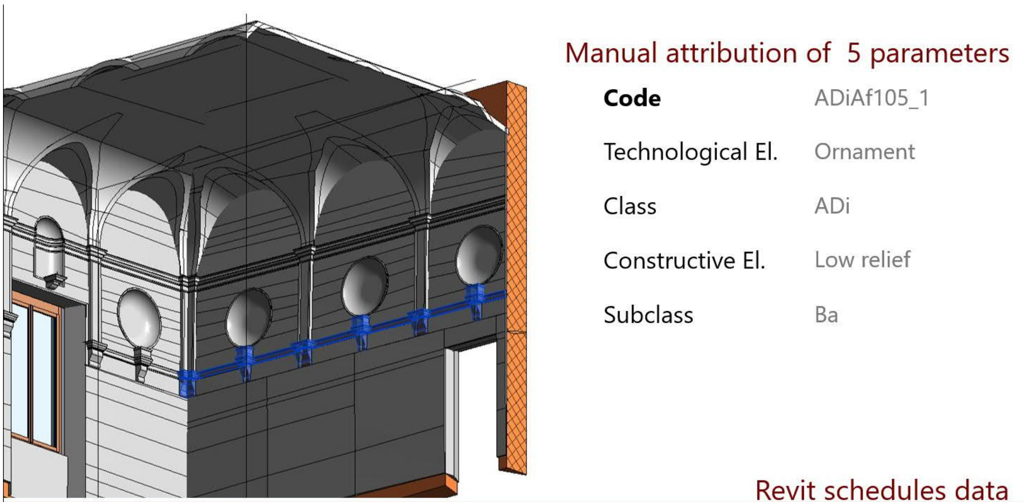
Even though this classification was conceived before BIM development, the need of breaking down the building according to technological elements suites well the BIM logic too. Each BIM model is generally defined by a "Work Breakdown Structure" (WBS), which identifies all the elements of the building 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.

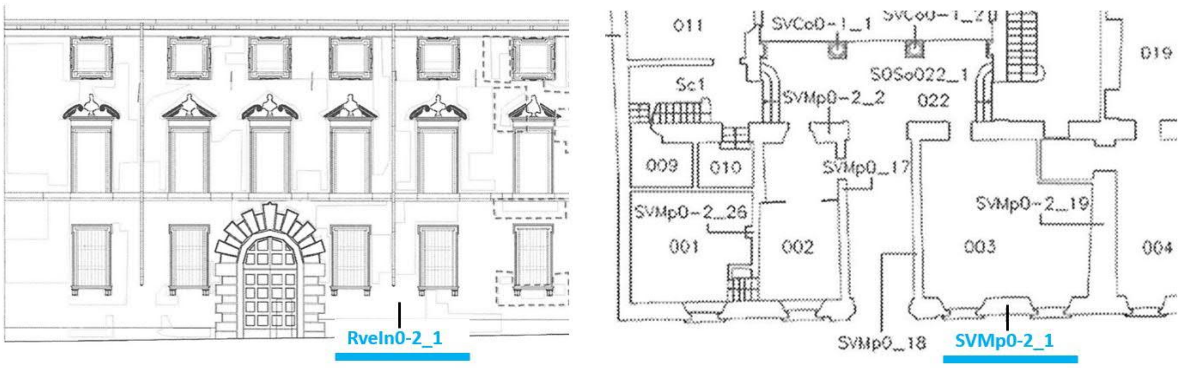


Fig. 2. Example of different classification of the same wall between elevation (Exterior cladding - RveIn) on the left. And plan (load bearing wall - SVMp) on the right

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.

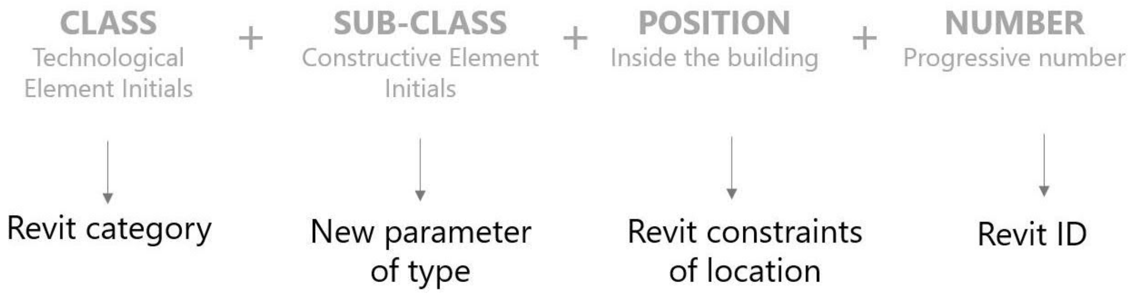


Fig. 3. Traditional and new classification comparison

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.

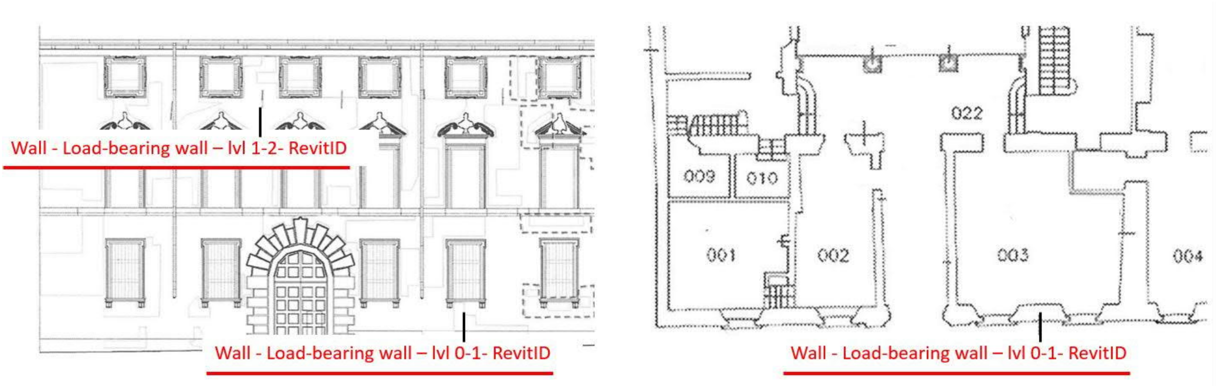


Fig. 4. New proposed classification comparison with the former (see Fig.1)

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)

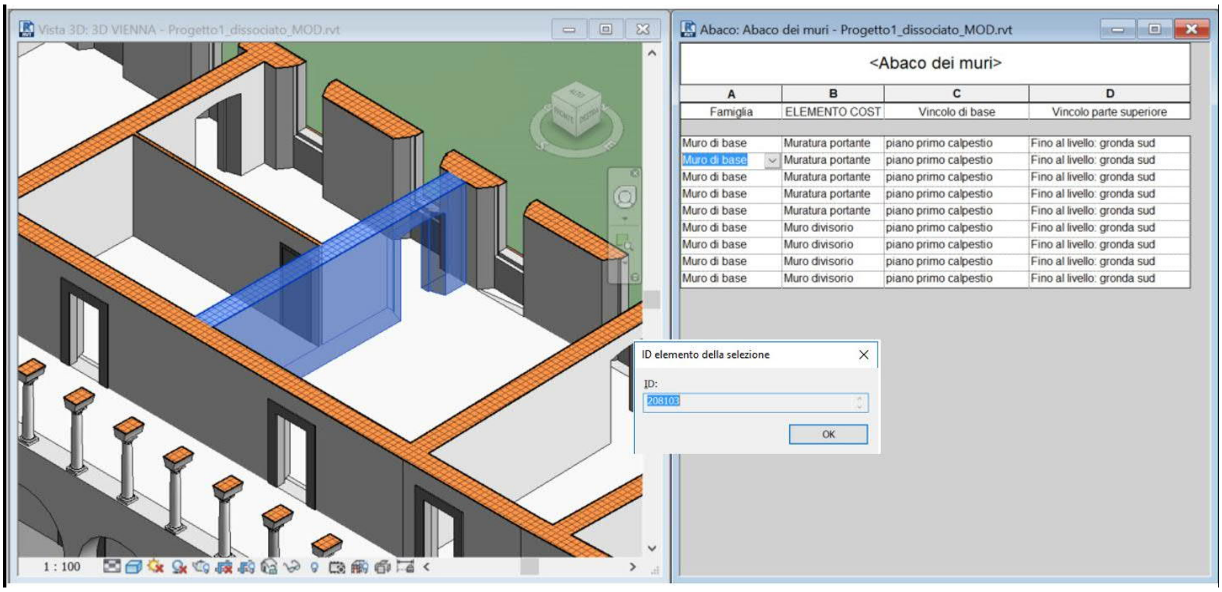


Fig. 6. Selected wall with the linked schedule

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).

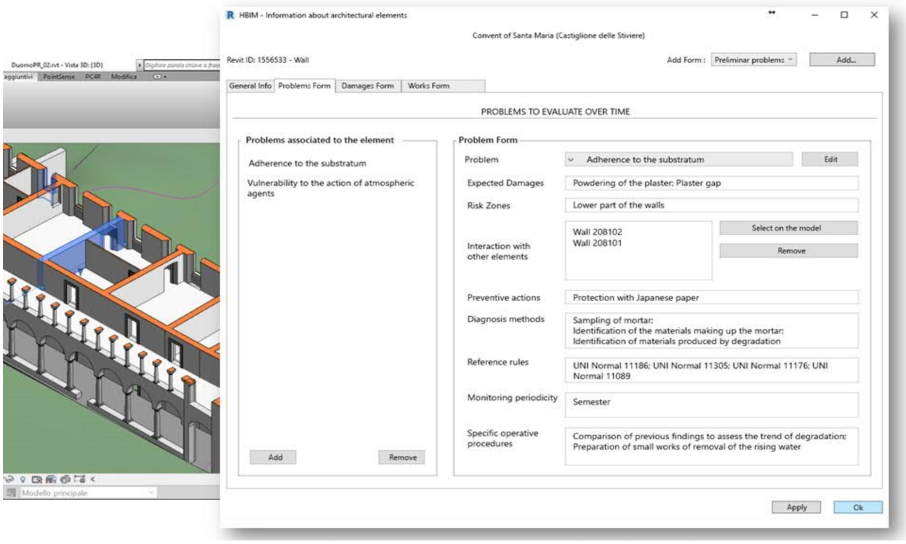


Fig. 7. Example of access to database inside Revit environment. The form refers to the evaluation of the pathologies that can affect the object

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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A New Perspective on Heritage and Multi-dimensional Representation with H-BIM

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The paper investigates the state of the art of “Heritage-Building Information Modeling” (H-BIM) vis-à-vis its specific challenges, envisaging possible new uses of current tools. It also devises new features that could easily improve current modelling/BIM packages.

“Building Information Modelling” (BIM) can be seen as a multi-dimensional modelling technique for “Architecture, Engineering and Construction” (AEC), where a database of different data-sets is linked to geometries, containing valuable information about physical and rendering features, among others. In case of heritage-buildings many specific challenges arise, since many more parameters (hence dimensions) must be considered, including forms of decay, historical and technical layers, degrees of exploration.

Moreover, two aspects characterize the use of H-BIM: the uncertainty about the surveyed elements – especially as to their hidden parts which, in a BIM logic, must nevertheless be accounted for – and the need to include overlapping geometries insisting on the same space relating to different aspects of the surveyed reality, e.g. stone elements and their deterioration patterns, as well as structures and their sub-elements.

As to the first aspect, while in BIM reality follows the model, in H-BIM the model must correspond to the surveyed data and possibly include different hypothesis as to the uncertain ones, along with certainty gradients. As to the second, the co-existence within the same model of the overall shape and of its constituents, so that the latter add up to a perfectly overlapping unity, closely matching the former, would allow for the full exploitation of current technology. Careful use of existing tools and suggested improvements thereto are set forth in this paper, in view of delivering BIM tools and practices that can better represent and describe heritage-buildings, extrapolate new data, as well as allow for simulations of various kind, thus also helping in their preservation and maintenance through optioneering based on reliable data.

Keywords:
H-BIM, Simulation, Multidimensionality.

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BIM: THE “TRADITIONAL” BUNDLE.

Before dealing with the specific aspects of “Heritage-Building Information Modeling” (H-BIM), it is worth recalling some aspects that characterize “Building Information Modelling” (BIM), since they are the building blocks of H-BIM, and their correct implementation may stretch H-BIM usefulness and employability even further.

Multidimensionality

BIM models do not store only geometrical dimensions (3D), but also time dimension, such as phases and design alternatives (4D), cost data (5D), project lifecycle information (6D), and more. “Cultural Heritage” (CH) projects can clearly highly benefit from storing and using a high number of data dimensions.

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Sharing

Also due to the multidimensionality features – which allow data that are relevant to different disciplines to be stored and exploited by different teams and professionals – BIM packages have been developed to be used cooperatively, also in a network. This feature is clearly even more relevant to CH projects, where multidisciplinarity is even more crucial.

Object-oriented/parametric approach

For the multidimensional pieces of information to be related to each other, geometrical elements need to be divided by semantic elements, such as walls, windows, pillars. They are instances of larger categories – the families – which, in turn, may be constituted by other sub-families. A specific instance then inherits its family features but differentiates itself from other instances through specific parameters. The approach mimics Object Oriented Programming and seems a major strength but also a major issue when dealing with CH projects, which tend to be dealing with non-standardized elements.

LOD/LOG per object/family

The object-based structure of BIM models allows for storing multiple datasets for the same object, which could be even added over-time and could represent the same "dimensions" at different detailing levels. Without entering the specificities of Level of Detail, Level of Development and alike, the main relevant characteristic is the co-existence of alternative data – also geometrical – insisting on the same object. As we will see, this feature can be particularly useful for H-BIM.

H-BIM: STATE OF THE ART.

Over the last decade the adoption of BIM for heritage buildings has been a promising research topic intersecting various fields of study. In fact, BIM models are multidimensional models storing not only 3D geometrical data, but also a much wider range of information that suits particularly well the CH sector, where a multitude of historical layers as well as of applicable disciplines – historiography, architecture, decay analysis, etc. – pertain to a single piece of architecture, hence (potentially) to a single model. Moreover, BIM packages are inherently conceived as a cooperative team working environment, greatly facilitating the sharing of information and the creation thereof among teams and disciplines.

While the potential of BIM for CH is clear, the development of specific Heritage-BIM (H-BIM) packages or even accepted workflow best practices has not been reached yet. Some major technical challenges, as well as lack of agreement on procedural standards, have hitherto hindered a wider adoption of H-BIM in the field, which advocates for a new approach to the very essence of it, at least in view of the future development of more specific software packages and best practices.

H-BIM: KEY CURRENT CHALLENGES.

Key open challenges that are preventing H-BIM from becoming a widespread tool for CH projects seem to all relate to the difficulty of reverse-engineer reality into an information-rich, semantic-aware, object-oriented model with a measurable degree of reliability. In fact, BIM software has been developed as a tool to engineer future buildings, a process where – in the industrialized architectural world of today – the correspondence between the abstract model and its realization is somewhat guaranteed by the industrial (tight) tolerances within the production of architectural elements, as well as by a set of consolidated best practices in the construction process. In other words, reality closely follows the model in case of new contemporary buildings.

As regards H-BIM, there is not yet a mature and reliable process to automatically "translate" the data from surveying techniques – especially laser scanning and photogrammetry – to a BIM model. In fact, even after error correction and appropriate segmentation, and even when referring to an appropriate semantic-aware database,

> *"… despite the fact that the semi-automatic process is a difficult, time-consuming task, it is currently considered to be the most effective process for documentation projects and the parametric modeling of architectural heritage …"*

[Facundo López et al. 2018]

For automatized scan-to-BIM processes, two main EU projects are somewhat promising, respectively as to point cloud segmentation and geometrical analysis, and as to shared ontologies and semantic-aware modelling[1].

As to geometrical dimensions, it is at least possible to measure the "Level of Accuracy" (LoA) by measuring the differences between the surveyed data (e.g. point cloud) and the BIM model, and to decide the "Level of Development" (LoD) of the model which, in turn, may be set as corresponding to a relevant LoA. Using open source software such as *Cloud Compare*[2] it is possible to get numerical and graphical data about the accuracy of the BIM geometries vis-à-vis the surveyed data [Quattrini et al. 2015]. However, there is no standardized way built in the BIM software packages to achieve this, nor any consolidated way to even represent such LoA across the model. Moreover, even by combining multiple survey techniques, including infrared photogrammetry and other techniques dealing with the hidden (not directly observable) parts of an architecture, the LoA in reconstructing the inner parts of any element is not usually even accounted for when representing the geometry of each BIM "object". Most H-BIM models mix measurable data with hypothetical ones within each object – e.g. wall surfaces and wall cores – thus raising more than one concern about the real usefulness of such a model as a reliable basis for CH projects.

However, it is the semantic-aware reconstruction that poses the greatest challenges (Fig. 1. Ontologies in H-BIM). In fact, even if survey data were available for the inner parts of the architecture, it would still be highly subjective how to subdivide and classify those data. As of today, even the recognition of "coarse" elements, such as the separation between walls/doors/windows is cutting edge, experimental technology[3].

A first aspect of such a challenge relates to the nature of the surveyed architecture itself, and to the theory of preservation: not all architectures were conceived as a set of geometrically coherent elements – as it might be the case with most classical, renaissance and gothic architecture – but heritage sites often show at least some layers of unplanned, informal and highly irregular elements. If for the former group of architecture a promising approach is the creation of shared repositories based on ontologies [Quattrini et al. 2015], where BIM "families" related to comparable architectures (by typology, place, time, etc.) are a toolbox applicable to the architectures at stake either by the expert or potentially even through AI, as to the latter it seems hard to even categorize all the possible situations and best practices.

[1] http://duraark.eu/and https://www.inception-project.eu/en
[2] https://www.danielgm.net/cc/
[3] http://duraark.eu/duraark-results-presented-in-cad-q-seminar/

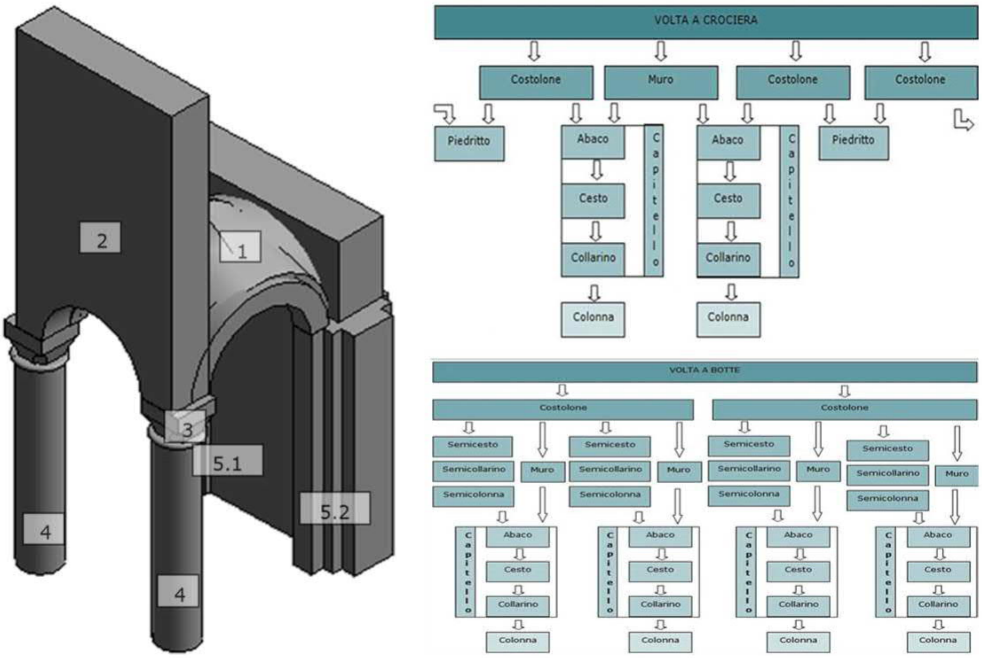

Fig. 1. Ontologies in H-BIM

In fact

> *"BIM approach includes information directly related to the object or its parts (both tangible and intangible such as material, dating, deterioration), yet it lacks a large amount of semantics about different context aspects (for example historical context, social information, environmental resources, other heritage artefacts information, etc.)[Simeone et al. 2014] In the field of built heritage, BIM model is integrated with ontology semantic relational system to enhance the representation of heritage knowledge and semantic reasoning. The integration can be an ad-hoc development based on BIM software [Acierno et al. 2017]. and a two-step modelling process by migrating IFC (Industry Foundation Classes) files to ontology environment for semantics richness [Quattrini et al. 2017; Bonduel et al. 2017]. The combined entity thus includes both object-oriented information, typically found in BIM platform, and semantic information, usually found in ontology modelling systems [Kalay et al. 2014]."*

[Yang et al. 2018] (Fig. 2)

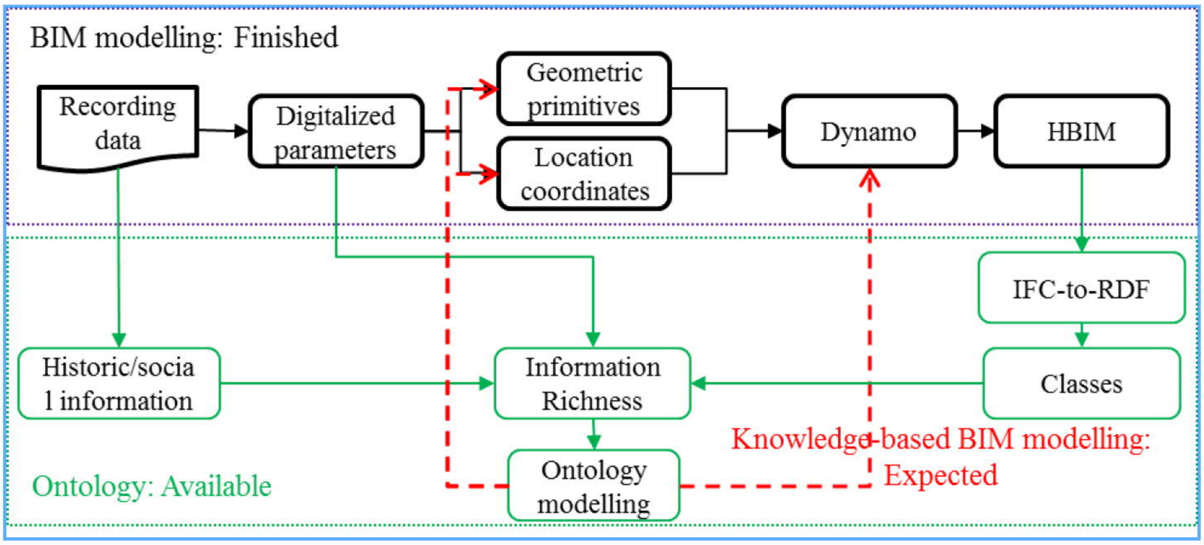

Fig. 2. H-BIM process and ontologies

Actually, the "normalization" of the surveyed architecture into more regular, standard elements, would risk resembling a Viollet-le-Duc approach to preservation, missing out the as-built dimension. Moreover, "regularization" might even make the BIM model not usable for some purposes, such as physical simulations, since the specificities and irregularities in shapes and materials must be accounted for in view of a reliable model.

For instance, while a contemporary wall made of very regular, industrially produced bricks can be easily described by an overall object encompassing the whole wall – where the internal partitions are accounted for by a sort of parametric 3D texture, and the physical characteristics are correctly approximated by a homogeneous average value across the wall – in case of an historically layered, decayed wall, the task at hand is even more daunting: should an overall wall geometry be identified as an "object" – a minimum geometrical unity as well as a basic "ontology", connotated by sub-elements and inner "layers" – or should each and every stone/brick be the minimum element, given their un-homogeneity? What about their physical attributes? And what size-limit to such a segmentation should we imagine? According to some scholars

> *"… the subdivision in small elements of the main architecture has to be connected with the aim of the BIM. The subdivision that takes into account the structural, architectural and decorative elements seems to be very reasonable, as it is also suitable for tridimensional analysis and not only 2D. Moreover, it represents the way all data will be accessed during the management of the architecture, so it helps the further steps of the BIM process (data entry, updates, etc.)."*

[Adami et al. 2017].

Possibly, since (H-)BIM models are supposed to serve multiple purposes, so should the model be rich, containing multiple, concurrent subdivision alternatives and LoDs.

In fact, a final problematic issue that seems deeply characterizing H-BIM today and hindering its efficacy as a preservation tool is the difficulty of accounting for the overlapping of geometrical data and even ontologies within one unique space. In fact, not necessarily do we need to choose among different spatial classification criteria. For instance, within the same spatial framework there can be "architectural elements" that can be recognized as pertaining to pillars, ribs and vaults, but also sub-elements, such as bricks, stones and mortar layers, and other overlapping geometries, such as incrustation and other decay elements often transversally affecting the architectural geometries, along intersecting shapes that follow physical rules, not architectural ones. Clearly, depending on the envisaged use of the model, different aspects would be relevant and thus preferred. Moreover, the cross-combination of those geometrically intersecting datasets could help extrapolating and inferring other datasets, and further contribute to achieve deeper understanding of the analyzed architecture.

This paper tries to imagine a new approach in the use of BIM technology for CH projects, where current software packages could be creatively used to include features not considered by developers, as well as to imagine future software improvements, whereby the foregoing challenges are dealt with by exploiting the potential model richness and computational power to the fullest, especially by allowing the storage of apparently “conflicting” geometrical information insisting on the same elements, and suggesting ways to represent such complexity and to use it for creating even richer models and simulations.

H-BIM: NEW APPROACH USING EXISTING TOOLS.

As seen, BIM technology bundles a series of features that were mostly thought in view of new constructions and were subsequently adapted also to CH projects. Since H-BIM is currently just the application, somehow the translation, of existing BIM technology to CH projects, many challenges have remained uncovered by commercial BIM packages. In this paragraph we will then dedicate a closer look to the available feature bundles to better evaluate which ones are most relevant to H-BIM, but also how each feature could be possibly adapted to H-BIM through use. In the next paragraph a series of new features are then devised and proposed to be possibly included in future releases of BIM/H-BIM packages to better suit CH projects.

We will analyze hereinafter some current BIM package features relating to key features/strengths of such technology and try to devise new uses better tuned to H-BIM.

Multidimensionality

As seen, BIM technology provides for the storage in one model of both geometrical and non-geometrical information, which fits CH projects well. In fact,

> *“… getting a rich HBIM model starting from accurate surveys is an unavoidable starting point to increase the conservation …”*

[Banfi et al. 2017]

However, the co-existence of different/alternative geometrical elements and pieces of information in the same space can be even more fruitful. Specifically:

- stretching the use of Project Phase also to include different historical phases – possibly including demolished or highly transformed architectures – may help grasping the historical evolution of the structure, and even interpolate missing data through a sort of ontogenetical simulation. This process could be compared to what historians do when trying to understand and describe historical phases: they usually refer to previous phases, so to understand the trends and the causal links, and even hypothesize future developments.

- stretching the use of Level of Detail. In BIM packages there are different Levels of Detail, and geometries are visualized based on a visibility parameter. Hence, by changing the LoD, different shapes and geometries are visualized for the same architectural objects. While the use of LoD is usually used to distinguish drawing styles by representation purposes – e.g. concept vs. construction – it could be profitably used to represent different geometrical datasets that, for instance, relate respectively to the architectural design (post/lintels/…), the building structure (bricks/stones/mortar layers), the decay elements (incrustations, etc.). Importantly, such geometries can compenetrate themselves, going beyond some BIM limitations that do not fit CH. However, one major limitation is that the selection of LoDs is model-wide, while CH projects may require a mixed representation thereof based on the objects to be highlighted. Another severe limitation in current BIM software packages is that only a limited number of Level of Detail are allowed, thus limiting the alternative datasets to be shown (e.g. in *Revit*[4] they are only three).

- stretching the use of linked models. Again, different disciplines and aspects could be included in one single main model by means of linked models. While this feature is usually exploited to store the parts of the model referring to a single discipline, such as architectural and structural geometries, it may be extended to different kind of even conflicting reconstruction hypotheses (e.g. more “abstract” – à la Viollet-le-Duc – vs. more “as built”). Similarly, the design option tool could be stretched to encompass even more data, not only for the future design, but also as to hypothesized data, such as, again, different historic reconstruction hypotheses.

[4] https://www.autodesk.com/products/revit/overview

Sharing

As to information sharing, there is nothing totally unique to H-BIM vis-a-vis "normal" BIM projects. However, while in such latter projects the usual flow between professional teams tends to be one-way – e.g. the engineers usually specify architectural design decisions as set forth in the BIM model, but often don't have an impact on the concept design phase – in creating a H-BIM model it seems crucial that technical knowledge helps architects reconstruct, i.e. reverse-engineer, the surveyed architecture and its decay, so to best approximate the status quo, greatly benefitting from a continuous exchange of knowledge and information among teams and disciplines. This holds true also as to design decisions, because often they would greatly benefit from physical/statical simulations to be performed before any intervention is made. In particular, if H-BIM includes different "types" of models, possibly with conflicting information, parallel work and coordination on each of such information "layer" speeds up process and facilitates cross-fertilization of expertise and knowledge, e.g. the simulation team guiding the survey team. It is worth noting that in CH projects could greatly benefit from information sharing not only among the teams participating to a specific project, but also among researchers in the field as to semantic parametric families related to the places and ages of the architectures at stake. An open repository paradigm would seem particularly suited for this and has been explored also in the framework of EU research projects[5].

Object-oriented/parametric approach

As already pointed out, Object-Oriented (OO) logic is possible also with totally irregular elements of heritage architectures, save for the wide degree of discretionality in segmentation/subdivision. Besides, each object can include geometrical elements with different degree of certainty, such as the directly observable surfaces of a wall and its internal structure. The creation of object/families that divide architectural elements by degree of certainty or by heritage ontologies/classifications is a possible way to better adapt BIM to CH projects. Again, a shared repository, possibly in the framework of an independent organization funded by academic institutions, is probably the way to go, even though IP rights and research funding might be issues to deal with to further implement such solutions.

As to parametrization, not necessarily does built heritage follow a stringent parametric logic. A case-specific approach seems necessary. Specifically, it would be advisable to ascertain "parametrizable" architectures (e.g. Greek, Renaissance), specific to the case at hand and discipline-based (stereotomy, historical research), as a pre-condition for applying parameters, at least the geometrical ones. As seen, repositories of families including relationships and proportions among parameters should be built and shared, possibly within the research community at large. Along with geometrical parameters, a set of CH-specific parameters would be purposefully agreed upon, for instance with respect to level of certainty and level of accuracy of the reconstructed model vs. the scanned data.

It is worth noting here that, besides the parametric features of BIM objects within BIM packages, there is another set of "parametric" tools – usually referred to as computational design tools – that are, and could be even more used profitably within or in connection to BIM software: it is the case of NURBS ("Non-Uniform Rational B-Spline")-based modelling tools, such as *GH for Rhinoceros*[6], an external NURBS modeler package, and *Dynamo for Revit*[7], a node-based programming tool for *Revit*. The interesting features of such type of software is the opportunity to create geometries that are only based on control points and mathematical functions and relationships, so that the resulting shapes are calculated in real time for representation and have an abstract geometrical nature, not linked to the specific scale or space references, apart from the starting control points. It then allows reconstructing a scale-less, mathematically describable drawing that can approximate the surveyed data by "interpolating" them. This process has been often used to "bridge" the discrete, scattered data from laser-scan and photogrammetry to continuous and mathematically describable shapes, ready for being classified by ontologies and "parametrized" with BIM information parameters. For instance, some scholars have been exploring a workflow to semi-automatize the creation of a H-BIM model starting from raw mesh data using *Dynamo for Revit* [Yang et al. 2018]. In addition, some external pieces of software, such as *Leica Infinity*[8], aimed at extrapolating shapes from the surveys could help bridging some of the gaps that are present at the moment, as well as serve as a good reference for devising future (H-)BIM features and seamless workflows.

[5] https://www.inception-project.eu/en
[6] Grasshopper (GH) for Rhinoceros (Rhino): https://www.grasshopper3d.com/page/download-1
[7] https://dynamobim.org/
[8] https://leica-geosystems.com/products/gnss-systems/software/leica-infinity

H-BIM: NEW APPROACH FOR DEVELOPING NEW TOOLS.

If adapting existing commercial BIM packages to CH projects seems the quickest and resource-aware approach to H-BIM development in the near future, more attention by the industry for developing specific H-BIM tools is clearly a realistic hope, also given the sheer market size of architectural projects dealing with some kind of CH settings. In view of such specific development, it is important to ask ourselves what challenges could be best tackled, and what features would be most needed in view of H-BIM specific software development.

Multidimensionality

In general, lack of information (e.g. as to the non-observable parts) and lack of geometrical regularity and consistence would greatly benefit from specific parameters within (H-)BIM software, possibly linked to visualization options, as follows.

Certainty/Accuracy: specific 3D-markers that encode (and represent) at least the level of accuracy and the level of certainty might be a great step forward – also in view of standardized procedures – with respect to attaching customized parameters to BIM families. It could be linked to a new system of model “Levels” (see further). Data may stem from the following point.

Categorization and storing of more types of data/models, potentially "conflicting": historical drawings, "rectified" drawings, survey activities, shape grammars and stereotomic knowledge, shared ontologies and reconstruction alternatives. All such datasets could beneficially be included – at least as data category – within (H-)BIM packages, so that standard plugins could be developed for matching and connecting those data and extract further insight on the architectures at stake. Here again, the creation of a standard data structure and labelling – possibly to be included within the “Industry Foundation Classes” (IFCs) – would help recognize and create best practices, and help sharing comparable data.

Sharing

While the de facto sharing of H-BIM families and other information is already feasible, it would be greatly more interesting to have (H-)BIM packages automatically linked to on-line repositories where families are uploaded and updated following a Wikipedia or Github[9] style, so to ensure at the same time a faster and more standardized data sharing and model building, as well as a sufficient degree of reliability.

Object-Oriented/Parametric Approach

First of all, while in standard BIM packages object-oriented and parametric features are united in describing every architectural element – such as a wall, defined by some basic geometrical starting data and “modified” through specific parameters – such an approach might not be the most appropriate for irregular elements that would still be objects, but would not be describable through simple measures. Therefore, while today external software packages are usually adopted for more complex and irregular elements to be imported and “objectified” within the BIM environment, it would be probably more efficient to have such modelling tools inside BIM packages and to be able to create different objects out of each of such shapes, and from a combination thereof. For instance, a standard family of irregular wall stones could be included in a wall family following the relevant ontologies, without any direct connection to a specific numeric parameter to create the shape. At most, semi-automatized shape creating tools may help smart-guess the real geometries starting from the available survey data, especially point clouds. Software like Revit can already be used to achieve these features – through customized families and possibly through node-based programming Dynamo [Yang et al. 2018] – but the process has not been standardized, nor is it user friendly: in fact, while standard families make it hard to even create a tilted wall, the conceptual mass tool is not intuitive, nor is it easy to achieve a fast and accurate result in this field.

Second, IFC classes could be fruitfully adopted for describing some other aspects of CH. For instance, a widened set of IFCs encompassing decay pattern families - e.g. ICOMOS (International Council on Monuments and Sites) - would allow for the creation of clearly defined BIM geometries representing decay in 3D, thus creating a far richer HBIM model. Likewise,

[9] https://github.com/

> *"Given that the IFD (International Framework for Dictionaries) defined inside the BIM software are not exhaustive for the Historical Building domain, the definition of dictionaries inside the "Historical Building Framework" (H-IFD) aims to contribute in creating an open DB, updatable, dynamically adaptive to the real context and multi-faced contents of the historical architectures"*
>
> [Oreni et al. 2014)]

Further analysis and simulation tools could then be developed within the model, combining datasets about various aspects of the surveyed geometry, maintaining a high degree of interoperability and standardization at the same time.

Moreover, physical simulation parameters and tools could be introduced within (H-)BIM packages and help smart-guessing 3D semantic elements, including non-directly observable parts, e.g. star-cracks, moist areas, but even internal brick subdivisions. "Synthetic data" could be parametrically produced and be extremely useful for matching data sets using AI. In fact, AI could then help matching those simulations to the specific case, also based on a growing *corpus* of tested cases shared among the researchers in the field. In some cases, CH interventions dis-assemble architectural elements and can therefore provide a reality check. For instance, huge stone pillars within the Basilica di Santa Maria in Collemaggio in L'Aquila, Italy, was disassembled and provided great insight on the real structure thereof, versus the previously imagined one [Reni et al. 2014].

Of course, an enriched model would require the co-existence of overlapping and interacting data belonging to different classes (e.g. decay vs. architectural elements), interacting and specifying each other, also geometrically.

Finally, some kind of structured relationship between objects that are not exactly bordering one another, as it is usually the case in BIM packages, but rather overlap in some areas – such as an overall mesh representing the scanned wall surface intersecting or neighboring BIM wall objects and/or wall-stones – would be much needed to allow for specifying each other, transferring and "stamping" relevant information from one another. In the example, the wall objects could have a specific texture applied to its surveyed faces coming from the overall mesh, applied as a *pro-quota* wrap.

Model levels (LoD, LoG, LoI, LoA, etc.)

Without entering the specific taxonomy between these dimensions, it seems that new (H-)BIM packages should include a wider variety thereof, offering standardized options to visualize and combine them also according to CH best practices. Among others, we can envisage the following improvements:

- object-specific LoD "switch": it seems that a general, model-wide switch for LoD is not answering to the real needs of a model potentially encompassing heterogeneous elements, where each "cluster" of homogeneous layers/datasets might be usefully represented using a respectively different LoD (this is now somewhat achievable by tweaking LoD visualization in the object visualization settings). In fact, even just for representation purposes, it seems useful to have the opportunity to selectively focus of details that might be relevant to the specific purpose at stake. If, for instance, the drawing wants to convey the status of decay, it would be not only redundant, but even distracting, adding additional "graphic noise" stemming from other aspects such as surface textures, and switching levels just by selecting the elements/categories would be at least a time-saver.

- range-based Level of Certainty and time-frame for analysis, including forecasted trends. More in general, adding some range-based system to represent non-binary data. Similar gradient analysis and representation is already carried forward in FEM software packages, for representing – by discrete approximation – systems where data values change in space along a continuum: typical is the simulation of *Von-Mises Stresses*[10]. Similarly, a gradient representation of deviation between modelled geometries and surveyed point cloud is often used for assessing H-BIM reliability based on the chosen LoA, usually using an external software package such as Cloud Compare, an open source software solution [Bonduel et al. 2017], with the implication of not being able to automatically feed-back the obtained data into the BIM model for further data combination and visualization (Fig. 3).

[10] https://upload.wikimedia.org/wikipedia/commons/9/9e/NonlinearStaticAnalysisSnapFit.png

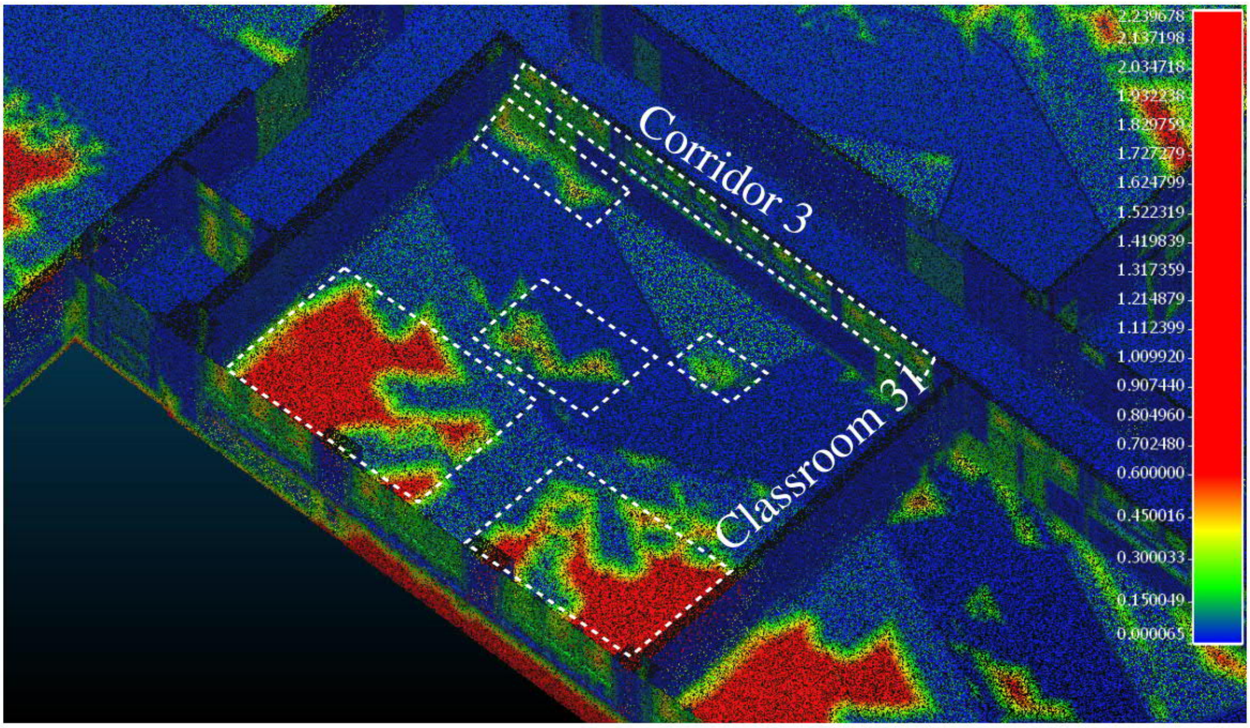

Fig. 3. Scan-to-BIM Output Validation

- new data type and combination thereof. For instance, new "synthetic" LODs, such as enhanced surface representation after scanning though displacement maps, or by texturization of single object through the combination and projection of other objects – also differing in spatial features – such as point clouds, meshes and alike representing scanned surfaces through normal and IR photogrammetry and laser scans vs. BIM walls vs. BIM wall stones and other wall layers objects.

- new graphic codes to represent different levels and data types. BIM packages are of course very customizable systems, very appropriate for creating a personal representation style. However, since in preservation there are a series of agreed upon standard graphic conventions, it seems that a robust set of pre-fab representation styles attuned to H-BIM projects would greatly improve the degree of universal “readability” of the models and a better starting point for a purposeful sharing within the research community.

Again, all such parameters should be available per object and per object group, not only model-wide, also because survey, model reconstruction and preservation project phases may not be carried forward and completed within the same time-frame, and some portions may even need a more in-depth survey than others: imagine heritage architectures where some portions were added in contemporary times using uniform materials and techniques, while other portions show a significant amount of historical layers and complexity. It should then be possible and even a standard procedure for H-BIM to be able to start off with survey data and a few generic and approximated “coarse” geometries, to be specified over-time as the surveying activities proceed, storing such subsequent detailing and reconstruction phases per-object – even with different-shaped objects insisting on the same space – so that different clusters of information could be utilized for representation, analysis and simulation as the case may be. This Mixed LoD approach [Banfi et al. 2017, p.11] has already been proposed for 3D city representation using GIS software in order to face challenges such as different dataset available for different buildings, etc. [Biljecki et al. 2013].

COMPUTATIONAL DESIGN, CH PLUGINS AND BIM

While, as mentioned, some BIM packages already provide computation design tools (e.g. *Dynamo for Revit*, a working workflow *GH-Archicad for Archicad*[11]), and some plugins for segmenting and dealing with point clouds – such as *Volvox for GH*[12] – are already available for helping develop NURBS modelling of surveyed data, there is still a lack of specific tools to help create a (H-)BIM model starting from surveyed data, especially point clouds and meshes stemming therefrom, if we want to go beyond the mere boundary recognition. Moreover, the transition from external parametric NURBS modeler, such as *Rhino*[13]*/GH* to BIM platforms is not always easy, as well as BIM plugins for such modelers are not yet as effective as proper BIM packages as a one-stop-shop solution. Therefore, we imagine a near future in which these set of features are – if not reunited in a unique software package – at least better coordinated with (H-)BIM, and specific automatized tools to help extrapolating BIM models from the available data are included. Physics simulation engines – now present in numerous software packages, especially the ones dedicated to creating gaming and realistic virtual worlds: see for instance *Houdini*[14] – could be purposefully exploited to create Synthetic Data about decay patterns, structural shifts and other phenomena impacting CH, and tested – also by AI [Tremblay et al. 2018] – in order to better approximate the real data gathered in the survey activities. See for instance Fig.4, comparing simulated and real dried mud images, as well as a "procedural crack" on a wall created using *Houdini*[15] as well as comparisons between artificially computed cracks and the ones happening in reality [Iben and O'Brien 2009].

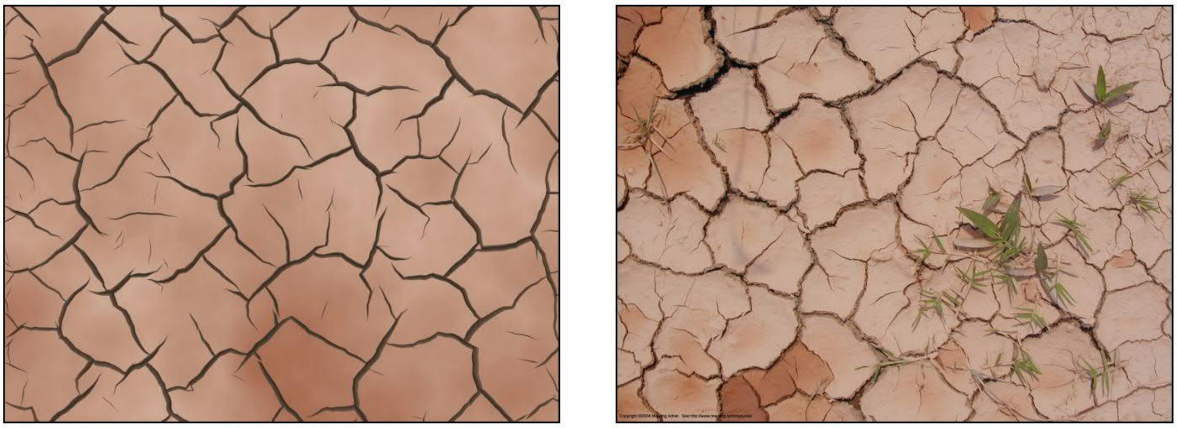

Fig. 4. A comparison between rendered dried mud (left) and a photograph (right)

The process could start from known data (e.g. observable wall surfaces) and a set of hypotheses to test (internal structure of the wall, material composition), and the simulated results could be then compared with the observed characteristics of the geometry at stake (e.g. the observable wall cracks, humidity traces, etc.). Basically, the same process of abstraction now carried forward by approximating real architectural geometries by means of BREPS (or B-reps – Boundary Representation) – save for later LoA checks – to be lately converted into BIM objects, could be performed with respect to the physical processes occurring on the architectures, in order to get a sufficiently accurate abstract-physical modelling of such processes. A similar approach is carried forward in the automotive industry as regards the mechanical robustness of prospected design solutions, as in Fig. 5. [Chanho 2018] and, more specifically, in "Finite Element Method" (FEM) analysis for AEC, as in Fig. 6. [Almeida et al. 2016] where, nonetheless, the approach is simplified, as the wall constituents are taken as a whole.

[11] GH-Archicad for Archicad is a software tool to bridge ARCHICAD (https://www.graphisoft.com/archicad/) to Rhino/Grasshopper (https://www.graphisoft.com/archicad/rhino-grasshopper/)
[12] https://www.food4rhino.com/app/volvox
[13] https://www.rhino3d.com/download/rhino/5/latest
[14] https://www.sidefx.com/products/houdini/
[15] https://goo.gl/images/R3Ejyr and https://vimeo.com/channels/529907/65805544

Fig. 5. Mechanical robustness analysis

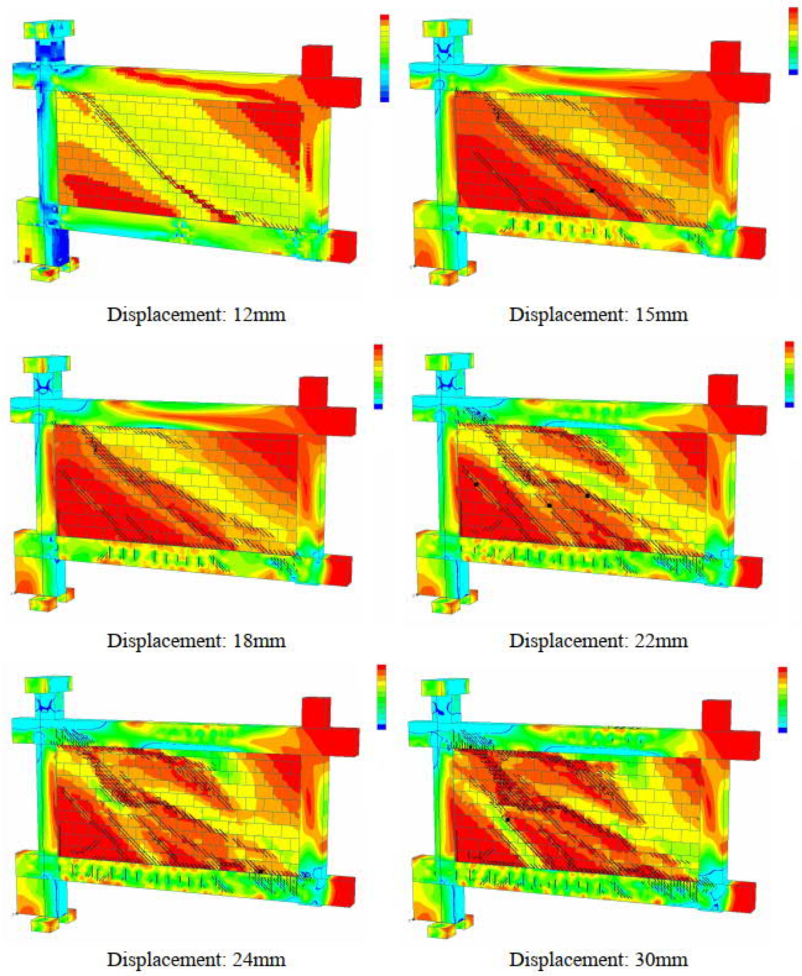

Fig. 6. RC frame and masonry Von Mises stresses and cracking pattern for several load steps

This extra layer of information could be useful for at least two main purposes. First, helping to figure out the missing data (e.g. hidden geometries); second, providing a powerful tool to simulate the prospected preservation plans and to tweak them to reach the required results.

As a last remark, the nature of BIM software packages may have to be questioned, possibly de-bundling aspects that are now seen as a necessary corollary of the BIM architecture, such as the "Object Oriented" (OO) and the parametric features. In fact, the shape creation/reconstruction and the "objectification" thereof through the categorization into IFC classes – possibly including relevant ontology structures and other data dimensions – could potentially be added and modified later in time, and not be necessarily included contextually with the creation of the geometries. Plugins for Grasshopper and Rhino to transform NURBS geometry into BIM geometry seem a good example of such an approach. See for instance *Grevit*[16].

As a final illustration of the foregoing analysis, the following set of images (Fig. 7) has been created to iconically illustrate the huge difference that exists at the moment between a standard BIM wall made of a uniform texturized material in Revit and a wall made of single textured stones using a modelling software like *Rhino/Grasshopper*. As the second image clearly shows, only the second wall would allow for even the easiest of physical operations, such as an "exploded" displacement of its constituent stones, which in turn would allow for a wider set of analysis and simulation processes. At the moment, it is possible to transfer such geometries in Revit (and other BIM packages), but the process is not a standard one, nor efficient, with some issues related to textures and other loss of information.

Even if we are aware of the many challenges at stake, as accounted for in this paper, we deem it crucial that H-BIM eventually start to follow a different and more specific approach to CH – building new agreed logics, features and practices – rather than just consisting in the use of standard BIM packages and practices awkwardly stretched and applied to heritage buildings. A combination of technical knowledge both in computational tools and in CH, along with a "political" will to foster the creation of new standards and practices, seems then an unavoidable building block for a better future H-BIM.

H-BIM: THE NEAR FUTURE.

To sum up, in order for H-BIM to become the flexible and powerful tool for CH projects that we all wish for, it will be key that a consistent and agreed upon methodology is developed – so to make sharing and comparing research results feasible – particularly as to the creation of a well-thought set of ontologies, as well as to allowing the coexistence of spatially overlapping multiple (and multi-disciplinary) data-sets.

A great achievement would be the creation of a reliable, multi-purpose unified model, where multiple data and dimensions – historical, physical, economical, etc. – not only can allow for various effective representation outputs, but could even help the very same model construction process, also through the use of AI algorithms creating and combining ontologies and physical phenomena, reciprocally reinforcing the degree of certainty of directly observable and inferred data. In other words, it is the "big data" within the H-BIM model and in the networked research community that could further strengthen the H-BIM model reliability and make the automatization of model creation less difficult to achieve.

Such an enhanced H-BIM technique could then finally help not only representing CH projects, but also help inferring new information and allow for a more grounded hypothesis testing in CH projects. If new packages dedicated to H-BIM would then constitute a great support of such new approach, it seems meanwhile feasible to creatively use the existing tools to make some steps forward.

[16] https://www.food4rhino.com/app/grevit-grasshopper-native-bim

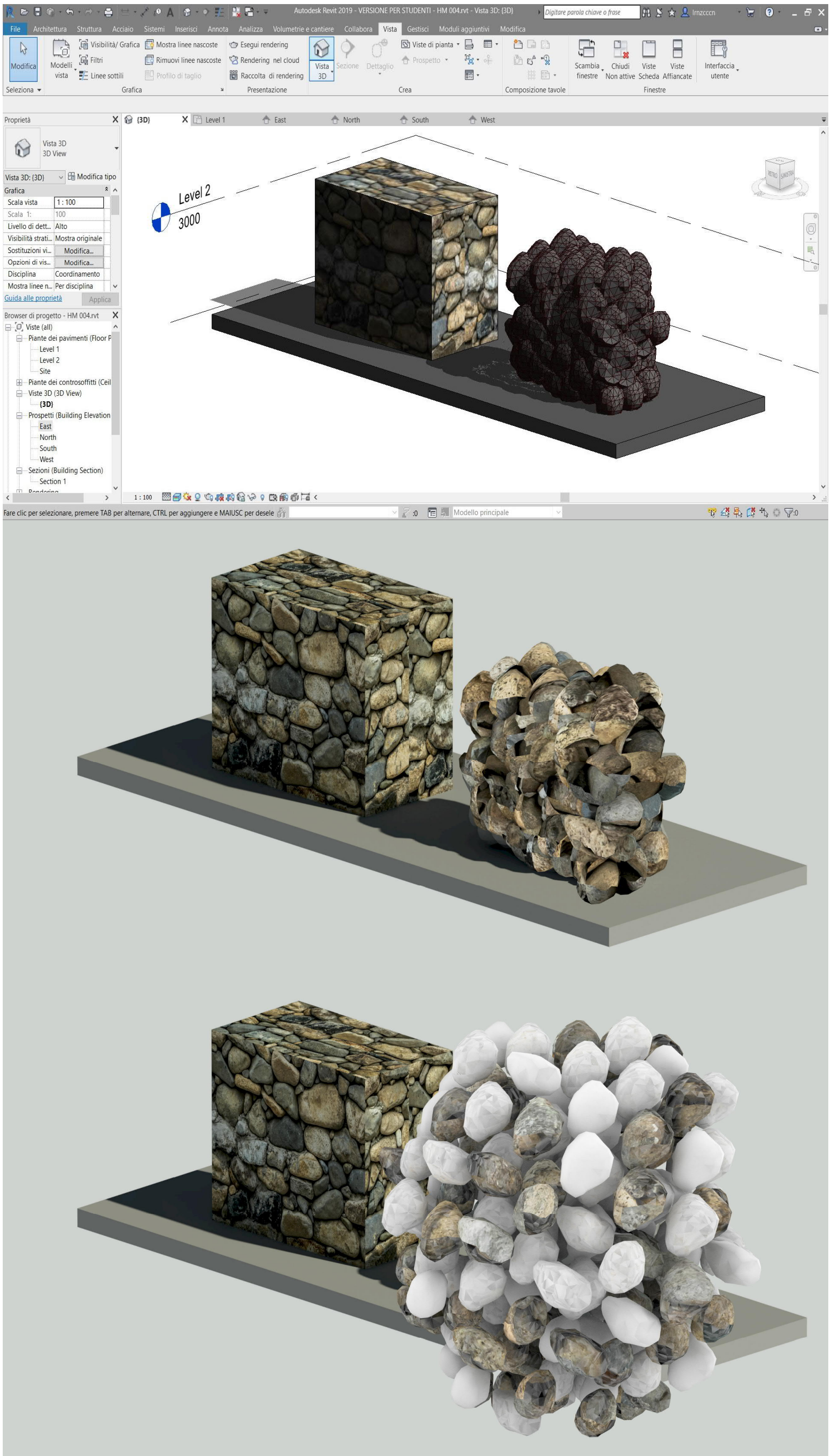

Fig. 7. Difference between "texturized" BIM wall (based on a parametric box geometry) and "simulated" conglomerate wall made of smaller objects, hence "explodable", thus allowing for various types of simulation and greater accuracy

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Letting a Wall Tell its Story: A Low-cost Interactive Proposal for Kyrenia Castle, Cyprus

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“Built Information Modeling” (BIM) is quickly becoming a standard in managing and documenting the built world for development and maintenance, but, when applied, this solution may be time consuming and expensive. The procedure proposed is an entry level alternative to BIM technology in situations with a limited budget and in need of moving towards a more complete BIM solution. In the near future, the BIM approach (based on data interoperability) will be more common and integrated, becoming a new paradigm in design interventions, maintenance plans as well as being easily accessible via VIM (Virtual Information Modeling) tools. This case study focuses on the investigation of the geometric aspects and informative surveys (via 3D laser scanning and photographic acquisition) of the walls of Kyrenia Castle in the island of Cyprus. Evolving from the surveys, a simple procedure has been created to allow the insertion of additional precise information from different means to complement and enrich the geometric modelling, such as types of construction techniques and materials of the walls, colors, static functions, state of conservation and photographs, in order to reach the final aim of the research, which is masonry dating. With this premise it is possible to propose solutions that, starting from digital survey data, can provide rapid and effective information, ensuring results that can be cross-referenced. The use of *Autodesk ReCap*[1] provides the possibility to link photographic images or external links, like references, data, or PDF files, to specific points within the point cloud. The resulting version of the point cloud is compliant with the use of AutoCAD *3D Studio Max*[2] and especially with the integration into *Autodesk Revit*[3]; it may positively influence the construction of a full BIM model, exploiting data gathered and linked to the point cloud for the creation of the general models and associated families.

Key words:
BIM, HBIM, 3D laser scanner, Data collection, Restoration.

CHNT Reference:
Gabriele Farre et al. 2018. Letting a Wall Tell its Story: A Low-cost Interactive Proposal for Kyrenia Castle, Cyprus.

INTRODUCTION

The island of Cyprus has always played an important role in the Mediterranean basin, located in a strategic geographical position: a crucial stop on the way to the Holy Land during the Crusader period; an important commercial crossroad between the East and the West in the 16th century, at the time of the Venetian conquest, and a strategic naval outpost along the Suez Canal in the 19th century, during the British occupation.

Multiple and varied cultures have affected the country, influencing local and traditional building techniques and shaping the language of its architecture. The overlapping of these cultural assortments can be found in the case study of the fortress of Kyrenia (Fig. 1), which, with the mountain castles of St. Ilarion, Buffavento and Kantara, established the northern defensive system of the island between the 6th and 16th century. The city, commanded by mountain defences, offered an umbilical cord in which supplies could flow from the mainland. [Perbellini 1973].

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[1] https://www.autodesk.com/products/recap/overview
[2] https://www.autodesk.it/products/3ds-max/overview
[3] https://www.autodesk.it/products/revit/overview

The purpose of the research is the investigation of the masonry typologies of the fortress, aimed at understanding its historical construction evolution. The result of the analysis has been conceived as precise information used to enrich and complement the knowledge acquired from 3D laser scanning survey elaboration, useful for operators in charge of managing a survey, establishing a preliminary BIM model.

THE CASTLE OF KYRENIA: HISTORICAL INFORMATION

Built next to the ancient port, the hub of social life since ancient times, the castle of Kyrenia dominates the city with its massive scale, overlooking the surrounding historical urban fabric that still preserves its traditional features.

At the time of the first Arab invasions in the 6th century, the Byzantine castle must have appeared in the form of a rectangular enclosure, distinguished by four angular horseshoe-shaped towers, two of which were incorporated into the later Frankish structures. The near Byzantine church of St. George, originally set against the castle, dates back to the 12th century [Enlart 1899; Perbellini 2011].

At the end of the century the island passed into the hands of the French family Lusignan, who enlarged the fortress and built the northern, eastern and western chambers which overlooked the parade ground, the east and south fighting galleries, the north-east donjon and the north-west square tower [Enlart 1899].

In 16th century the island became domain of the Venetian Republic. The construction of the north-west and south-east Venetian circular bastions dates back to this time, as well as the southwest polygonal bastion, punctuated by narrow Italian passages. The Byzantine church of St. George was incorporated into the structure against the north-west bastion and was turned into a crypt when the Italians realized the western ramp to facilitate the transport of cannons to the summit walkway. The southern and eastern fighting galleries were filled with ground, forming massive spur wall reaching the maximum thickness of 22 meters to defend the fortress from cannon shots [Megaw 1964; Perbellini 1973; 2011].

In 1570 Cyprus was conquered by the Ottomans, who turned the fortress into a prison, and remained in their possession until 19th century, when the island fell under the British domain. Gaunt historical sources document these historical moments since the fortress became accessible solely to the military forces. The Frankish northern areas suffered severe alterations and were transformed into detention cells. The outer original curtain wall survives, crowned by a battlement dating back to the 13th century. Numerous internal passages and vents were obstructed [Enlart 1899; Megaw 1964; Perbellini 2011].

The castle passed into the hands of Cyprus Department of Antiquities in 1950 as an important ancient monument. Multiple restoration interventions took place during the next two decades. In 1976 the east chambers became headquarter of the Shipwreck Museum, which is still active today [Megaw 1964; Katzev 1981].

BIM: A NEW PARADIGM FOR THE ANALYSIS, PROTECTION, AND CONSERVATION OF ARCHITECTURAL HERITAGE

BIM is an approach that utilizes 3D digital representation of a database allowing multiple users to read, add or modify 3D or 2D data. The main purpose of this process is to increase the efficiency of workflow, collaboration and interoperability of information in the areas of planning, designing, constructing and management of buildings and infrastructures. Ideally, a BIM process allows collaborators from various fields, from designers to constructors, management and maintenance or demolition crews, to access the necessary data to better inform their work, but this should not necessarily be limited to large-budget projects.

A commonly-believed limitation today is that expensive programmes, such as *Autodesk Revit* or *Graphisoft ArchiCAD*[4], as well as highly-trained professionals in charge of planning the software, are needed to develop BIM components in a design process. However, this complex and costly 3D modelling software is not necessarily required, simply because BIM is a process, not a software.

When applied to the existing building, and the historical ones in particular, the real goal is to comprehend how the BIM can represent a concrete advantage for the study of those artefacts consisting of unique elements made of complex geometry and whose knowledge is often intuitive, while for a new building the very high level of detail

[4] https://www.graphisoft.com/it

guaranteed by industrialization of the components ensures completely reliable data. In this framework, the BIM model describes the form of the object but sacrifices the profound knowledge of the artefact which, even today, is realized only through a complex process of analysis that does not belongs only to the form but also to the changes that its specific components have endured over the years.

Basically, the BIM technology can certainly constitute an advantage in project interventions on existing buildings, but it can also become a significant disadvantage if it leads to an excessive simplification far from a profound knowledge of the building. Analyzing any artefact it is easy to ascertain how it is represents a complex and unique system, substantially unrepeatable. Likewise it is evident how the process of decomposing such a system is still today entrusted to the so-called graphic analysis largely based on traditional design.

A good project approach must be based on the knowledge of the manufactured product developed through qualitative analyses which permit to understand its nature and identify critical issues that arise first as a design and then becoming a matter in the realization phase. Precisely because of this complexity, starting a BIM process from point clouds or digital photogrammetry process to construction of surfaces from their interpolation and rendering, must be considered a necessary step in the evolution of BIM technology, facilitating the exchange of information between operators managing the project [Bianchini et al. 2016].

In this way it is allowed the extension of the BIM process to the phase of digital survey. Laser scanning tools have been employed for the case study to capture data through a less expensive and complex methodology. The use of the software *Autodesk ReCap* allowed the insertion of external data via links to historical documents and references. The insertion of photography has also been used to enrich the information provided by the survey. Purpose of the research is to demonstrate how fields such as heritage preservation, which often suffer of a restricted budget, can also benefit of the attributes of BIM technology, starting from the beginning phase of the survey. [Biagini and Arslan 2018].

3D LASER SCANNER SURVEY

The survey has been conducted employing the digital methodology of laser scanning, which guarantees a highly precise return of the scans performed. The instrumentation used is the laser scanner type Zoller + Fröhlich 5006h. This kind of tool possesses high quality features such as 360° horizontal/ 320° vertical picking range, an accuracy of 2 mm to 10 m distance and standard reflectance. The scans have been performed in high mode, capturing 1 point each 4 mm to 10 m distance, and in medium mode, capturing 1 point each cm to 10 m distance.

The process consists of two phases of which the first is the digital data uptake: taking a distance measurement in every direction, the laser scanner rapidly captures the surface shape of objects, buildings and landscapes, combining multiple surface models obtained from different viewing angles, or the admixing of other known constraints (Fig. 2). The second phase of the process is the digital data elaboration: The result of the acquisition is a set of points scattered in a regular 3D space model (point cloud), generated by polar coordinates and managed by the software automatically through Cartesian coordinates. The final result of the acquisition of digital data has been subsequently elaborated using the software *Autodesk ReCap*, which allows extrapolating plans, sections and elevations of the object, to perform measurements and verify checks. The processed and readable file can be then imported on proper BIM softwares and transformed into a 3D model to obtain architectural and structural designs.

MASONRY ANALYISIS

Construction technique of the masonry, materials, shape, dimensions and assembling of the blocks, denounce the epoch of realization of the architectural artefact, its geographical location, state of conservation and static disruption (Structural integrity analysis; Chemical, physical and biological decay analysis).

Numerous traces left on the surface of the vestments of the fortress, such as beam holes and shelves (Fig. 4), collapsed vault traces, mason' marks impressed on the blocks and placed throughout the castle (Figs. 5-6), all of which provides suggestions about the past architectural conformation.

The masonry fixtures are composed of local stone, a tophaceous limestone in grey or pinkish-blond color. It is possible to identify three macro-categories of masonry typologies, according to the historical period and belonging respectively to the Byzantine phase, Lusignan phase and Venetian phase (Fig. 7).

Byzantine masonries consist of large square blocks of greyish color and of uneven sizes on *opus isodomum* beds; Frankish masonries are much more regular in the vestments, destined to remain exposed as much external as internal chambers. The uncovered sections also denounce the very homogeneous nucleus of the same stone, but with irregular segments, particularly in the late Frankish period. The Venetian paraments differ from the Frankish ones by their smaller size, while the core, given the large thicknesses, is often made up of incoherent material. The Italian engineers plastered only the splices between the blocks, probably due to the considerable extension of the vestments [Perbellini 1997]. A similar system can be found in the defensive walls of Chania, Crete, also under Venetian rule at that time (Figs. 8-9).

THE USE OF *AUTODESK RECAP* TO SUPPLEMENT THE BIM MODEL

The use of the *Autodesk ReCap* software allows the insertion of additional information into the point cloud, such as photographic images and external links concerning the masonry survey, which would otherwise be difficult to identify. This solution provides significant awareness and knowledge of the artefact for the operators managing the digital data, starting from the preliminary phase of the survey and contributing to develop the construction of a full BIM model (Figs. 10-18). In this way it is easier to understand the architectural object from the beginning: the inserted notes and images provide important help to the operators working on the point cloud base who can quickly solve any modelling issue. At the same time, the simple procedure of adding notes over the point cloud in *Autodesk ReCap* allow operating this task even by beginners to this software, like students, volunteers, etc. The enhanced point cloud becomes then a better and more complete documentation tool for any further representation and modelling.

The solution proposed resolves some open questions deriving from the management of the digital survey, such as the deal concerning the operators creating parametric model out of the point clouds, which are often expert in modelling but dispose of a limited direct knowledge of the surveyed architecture. Operators might find the information coming from the simple point cloud tricky and difficult to manage, causing possible misunderstanding and mistakes. Also, in this way the operations of interpretation taken by the BIM operators may slow down the understanding process. A further question concerns the diagnostic analyses fundamental for the understanding of the artefact, which could be hard to interpret directly from the point cloud; not least, the level of details obtained from the point cloud can be very high, but certain characterizations can be difficult to focus on. Adding further information during the survey process could solve this kind of doubts identifying and clarifying the nature of the artefact.

Multiplex benefits increase the efficiency of a full BIM technology, starting from the preliminary survey phase: The interpretation process can be significantly accelerated integrating graphical, textual and photographic elements directly in the point cloud; in this way BIM operators would no longer have to interpret the point cloud only through the geometrical dataset, but supported by multi-competency information. Enhancing the point cloud with metadata and graphical information contributes to ensure a more aware 3D modelling phase that can be used following very simple procedures even by inexperienced operators.

CONCLUSIONS

The incongruity between the project and the survey of the artefact often represents one of the major causes of the delay during the construction phase, increasing times of planned costs. The relationship between BIM and survey needs that the last one permanently becomes the first chain ring in the BIM process, since the subsequent project elaborations depends on its reliability. This aspect should be considered as a primary objective on the impact of the whole process, aimed at simplifying and speeding up the working process, guaranteeing greater protection not least for the entrepreneurial risk. Furthermore, in the “BIM Execution Planning” (BEP) are defined in detail the matrices of the whole supply chain of responsibilities in order to specify the activity of each subject, its relevance, timing and dependence on the times and costs of the construction site. The application of this methodology, vantageous for the design of new buildings, can be equally valid also on existing buildings because its true potential is linked to the definition of a new mode of collective work in which the different professional technicians, clients and users interact in order to limit changes and surprises. Beyond the technical or performance specifications of the software, there must be a change of perspective compared to the past that makes BIM an interesting and probably irreversible process [Bianchini et al. 2016].

The proposed methodology can validate and clarify especially the transition phase between the survey and the subsequent development of the 3D model design. The addition of data included in the point cloud can provide further information to the operators in charge of developing the 3D model, helping them to achieve an easier and quicker comprehension of the survey. Using the software *Autodesk ReCap* it is possible to exploit the digital point cloud survey to form a foundational base where information, texts, photos can be added as additional indications. This alternative method provides lower cost mean for managing sites and structures such as historical contexts, and it can be revealed as essential for fields such as historical preservation and restoration, which are often underfunded and in need of efficient management programs. Future development of cost efficient and simple-to-use programs and methods is also needed to support the research and to ensure the preservation of heritage sites.

FIGURES

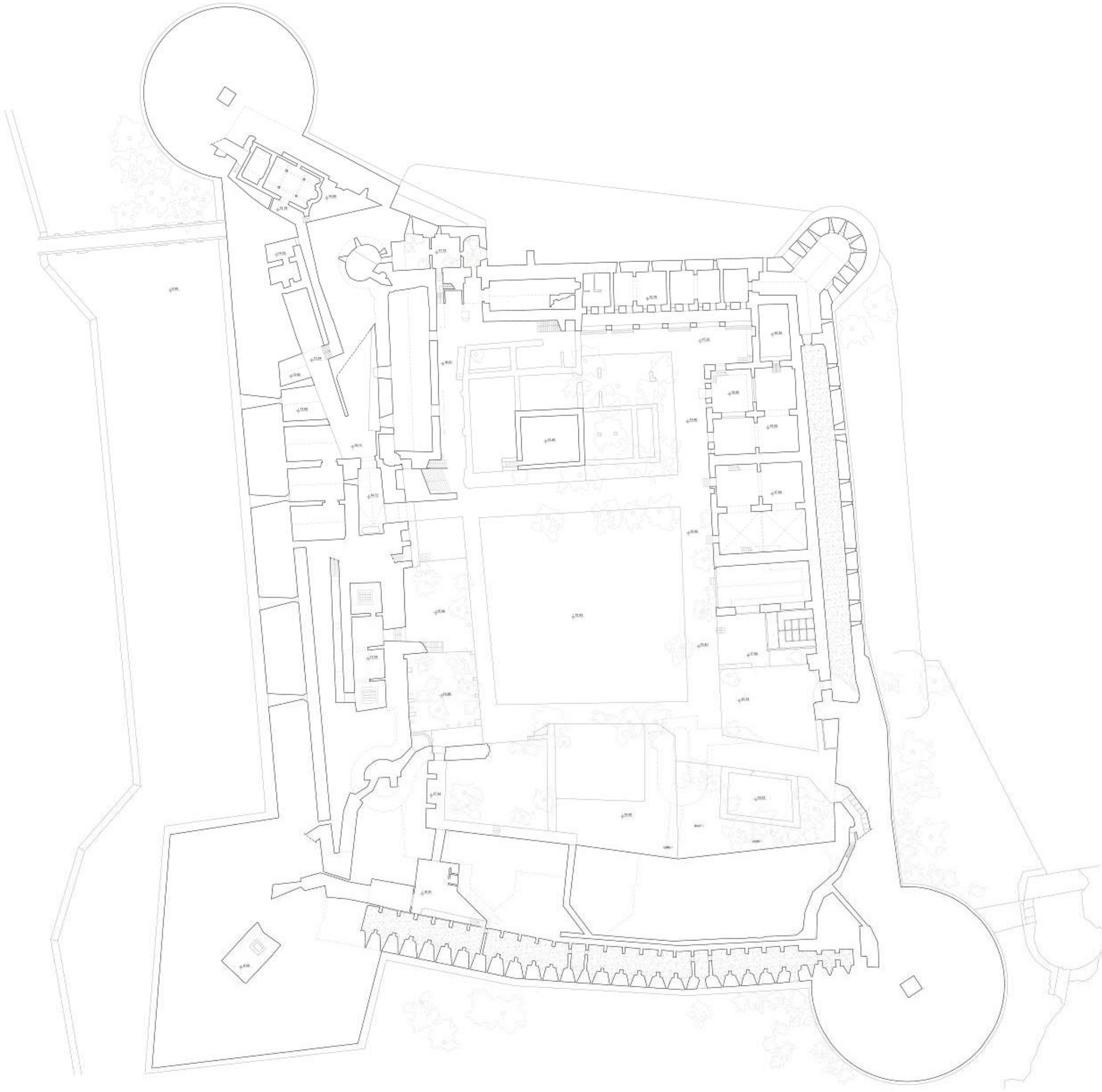

Fig. 1. Plan of the castle of Kyrenia (© E. Valletta)

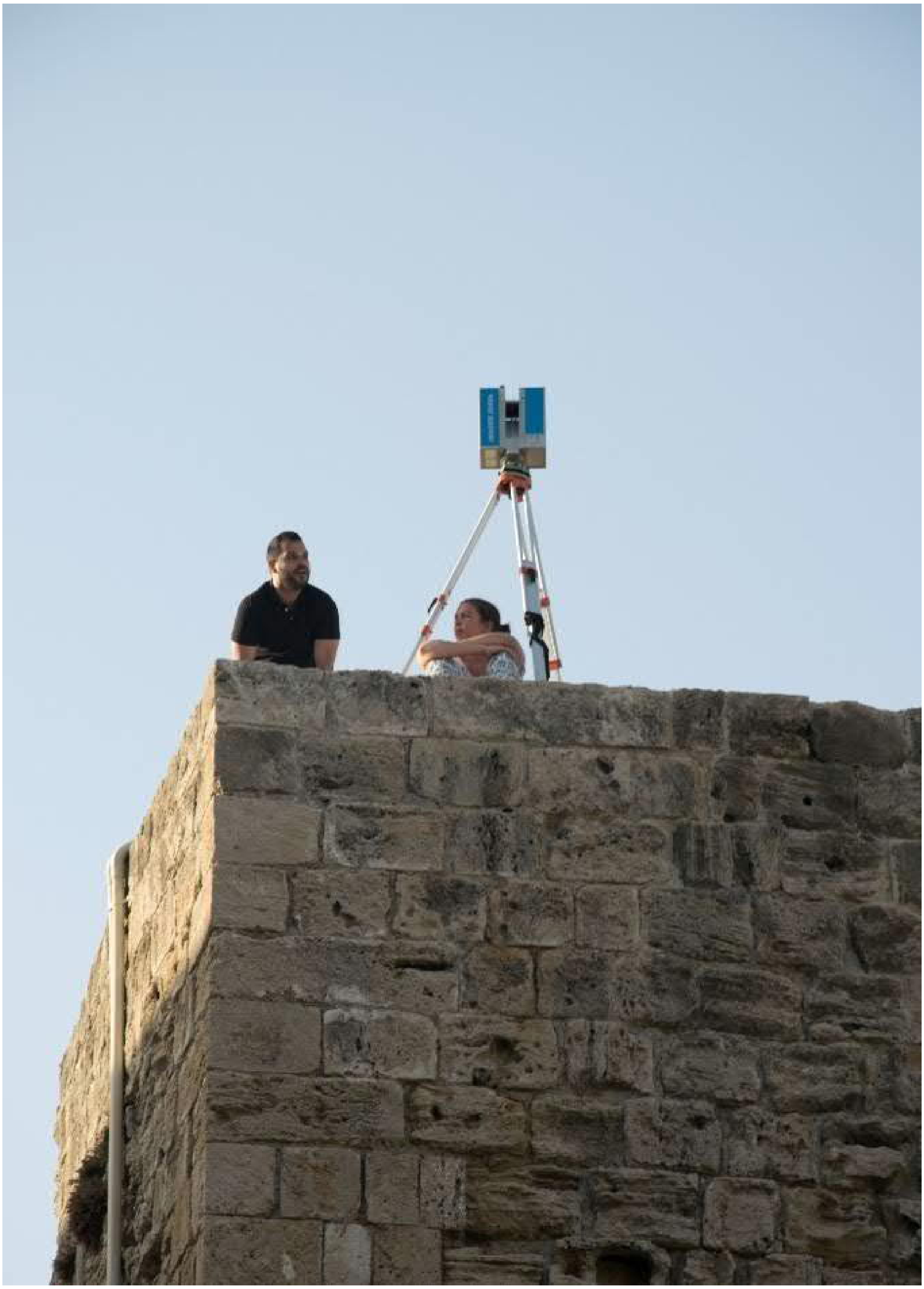

Fig. 2. Laser scanner survey: digital data gathering (© G. Verdiani)

Fig. 3. Laser scanner survey: elaboration of digital data in Autodesk ReCap

Fig. 4. Masonry analysis: balcony shelves on Lusignan masonry testify the past presence of upper storeys (© E. Valletta)

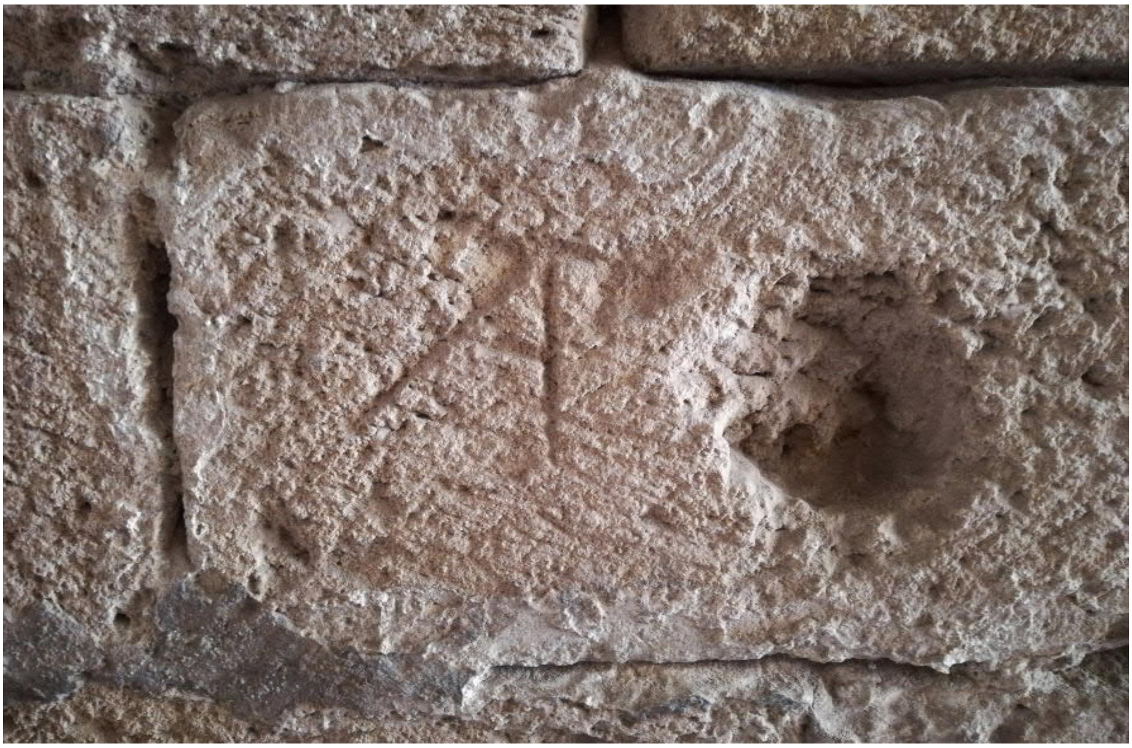

Fig. 5. Masonry analysis: mason's mark impressed on Byzantine masonry (© E. Valletta)

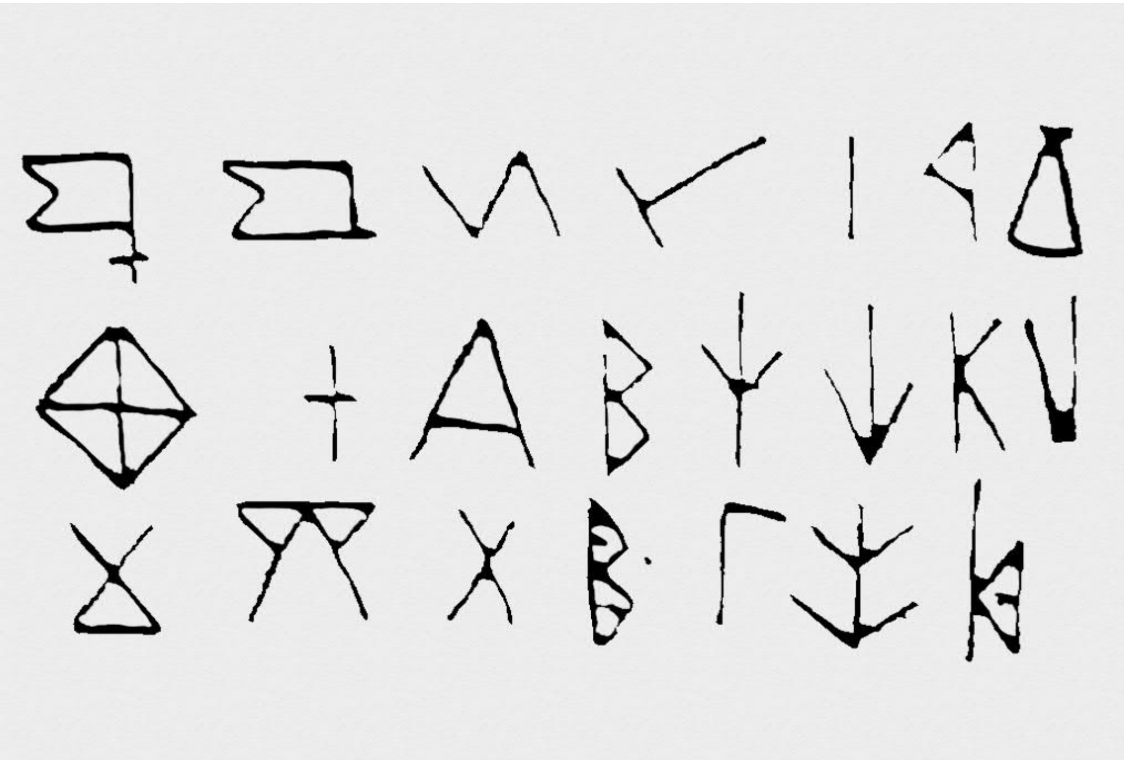

Fig. 6. Masonry Analysis: classification of masons' marks of the castle (© C. Enlart)

Fig. 7. Masonry analysis: St. George Byzantine Church included between Venetian and Lusignan masonry (© E. Valletta)

Fig. 8. Masonry categories in Kyrenia Castle (© E. Valletta)

Fig. 9. Masonry survey of Kyrenia Castle (© E. Valletta)

Fig. 10. Insertion of masonry survey into the point cloud - Byzantine Masonry (330-1191)

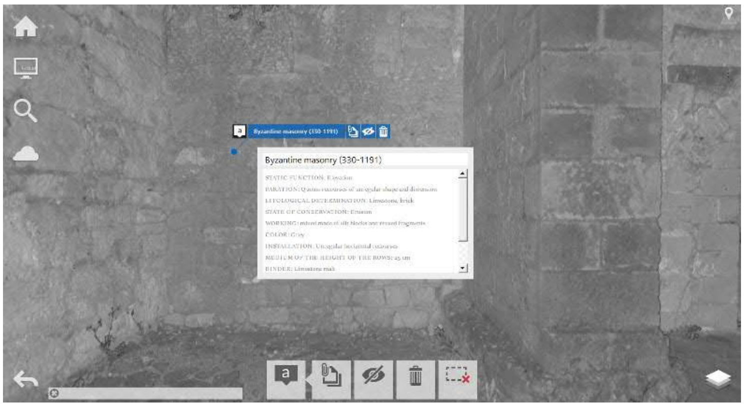

Fig. 11. Insertion of masonry survey into the point cloud - Byzantine Masonry (330-1191)

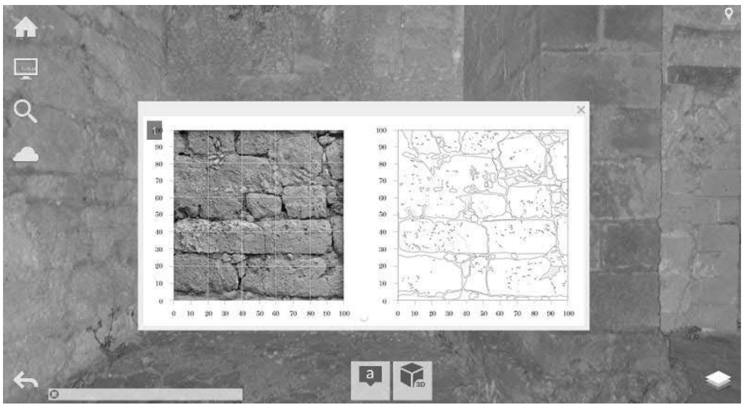

Fig. 12. Insertion of masonry survey into the point cloud - Byzantine Masonry (330-1191)

Fig. 13. Insertion of masonry survey into the point cloud - Lusignan Masonry (1192-1489)

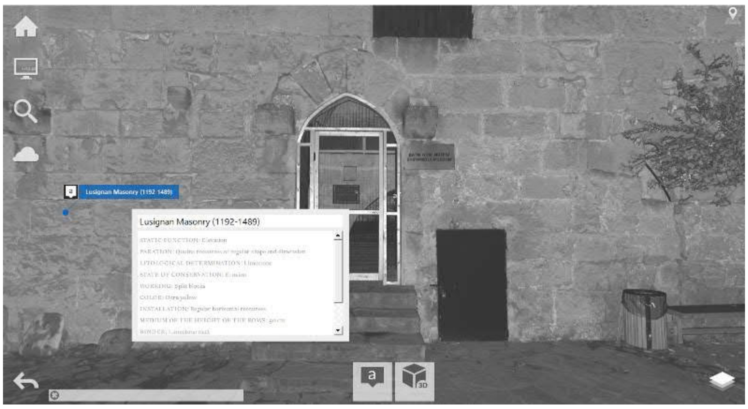

Fig. 14. Insertion of masonry survey into the point cloud - Lusignan Masonry (1192-1489)

Fig. 15. Insertion of masonry survey into the point cloud - Lusignan Masonry (1192-1489)

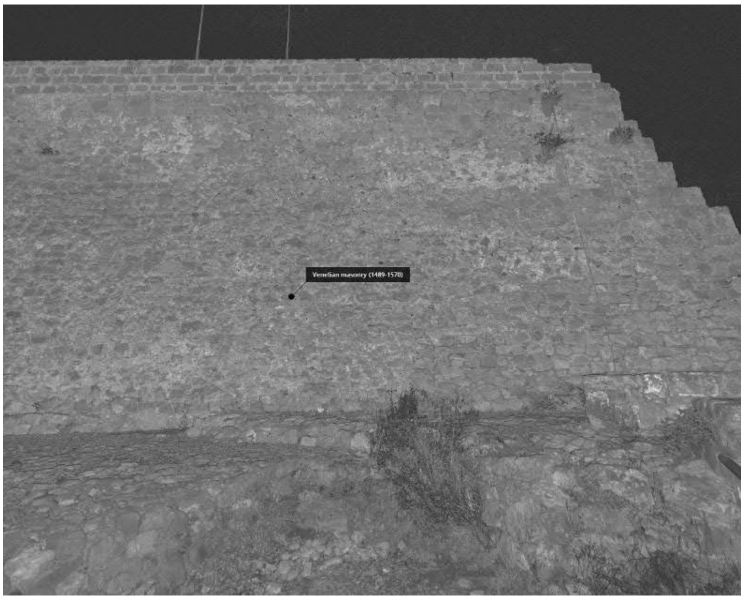

Fig. 16. Insertion of masonry survey into the point cloud - Venetian Masonry (1489-1570)

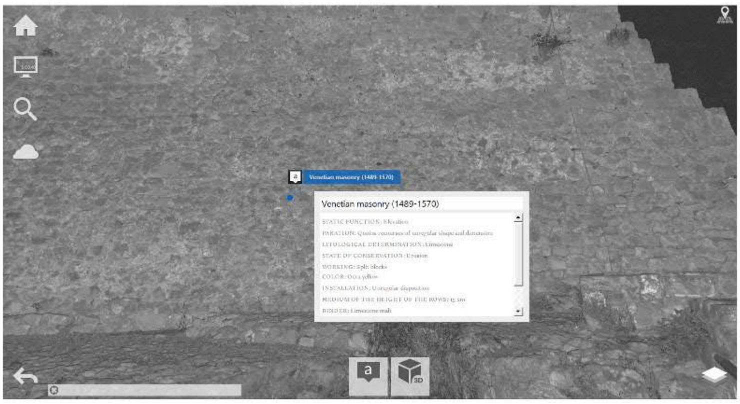

Fig. 17. Insertion of masonry survey into the point cloud - Venetian Masonry (1489-1570)

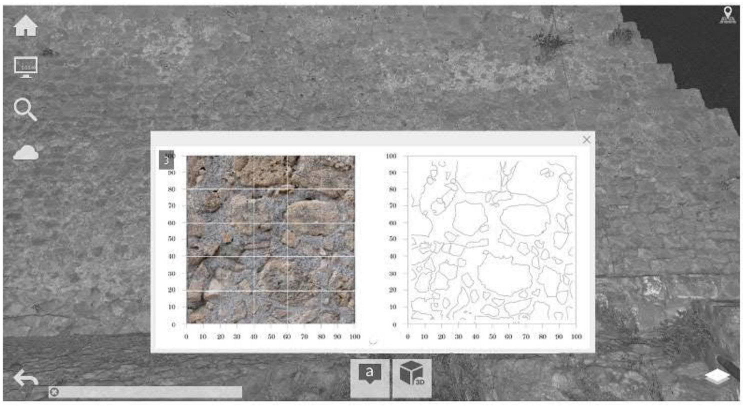

Fig. 18. Insertion of masonry survey into the point cloud - Venetian Masonry (1489-1570)

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