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HBIM DATA MANAGEMENT IN HISTORICAL AND ARCHAEOLOGICAL BUILDINGS

1. Introduction

The idea of Building Information Modeling (BIM) took shape in first rough forms since 1970: in 1974 in an internal report of Georgia Institute and, further, in an article of «AIA Journal», prof. Charles M. Eastman proposed an excellent model of three-dimensional system for building design (Eastman *et al.* 1974, 1975, 2011) successively named BIM. With BIM, it could be possible obtaining plan views elevations and sections from a single model together with lists of materials and analyses of various types (Eastman 1976). Every operation or modification applied to a part of the model should also update all the information connected to it and vice-versa.

The concept of BIM has evolved until today, with the introduction on the market of some dedicated software that use libraries of parametric objects based on the IFC (Industry Foundation Classes) standard (Laakso, Kiviniemi 2012) for the digital description of the built asset industry (buildingSMART 2020: https://www.buildingsmart.org/standards/bsi-standards/industry-foundation-classes/). IFC is an open format that allows the exchange of data between different software in a single database schema, grouping building elements into families according to a hierarchical and relational model. In this way, the 3D modelling phase is made easier and faster.

The evolution of software capabilities is allowing BIM to involve not only architects and construction engineers but also all those figures that come into play in the construction of a building project. It is, therefore, a methodology that follows a building from its conception to its actual realisation, finding its usefulness also in the subsequent management and maintenance phases thanks to the integration with the survey and monitoring techniques (Volk, Stengel, Schultmann 2014).

Initially, BIM tools were developed for the design and management of new buildings; in fact, it is mainly based on the use of standard models of parametric objects. The use of the BIM model, for the design phase of the new constructions, takes the name of as-designed BIM. In a second moment, since in Europe the management and maintenance of the building became the most widespread Architecture, Engineering and Construction (AEC) activity (Haapio, Viitaniemi 2008), the BIM model was also applied to the existing buildings, to support all the monitoring, management and maintenance operations that accompany the entire life cycle of each building asset. The latter approach took the name of as-built BIM (Huber *et al.* 2011). In this field the acquisition of necessary information for planning maintenance interventions of the building represents a complex operation (Vacca *et al.* 2018) that is not yet developed enough (Graham, Chow, Fai 2018).

In more recent years, as-built BIM is acquiring importance in the sector of Cultural Heritage (CH). The idea of developing a virtual model of a monument that goes beyond a simple and realistic representation is becoming increasingly common. What has been defined as Historical BIM (HBIM) would be a new methodology, that is open to the management of historical architecture using reusable libraries of parametric objects (Lopez *et al.* 2017). These elements are constructed through the geometric data obtained from the survey (Dore *et al.* 2015), to which it is possible to associate different types of information by creating models that can be updated over the time.

All the aspects previously addressed and discussed are sensible aspects to be explored deeply to implement BIM models of CH.

2. Materials and methods

Considering the HBIM, from the beginning of the research in this field, the correct categorisation of every element of a selected historical building in a standard system has been an interesting challenge to study. In fact, some problems already present in the as-built BIM are more relevant in the HBIM. First of all, it's necessary to consider that BIM was born as a methodology dedicated to the design of new constructions, directing the development of most of the software on the market towards this solution. The use of libraries of building objects, in fact, helps the designer in choosing the best elements, between those ones included in the used library, also allowing, within certain limits, personalisation of the elements themselves. Instead, in the modelling of existing buildings, it's frequent to find components that require additional modifications (Logothetis, Delinasiou, Stylianidis 2015). Even more, historical or archaeological buildings present very particular architectural elements that are no longer in use in most recent buildings and, for this reason, they are not present in standard common libraries. Indeed, all the elements belonging to the same category are often made with different configurations and decorations, thus creating a wide variety of construction models. This huge variety of possible combinations strongly increases the difficulties related to the modelling phase and even more to the parameterisation of objects. In fact, the parameterisation of the components that should compose existing building, finalised to the creation of an HBIM model, is more complex considering the heterogeneous geometries that compose the construction (Chiabrando, Sammartano, Spanò 2016).

For this reason, the creation of a standard library of reusable historical architectural elements remains mostly an unresolved problem. The aspect of the parameterisation of objects belonging to a reusable digital library (Ioannides, Magnenat-Thalmann, Papagiannakis 2017; Prizeman *et al*. 2018) should constitute a fundamental requirement within the HBIM methodology as it has been theorised. The development of a standard categorisation needs a correct breakdown of a historical building obtainable only applying modelling procedures that can take into account features and functions of different elements. Regarding the correct BIM structure modelling of a historical or archaeological building, a particular focus is necessary for the study of interconnections between single elements, to obtain the real behaviour of the entire construction. It could be the case of the HBIM methodology applied to the Romanesque church of Santa Maria at Portonovo (Quattrini *et al*. 2015).

Another fundamental aspect to consider in HBIM design is the focus on the purposes of the output model, developed according to the BIM uses described below. In fact, as presented below, the categorisation of elements, the survey technologies and modelling techniques to adopt should be strictly linked to the final function of the HBIM model (Oreni *et al.* 2013).

In light of the latest research, through the presentation of some case studies developed at GISLab (http://gislab.geomatica.unipa.it/), the problems related to the construction of an HBIM model will be explored, to propose possible strategies to follow correlated to the final use of the model. At the same time will be illustrated the best survey techniques considering the required level of accuracy, strictly connected to the implementation needs of the final HBIM model.

3. Variables to consider for the construction of the HBIM model

In these years, the potential of BIM applied to historical buildings has been studied within the GISLab considering, in particular, archaeological sites. The case study dedicated to the crypt of the Chiesa dei SS. Sergio and Bacco in Rome allowed experimenting a workflow (Fig. 1) necessary for the construction of a complete HBIM model (Scianna, Gristina, Paliaga 2014). Modelling operations need three preliminary phases, which consist of the collection of building information, the survey and the categorisation of the construction elements. The in-depth knowledge of the historical good, in fact, is an essential element for its correct modelling according to the BIM methodology and very often the only topographic survey is not enough. The categorisation of the constructive elements, for better understanding the function of the architectural elements and the relationship with the objects, plays a fundamental role in the modelling activity and the attribution of semantic information to the designed elements. The modelling phase, finally, provides a series of outputs in different formats and usable for different purposes (interoperability, 2D drawings, etc.).

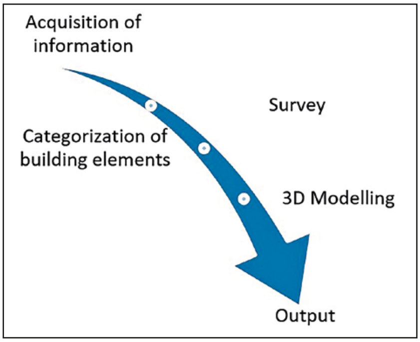


Fig. 1 – The workflow for the construction of an HBIM model.

In the context of the construction of the BIM model in general, but even more so in the case of HBIM, a series of fundamental variables come into play during acquisition and processing:

– design needs;
– objects complexity;
– presence of deterioration in buildings;
– architectural variety.

From an operational point of view, the effectiveness of an HBIM model can be measured through the satisfaction of needs that required its realisation. In particular, it has been proven that it is impossible to create an HBIM model that can satisfy all possible design, construction and maintenance requirements. As described below, in fact, some requirements often conflict with each other during the creation of the model, becoming alternative choices.

Many of these needs, called BIM uses, can be identified, including:

– structural analysis;
– energy analysis;
– mapping of degradation;
– analysis of the cracking patterns;
– monitoring operations;
– metric calculations;
– restoration and reconstruction operations;
– sharing of Cultural Heritage (CH);
– extension of accessibility also to the disabled people.

Each of these requests needs the creation of an appropriate model, in which the level of detail in the 3D graphic representation and the semantic description of the architectural good can be more or less pushed according to the project needs. Furthermore, depending on the type of application required, a certain degree of interoperability within the HBIM process becomes necessary. In particular, it becomes essential exporting and importing the model in different formats in specific software, often not produced by the same software developer. BIM/HBIM methodology uses both semantic and geometric description of constructive elements. In HBIM, the semantic classification and description of elements seems less complex than the geometric one.

As regards the representation of the architectural elements, it's necessary to consider their complexity for accurate 3D modelling, that is always required in cases of degradation mapping or reconstruction operations. Very often, in historical buildings, there exist very complex architectural structures not fully visible in the first phase of the survey. It is not always possible to identify hidden architectural elements inside the walls, such as the support points of arches and vaults, or structural discontinuities. For this reason, an exhaustive knowledge of the construction technologies of the studied object is essential.

Another factor that characterises historical buildings and represents a further variable for the construction of the HBIM model is the presence of degradation. In particular, the deterioration due to the collapse of parts of the artefact makes the use of parametric objects very difficult, also complicating the modelling phase. Furthermore, to generate an analytical model for carrying out static analysis of the building, specific geometrical parameters must be

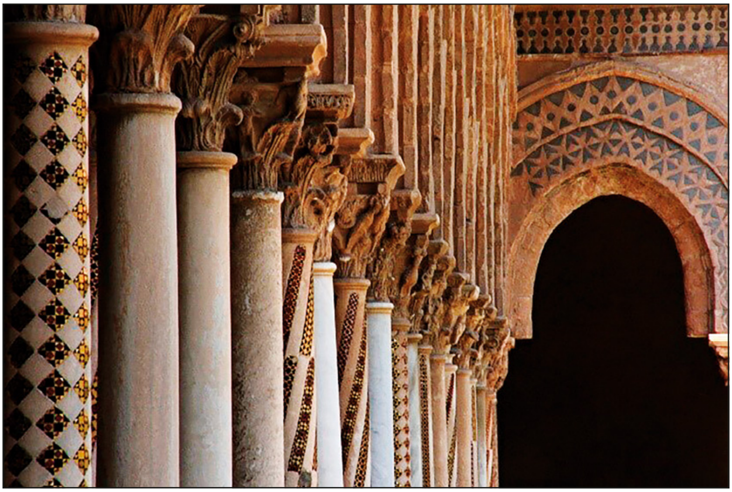


Fig. 2 – An example of the variety of architectural elements with the same function in a monumental historical complex (Monreale Cathedral). The shape of every capital is different from each other, and full assimilation to a standard model is impossible. The complexity of these objects hinders the construction of standard libraries.

respected during the creation of the load-bearing elements. In this case, therefore, the need of a faithful representation of the degradation conflicts with the simplified modelling for structural analysis. In fact, within the model, the behaviour of each component, enriched with semantic information, is closely linked by certain relationship to the other elements that surround it.

An additional variable to consider in HBIM modelling is the variety of architectural elements. This is a persistent aspect in CH and is manifested through the diversity of similar elements, even within the same building, with the same architectural and static function. This variety is due both to the presence of several variants within the same type of element (Fig. 2) and to the handicraft production of the components, which determines the uniqueness of each product. This feature constitutes another variable which can significantly complicate modelling in HBIM.

4. HBIM

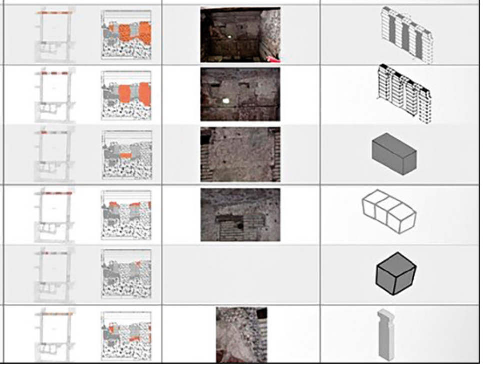
4.1 *Modelling requirements*

The presence of standard parametric object libraries is one of the main features of BIM software that offers significant advantages in modelling. The construction of libraries of specific objects for CH is, therefore, a fundamental requirement for HBIM methodology. However, as highlighted above, the constructive elements of historical/archaeological architecture show features deeply different from those of the architectural elements in contemporary constructions. It's necessary to develop these libraries to perform a breakdown of the historical asset into categories and to identify all the components and related functions (as in the modern building system).

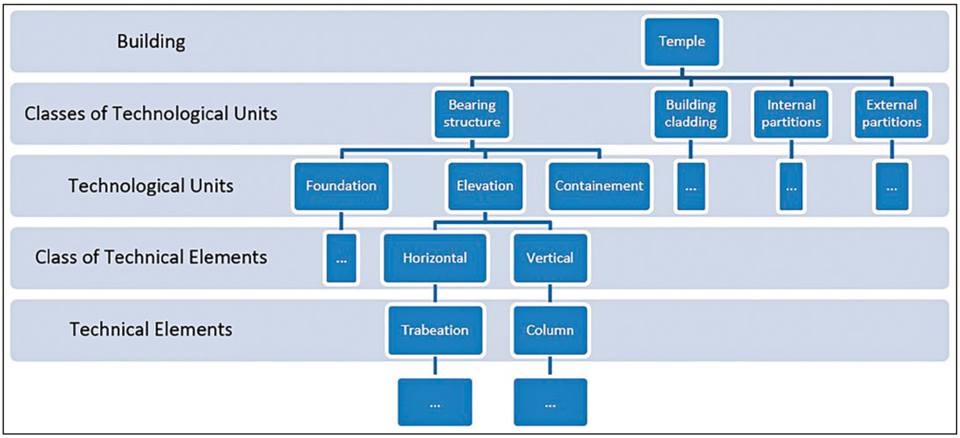
For example, in the case studied by the GISLab of the Church of SS. Sergio and Bacco in Rome, before the actual realisation of the model, was created a hierarchical database of architectural elements that subsequently allowed identifying the relationships between the various elements (Tab. 1). Considering, instead, another case study dedicated to the creation of an HBIM model of a Doric temple, it's necessary to breakdown the entire building, identifying so the bearing structure and therefore the elements that compose it, similarly to what happens in the decomposition of the modern building system envisaged by the Italian UNI 8290 standard.

This breakdown into hierarchical Classes of Technological Units, Technological Units, Classes of Technical Elements and Technical Elements, therefore, allows understanding the role and the behaviour of each element that makes up the building organism (Tab. 2). After the identification of a specific architectural element, it is necessary to identify the fundamental features required for the parameterisation of the model. Therefore, each component must be further decomposed to understand its geometric features, relations

DATABASE	PLAN	PHOTOGRAPHY	MODELLING
_ BUILDING ELEMENTS:			
1 - pillared architraved / infill			
1.1 - opus quadratum pillars			
1.1.1 - Aniene's tuff blocks (60 x 60 x 125 approx.)			
1.2 - opus quadratum lintels			
1.2.1 - Aniene's tuff blocks			
1.3 - infill in opus reticulatum			



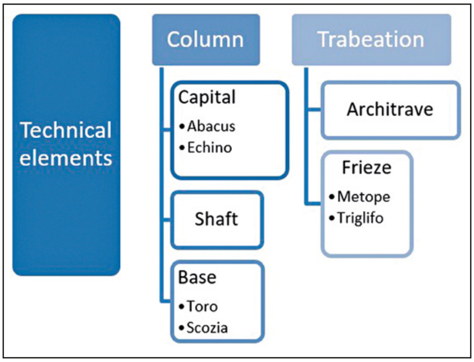
Tab. 1 – An example of a hierarchical database of architectural elements.



Tab. 2 – Breakdown of the structure of a Doric temple.

and constraints with the other elements, the parameterisable parts and the semantic information that can be associated with it.

The identification of relationships with other elements and constraints is a fundamental step to connect the components of the structure and to establish the dimensional variables of each object. Correct insertion of the constraints is also necessary if a full working parametric final model is required (Aubin 2013, 209-242). Even if the use of parameterisation of constructive elements



Tab. 3 – A breakdown into categories of technical elements in a Doric temple.

(synonymous of standardisation and repeatability) is not mandatory, definitely its use allows obtaining a complete model of the building asset. This kind of model results lighter and more suitable for subsequent automatic structural or energetic processing.

The parts that make up a Doric column, for example, have been modelled separately and "hooked" each other considering the real behaviour of the architectural elements (Tab. 3). The modelling of the column started considering some main distances that are made parametric using the diameter of the column as reference. When the height varies, each part of the column varies its size while maintaining the correct proportions (Figs. 3, 4).

This relation creates a family of parametric columns in height and width. The University "Federico II" of Naples realised a similar HBIM model of a Corinthian column for the valorisation of the site of *Liternum* (Cera 2017). Even in this case the model is composed of three parts: a parametric shaft, the parametric profile of the attic base and the circumference of the column's base, and a mesh of the capital subject only to the change of scale. Differently, in the realisation of the HBIM model of the Etruscan temple of Marzabotto for the ArchaeoBIM project, a more in-depth parameterisation of the Doric columns was carried out based on the Vitruvian indications. The same columns were then used as a metric reference for the entire elevation and therefore for the temple (Garagnani, Gaucci, Govi 2016).

However, the variety of architectural elements previously highlighted and the presence of degradation on ancient structures make not exhaustive this kind of parameterisation. Hence, in another case concerning the realisation of an HBIM model of a column of the "Temple E" of Selinunte Archaeological Park, a different way to parameterise a column has been studied, through the help of architectural pattern books such as *The Classical Order of Architecture*

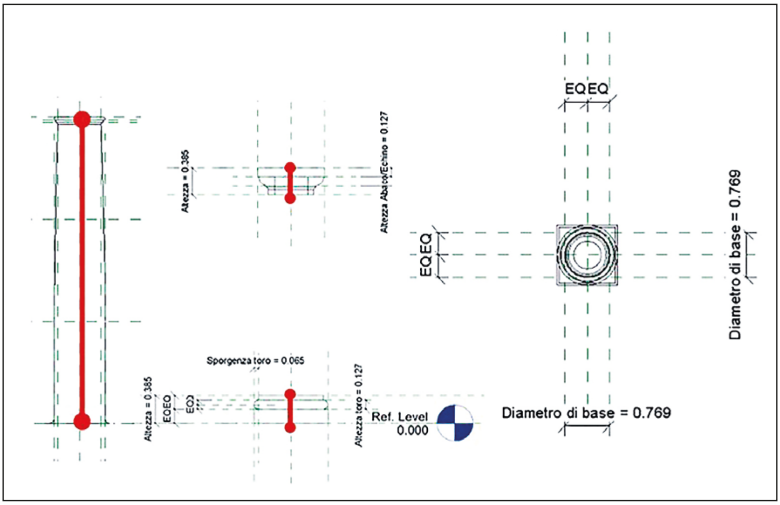


Fig. 3 – Parameterisation of the Doric column.

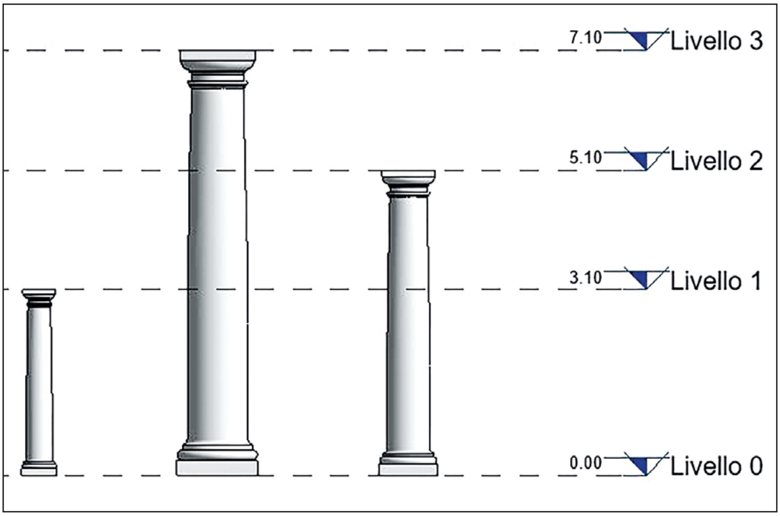


Fig. 4 – Column scale variations based on constraints.

by Robert Chitham. It has also been necessary to extract the section from the cloud of the column to create parametric profile families. It's possible to realise a parametric element that best respects the real geometry loading the profile of the section of the point cloud into a profile family in which specific automatic

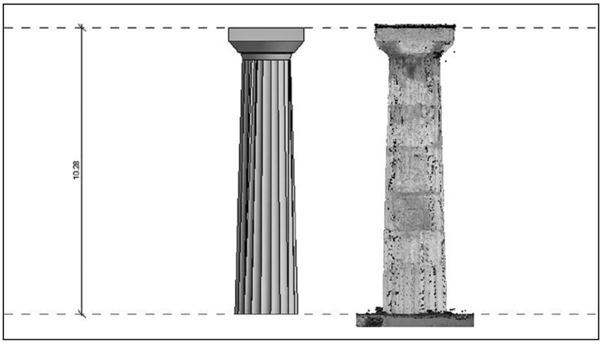


Fig. 5 – Comparison between the parametric model and point cloud of a column of the Doric Temple E of Selinunte.

solid modelling operations are applied (Scianna, Gaglio, La Guardia 2018) (Fig. 5). Hence, in this example the column could be adapted to the point cloud.

However, since these are automatic operations, it is not possible, in many cases, to represent irregularities caused by collapses or other types of degradation. Considering this example, therefore, ad hoc manual modelling is more effective and less time-consuming.

4.2 *Level of detail and level of development*

In HBIM modelling, it is not always necessary to represent an architectural element with a high level of detail. The level of detail of a BIM object is the graphical accuracy to achieve in modelling and it depends on both the scale range (maximum and minimum) of representation and the use of the final model. Considering, for example, a Corinthian capital, the level of detail changes considerably depending on the needs of model reconstruction.

The level of Development of a BIM object is, instead, composed by a geometrical and a semantic component. In particular, the Italian UNI 11337:2017 considers the Level of Geometry (LOG) and the Level of Information (LOI) as the two components of the Level of Development. The LOG consists in the graphic representation of the model, instead the LOI represents the semantic description associated to it. Furthermore, the level of development to achieve must be outlined considering the final purpose of the model. The detailed levels established by the AIA BIM Protocol are cited below:

– LOD 100 – Conceptual representation
– LOD 200 – Generic models and quantity indication
– LOD 300/350 – Executive Design
– LOD 400 – Construction Design
– LOD 500 – Artefact as realised

In every of these LODs both graphical and semantic aspect are considered.

Taking the example of the Corinthian capital again, if the purpose is to carry out a structural analysis of the building, a conceptual or generic representation of the model would be sufficient (as required by the dedicated software) (Fig. 6, a-b). Vice versa, in the case of a restoration intervention, it would be necessary to show the artefact as it is, deepening the modelling with a level of advanced development (Fig. 6, c).

The Italian UNI 11337 defines, instead, different levels of development in which are included the Level of Geometry (LOG) and the Level of Information (LOI):

– LOD A - symbolic object
  LOG - symbolic 2D representation
  LOI - rough positioning
– LOD B - generic object
  LOG - approximated volumes
  LOI - definition of function
– LOD C - defined object
  LOG - detailed representation
  LOI - definition of metrics and materials
– LOD D - detailed object
  LOG - detailed representation
  LOI - detailed materials, stratigraphies, structures
– LOD E - specific object
  LOG - complete representation of the object
  LOI - technical information about the construction
– LOD F - executed object
  LOG - as LOD E
  LOI - maintenance manual, certifications
– LOD G - updated object
  LOG - as LOD E or as modified
  LOI - maintenance date

In general, LOD is, therefore, a factor that must be defined before the modelling phase, to establish the point of definition of the final model.

Another example could be the 3D reconstruction of a Greek column in Autodesk Revit, where the modelling approach changes substantially depending on the aim of the final representation. In particular, the representation of the entasis (the curvature of the column profile) complicates the modelling significantly and should be avoided if the purpose of the work is the construction of a conceptual model for structural analysis. At the same time, the entasis representation should be inserted in the case of a restoration or conservation

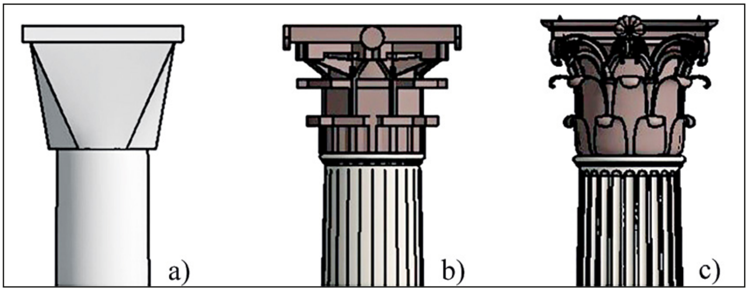


Fig. 6 – Three different levels of graphic detail of an HBIM model of a Corinthian capital.

intervention. Furthermore, the difficulties in modelling depend also on the BIM software used. An element that cannot be modelled in Revit could be made in ArchiCad and then imported in the first software or vice-versa. However, as said before, the interoperability between BIM software is not completely working yet, especially with historical architectural elements.

5. Survey methodologies for HBIM

5.1 *Survey methodologies and accuracy*

The reference and the trace coming from a point cloud of the real artefact, generated during the survey phases, are fundamental for the construction of an HBIM model (Anton *et al.* 2018). As previously mentioned, in recent years, traditional survey technologies have been revolutionised, sometimes modifying the type of approach of data acquisition phases (Fig. 7). Significant progress has been made in the field of TLS (Terrestrial Laser Scanning) detection and close-range photogrammetry acquisition, allowing the collection of different kind of data about a CH object (Guarnieri *et al.* 2017). In particular, considering the acquisitions from TLS, nowadays instruments allow acquiring very dense point clouds, obtaining very high levels of accuracy in short times. Many devices now allow automatic cloud alignment and correct georeferencing of the final model through connection to the GNSS network. In the field of architectural survey, the levels of accuracy achieved by this type of technology are now millimetric.

Significant advances have also been achieved in the field of photogrammetry, where the development of the SfM-based algorithms (Structure from Motion) allowed obtaining reconstructions of point clouds of environments starting from the acquired images. The SfM algorithm automatically detects the homologous points by recognising the corresponding contours through iterative processes. Through this procedure, by connecting the point cloud to a network of known coordinate targets, it is now possible to obtain centimetric

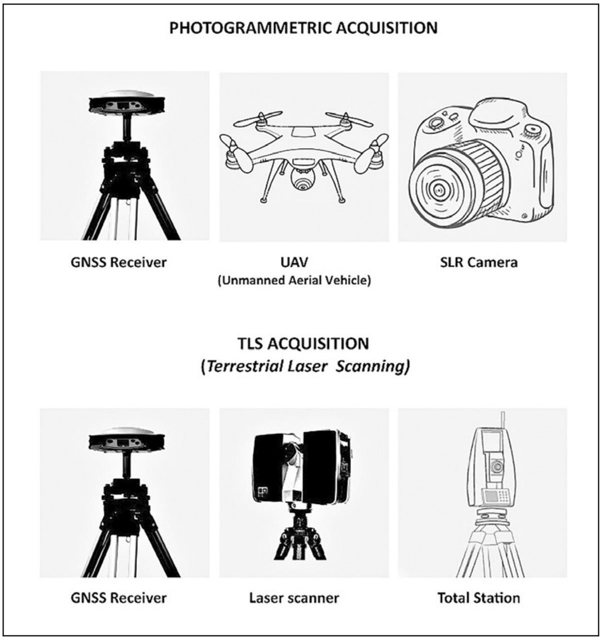


Fig. 7 – Data acquisition and survey methods.

levels of accuracy. The recent development of UAV (Unmanned Aerial Vehicle) equipment has greatly enhanced the possibilities of photogrammetric surveying, allowing a complete point cloud reconstruction of a building, based on aerial images taken from different angles.

This technique is still under development, but there are definite improvements in sensor quality (Pepe, Fregonese, Scaioni 2018), camera resolution, and in the 3D management of the flight path for the UAV navigation (Mangiameli *et al.* 2013). In recent years the UAV instruments have also been used by equipping drones with laser scanner instruments, to scan the territory during flight. However, the costs of instruments and risks related to this type of solution limit its use. Today the TLS acquisition achieves higher levels of accuracy than photogrammetric one. However, the distribution of point clouds obtained by TLS instrumentation is closely linked to the positioning of the instrument (which is why it is sometimes impossible to use it in inaccessible places).

The photogrammetric acquisition, on the other hand, allows obtaining a uniform distribution of the point clouds on the considered territory, using much less expensive instruments and in-flight shooting, regardless of the level of accessibility of the area (allowing more freedom in the positioning of the Ground Control Points). The possibility of obtaining a point cloud uniformly distributed, that will be analysed later, is essential for the construction of an HBIM model. In this field, the work carried out by the Department of History and Culture of the University of Bologna for the "Grande Progetto Pompei-Piano della Conoscenza" shows the importance and effectiveness of the most modern and non-invasive survey techniques. These aimed at the realisation of an HBIM model that can help in the reconstruction of fragments of the archaeological site and in planning intervention strategies for the restoration of the landscape of Pompeii (Silani *et al*. 2017). There are many factors to consider to choose the most convenient acquisition methodology, and the maximum accuracy level is not always the most important prerogative.

5.2 *Level of accuracy related to the purposes of the HBIM model*

The design requirements of the HBIM model influence the choice of the most appropriate acquisition methodology during the survey phase. A high level of accuracy is necessary, for example, to highlight the cracking pattern of a wall or to monitor the tiny displacements of an intrados of a vault. In this case, it is essential to acquire a point cloud with millimetric precision through the use of TLS instrumentation. However, in all other cases, for the construction of an HBIM model that meets the requirements of design and architectural representation, the restitution of a point cloud uniformly distributed with centimetric accuracy results exhaustive (Tab. 4).

An example was the three-dimensional reconstruction of the Manfredonia Castle of Mussomeli, developed by the GISLab laboratory, as part of the European project PON NEPTIS (Scianna, La Guardia 2018). The aim was to obtain a 3D model that could be viewed and explored on the web and also used for sharing CH information and extending access to the disabled. In this case, the photogrammetric reconstruction from images taken by UAV was chosen. The considerable width of the survey area and the irregularity of the environment surface have forced to reduce the accuracy of the point cloud, but the error range has been kept within ten centimetres. However, the reconstructed model has been fully functional, respecting the requirements set. The survey activity and the subsequent construction of the HBIM model of the Fornace Penna, held for the Benchmark 2017 and 2018 sessions (Piras, Di Pietra, Visintini 2017; Scianna, Castagnetti, Matrone 2018) organised by the Italian Society of Topography and Photogrammetry (SIFET), is, instead, an example that allows some reflections on survey operations for HBIM applications. In particular, an HBIM model has been obtained using the point cloud generated by the photogrammetric restitution of images taken by UAV (Fig. 8, a-b). This model could be useful for many activities, including structural analysis, degradation mapping, web navigation. Therefore, the use of the TLS survey appeared to be unnecessary compared to UAV survey to obtain an HBIM model that could meet these requirements.

Applications in architettonic scale	Low accuracy (2-3 cm)	Average accuracy (1 cm)	High accuracy (1-2 mm)
Structural analysis	•	•	
Energetic analysis	•		
Mapping of degradation		•	
Cracking pattern analysis			•
Monitoring operations			•
Metric calculations	•	•	
Restoration and reconstruction		•	
Sharing of Cultural Heritage (CH)	•		
Extension of accessibility to the disabled	•		

Tab. 4 – Accuracy levels required based on the application of the HBIM model.

The model was created following a breakdown of the parts of the building (pillars, arches, structural walls, etc.) through the observation of the images taken by the drone and tracing the geometry of the point cloud. For each element, particular families have been created that respect their actual behaviour. The parts were then joined respecting the real geometry. Thus, an HBIM model useful for multiple activities was obtained, including structural analysis, deterioration mapping, online use, based on the point cloud generated by the photogrammetric restitution of images triggered by UAV. Finally, the textures used to complete the model were generated from the orthogonal projections of the mesh coming from the point cloud. Furthermore, an analysis was produced on the comparison between the BIM model created and the point cloud using Faro CAMS PointSense plug-in. It calculated the orthogonal distance between the points of the cloud and the considered face, showing greater deviations at the upper part of the walls where the section of the walls thins due to tapers and collapses (Fig. 9).

Another interesting case study concerns the realisation of the HBIM model of "Temple E" of Selinunte Archaeological Park, starting from the point cloud. Taking into account what has been said above, the main goal of the research was the construction of a 3D model that could be transferred to the structural calculation software. A classification of the elements was carried out to identify the most appropriate software components for the modelling of the parts. Also, in this case, Revit was chosen as BIM software, as it allows easy and effective modification of the architectural elements belonging to the library.

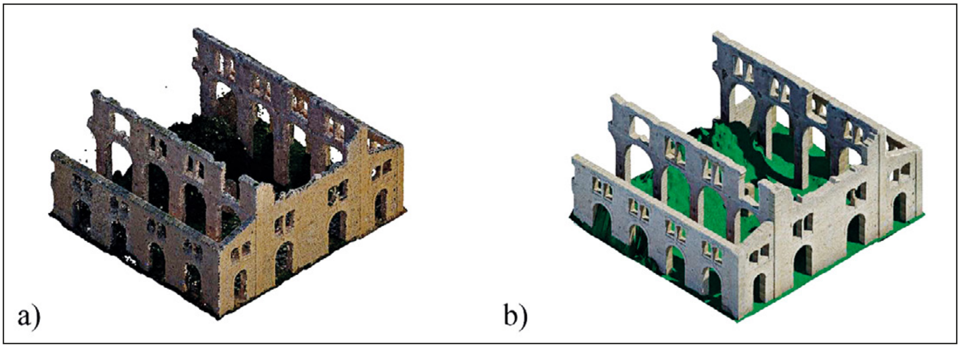


Fig. 8 – a) Point cloud and b) HBIM model of Fornace Penna.

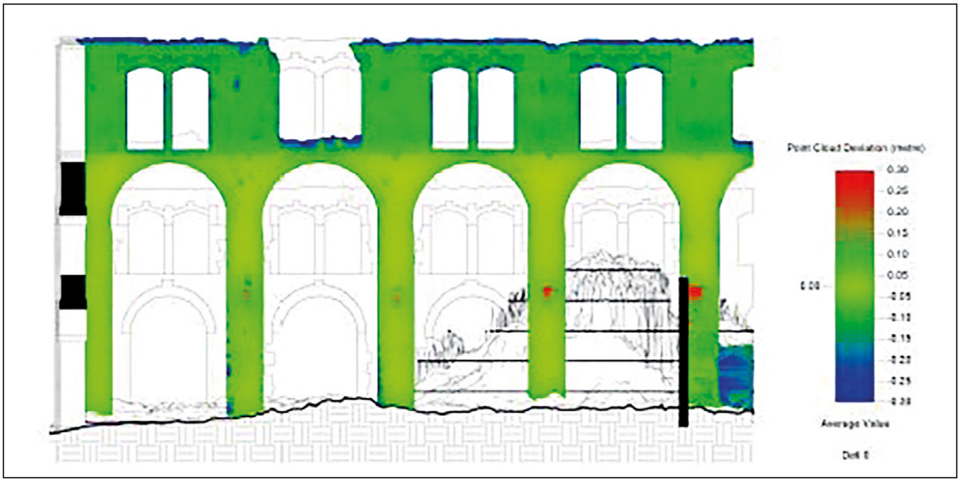


Fig. 9 – Comparison between the point cloud and the BIM model.

Experimentation has brought to identify some new problems related to the graphic representation as faithful as possible to the original only using BIM software. In the process for the realisation of the columns, techniques developed in previous experiments were used: extraction of the longitudinal sections from the point clouds of the columns and insertion in nested families within the BIM software. For the realisation of the base, instead, mass elements of its components were made (*euthynteria*, *crepidoma* and *stylobate*), converted then into floors. However, the software automatically creates perfectly horizontal floors that do not reflect the shape of the real base of the temple under examination. The latter presents some differences in dimensions in

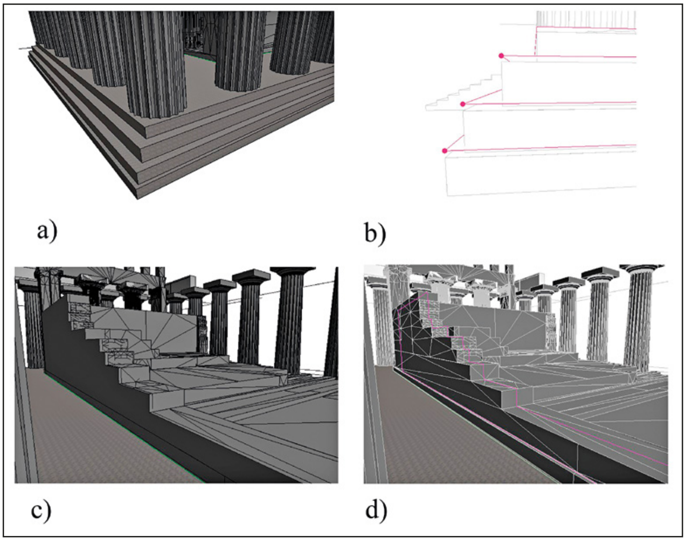


Fig. 10 – a) Physical model of the basement; b) highlighting the analytical model of the horizontal crepidoma and distant in some points from its physical model; c-d) realisation of the walls of the *naos* by modifying the profile of the wall element.

its points, and an accurate adjustment was necessary. The same process was applied to the construction of the *pronaos* base. However, the automatically generated analytical model is perfectly horizontal. Therefore, it deviates from the physical model, and vertical adjustments are not possible (Fig. 10, a-b). The walls of the naos instead, despite the high level of degradation due to collapse, did not present particular difficulties in modelling. It was enough to adapt the prospectus of the walls to the shape of the real ones (Fig. 10, c-d).

The temple, as previously mentioned, is mainly degraded, a very evident aspect, especially in the entablature. The realisation of it presented a series of difficulties linked both to the need for graphic representation and to aspects relating to the homogeneity of the analytical model. The architraves were obtained modifying the beams inside the software. However, they inherited some behavioural characteristics that required some adjustments. When the beams, already predefined in the software, meet a pillar, belonging to the family of structural pillars, at a corner, break the joint with the next beam. It represents only a graphic problem since from the analytical point of view, the beam, the pillar and the successive beam are well connected (Fig. 11, a-b). This problem of representation was solved by inserting mass elements in correspondence of the four corners of the temple, which are not relevant from an analytical point of view (Fig. 11, c).

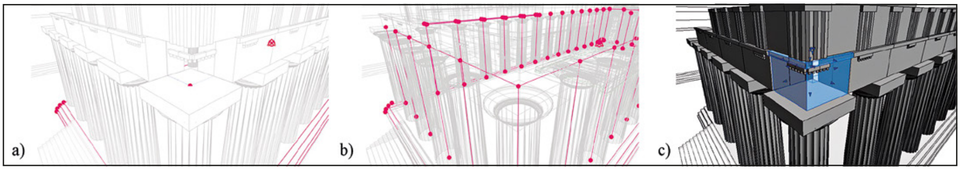


Fig. 11 – a) Interruption of the physical joint between beams and column at the corner; b) homogeneity of the analytical model at the corner joint; c) mass element inserted at the corner joint.

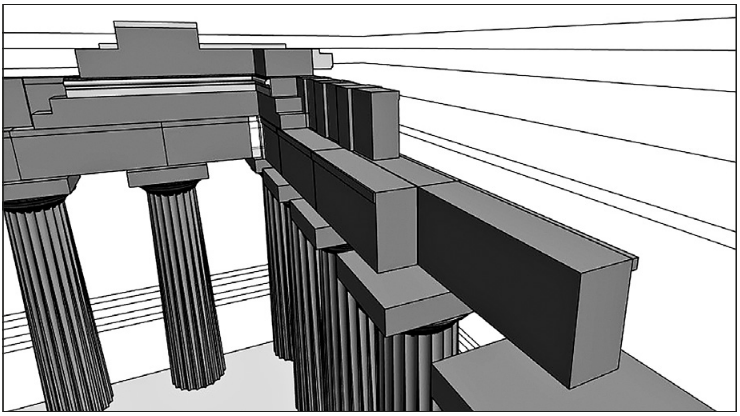


Fig. 12 – Side-by-side architraves.

Furthermore, to respect the ancient construction technique of the temples, two rows of beams were used side by side. It was also decided not to use a single continuous "beam" element that joined the various columns. Instead, consecutive blocks of short beams, whose joints are located at each column, were used (Fig. 12). The rest of the entablature has been realised with elements belonging to the wall family and with elements belonging to the generic model family, suitably modelled to respect the presence of degradations due to collapses.

For the structural calculation, Autodesk Robot Structural Analysis has been used, as it is directly connected to the Revit model. When the analytical model is loaded into the software (Fig. 13), it is necessary to assign (to beams and pillars) a section chosen from the list pre-defined inside the software (allowed materials are steel, concrete and wood) compliant to the regulations of the different countries. It was therefore not possible to insert custom sections corresponding to those used for the Doric columns and the entablature. This aspect didn't allow the realistic structural calculation but allowed to test the interoperability envisaged by the BIM methodology also in the case of HBIM.

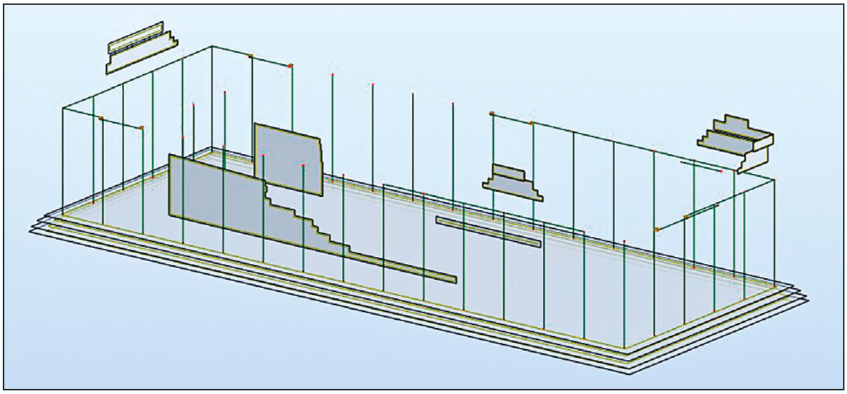


Fig. 13 – Analytical model inserted within Robot Structural Analysis.

6. Discussion and conclusions

The study cases shown in this article highlighted the potentiality of a developing methodology in which remain several limitations. Most of the problems encountered are related to the modelling phase and mainly due to still obvious software limitations. The use of a parametric object library and the high levels of accuracy, reached in the survey phase, offer advantages that, unfortunately, are not yet fully exploitable.

The categorisation of the building construction elements provides more excellent knowledge of the structure, also thanks to the information obtained through the survey, and also offers great help in planning correct modelling and parameterisation of each component of the building. However, the creation of parameterised three-dimensional objects is a very complicated step in the modelling phase. The variety of forms in historical architecture requires modelling operations that are sometimes hard considering the software available on the market. However, advanced parameterisation of an architectural element is not always useful in the BIM approach to CH. As highlighted previously, in fact, the variety of architectural elements due to stylistic choices or construction techniques and the presence of degradation make the parameterisation of the components often not very useful and time-consuming. It is often better to manually model every element, and to add appropriate semantic information directly.

Moreover, despite the excellent levels of accuracy achieved today through the survey tools, their full exploitation is not always possible. Depending on the planned use of the model, both the level of development to be achieved in the HBIM model and the 3D modelling operation vary greatly. In some situations, the software itself also requires specific modelling of the individual parts to respect constraints and relationships between the elements. For example, in the case of the modelling of the Fornace Penna, also finalized to structural analysis, it was necessary to simplify, in some parts, the actual geometry of the artefact. In fact, for structural analysis, the software requires a more elementary geometry to perform an automatic structural calculation. Depending on the type of modelling carried out and the software used, also the interoperability of the IFC format is not always guaranteed. However, high levels of accuracy are effectively required and exploitable in cases like the study of the crack pattern of a building. Hence, the level of accuracy is closely related to the level of development to be achieved in the modelling phase.

Despite the highlighted limits, the construction of an HBIM model is beneficial for the conservation and enhancement of CH also allowing to register actions like maintenance or restoration and is a tool that can be used to spread CH knowledge.

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ABSTRACT

Recent technological evolutions in the acquisition and management of building data are offering new opportunities for digital reconstruction. At the same time, the BIM (Building Information Modeling) methodology, based on the implementation of libraries composed of parametric objects provided by the IFC (Industry Foundation Classes) standard, allows the design and management of data of existing buildings, and, in particular, historical and archaeological buildings. In the latter case, the great variety of Cultural Heritage (CH) distributed over the European territory, and the ability of BIM to cover the life of buildings or/and other artefacts from a geometric, descriptive, physical and static point of view, have stimulated the development of the HBIM (Historic BIM) modelling. The HBIM approach should consider the complexity of historical or archaeological buildings or artefacts, with particular attention to possible fragmentation or incompleteness of parts. In this work, different approaches regarding the survey, restitution and data management will be described, finalised to the construction of an HBIM model, considering different possible variables, emerging from different study cases.