BIM for built cultural heritage: the case of the Baptistery of San Giovanni in Florence.

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Abstract. Whenever an operator approaches the three-dimensional modeling of an architectural object, he always must compose together a series of simple elements. This logic of additive and hierarchical composition finds an excellent application in BIM processes for built heritage, where the operator is called upon not only to compose the architectural elements together but also to break down the architecture by investigating its parts and mutual links. The main difference between the BIM model for new buildings and the existing one lies above all in the concept of the ideal model. In fact, while for the new building the model proceeds from a project and gradually develops with it, in the historical building the only starting point is the current state of the building, told through the surveys and documentation. It is necessary to model an as is, that starts from historical and bibliographic research in the first place, and which is supported by the survey and diagnostic analyses that account for the structure beyond the skin of the building, investigated by the numerical models. Once the model has been created, it can always be implemented with new information coming from further analysis and represent not only the current state of conservation of the artefact but also consider the different evolutions over time. In this context, the proposed research describes the BIM modeling process applied to the Baptistery of San Giovanni in Florence, trying to clarify the terminologies used in this application and defining an application methodology by stages, based on the decomposition and reconstruction of historical architecture.

1. Introduction

Building Information Modeling systems, combining solid and parametric modeling with data management and sharing systems, offer new scenarios for the knowledge and communication of historical heritage, especially for the storage and management capacity of large amounts of information. Precisely for this reason, in recent years they have been the subject of numerous researches in the field of architectural design and representation. However, despite these processes have extraordinary potential, there is still no codification of an operational methodology for the realization of BIM models for historical buildings oriented to documentation but also to the management and restoration of heritage. In this sense, the research intends to analyse the potential and critical aspects deriving from the integration of BIM systems in the documentation, knowledge, communication and management processes of Cultural Heritage. Numerous difficulties arise when approaching the modeling of historical architecture, first due to the high flexibility that the modeled elements must have and which clashes with the standardization and repeatability criteria inherent in the software. In any case, the starting point of any analysis on historical architecture is always the massive acquisition of data through non-contact three-dimensional survey techniques such as TLS or SfM, which in the case of BIM can be imported directly into the platform and used as a basis for modeling. In this, the platform will have to host a large amount of heterogeneous data from surveys, analysis and historical research, with different formats...
(1D, 2D and 3D) and allow not only maximum flexibility and interoperability, but also provide proof of reliability of the objects modeled according to the well-known concept of the level of reliability. The methodology used starts from the recognition of the inert data of the case study, defining a starting database that will guide the modeling operations. This will be followed by the decomposition of the architectural artefact and the subsequent reconstruction through reasoned parametric modeling. The case study used for the application of the BIM process is the Baptistery of San Giovanni, a historical monument rich in stratifications that will offer interesting insights into the procedures to be adopted.

2. The Baptistery

The Florentine Baptistery, as for almost all structures that have this function, has an octagonal plan made of masonry, divided in elevation into three different registers [1]: first register, from the ground floor to the first lintel, the second register with windows newstand, and the attic with loopholes. The structure is covered internally by a dome finely decorated with mosaics with a gold background, hidden on the outside by a flat-pitched pyramidal roof with a lantern. The west side, different from the other elevations, houses the so-called scarsella, or the quadrangular apse. The whole monument is encrusted with the two-tone marble coating in white Carrara and green marble of Prato, typical of medieval buildings in the area.

As mentioned above, the analysis of the monument's construction phases is preparatory to understanding this, as well as the possibility of inserting this information into the BIM platform for each element modelled using "phase filters". The building phases of the monument can be summarized mainly in three moments [2] consisting of the actual construction of the artifact:

A first phase, at the end of the 11th century, sees the construction of the rough structure without the cladding, the construction system with vertical pillars and radial partitions and the provision of a wedged dome. A second phase, between the end of the 11th and the beginning of the 12th century, in which the external marble cladding and the pyramidal roof were created, or a phase, so to speak, of “marbling the monument”; finally a third phase with the campaign for the realization of the internal mosaics of the dome and the scarsella, and the realization of the lantern on the roof. All further phases will be aimed at the conservation of the architectural artefact and its ornamentation according to the taste of the time, such as the construction of the three bronze doors and the related sculptures commissioned by the Calimala Art between the end of the 15th and 17th centuries.

3. The survey: acquisition campaign

The first architectural survey of the Baptistery that had a scientific character is that of Carla Pietramellara in 1973. However, various studies involving the origins and the architecture of the monument may have begun as early as the sixteenth century. It is therefore inevitable that we consider a whole series of other representations of the monument (and basis upon which the authors had elaborated their theories). The oldest plan of the Baptistery of San Giovanni dates to the mid-fifteenth century, by Giuliano Da Sangallo, along with one of the internal facades (Biblioteca Apostolica Vaticana, Barb. Lat. 4424. Cc. 34r. And I33v.).

The survey on which the proposed study is based was conducted in 2013 by Center of Interdisciplinary Science for Art, Architecture, and Archaeology (CISA3) at the University of California San Diego. Different data acquisition methods were used, including terrestrial laser scanning, Structure from Motion, infrared thermography, stereo spherical gigapixel imaging, and ground penetrating radar. Data were fused using CISA3’s proprietary point cloud rendering software Viscore.

A total of 62 individual TLS scans were performed and aligned to create an overall point cloud with a half billion 3D data points acquired [3]. The large amount of data acquired resulted in not only a more faithful representation of the monument, but enable researchers to go beyond the wall surface, defining information regarding the materials and their state of preservation; this is all information that can be integrated into the BIM model and that determines the level of objective reliability of each modeled element.
Fig. 1. Above: general view of the point cloud acquired with Faro on the left; right side high-resolution image of the dome. Below: details of the mosaic of the dome acquired with the two technologies mentioned above in comparison.

4. Semantic segmentation

As already highlighted, it is possible to break down each architectural artifact into a coordinated set of more or less simple elements; the practice of breaking down and analyzing the constructive and formal elements of the building is called Semantic Segmentation [4]. In fact, the elements are articulated and composed in a hierarchically organized manner according to a specific language.

The segmentation of the model can be based on structural analysis, or on the decomposition of formal elements, and all levels are classified in a hierarchical manner. Each time we start the BIM process, particular attention must be paid to analysing how these elements are held together, and according to what types of typological and morphological links.

The operation of breaking down the building into its parts also helps to better understand its construction and increases the level of knowledge of the architectural building. Nowadays this segmentation operation is performed on the numerical model thanks to the use of some algorithms such as spatial proximities and deep learning; however, the process of breaking down architecture into its ontologies is a common process in the disciplines of representation, and akin to the practice of graphic analysis.

In the specific case, the semantic segmentation was initially dealt with on an orthophoto basis, identifying not only the constructive and functional parts of the facades but also hierarchically identifying the architectural elements such as doors, windows and capital (Fig. 2 – 3).
5. About Level of Development

The growing use of BIM processes makes it necessary to clarify the concept of graphic detail and level of development [5] of the model elements. In fact, there is often misunderstandings regarding the distinction of these two concepts. In fact, in the field of new constructions, starting from the project it is necessary to clarify a priori the level of development required, both as regards the geometric and graphic information and the information attributes. In addition, the level of "detail" of BIM increases as you progress with the degrees of design: from a first phase in which the model is characterized by information on the existing condition, we move on to a model that becomes more and more similar to the project and to the concept of virtual model "as built", thanks to a level of construction detail that makes it practically achievable. The level of development therefore moves at different speeds that can also come from different professionals who are called to work in teams. Even in the field of built buildings we find ourselves in the situation of having to select the level of development for the modeling of the elements in advance, however what is modeled is not an as built but an as is, i.e. the state in which the architectural artifact is, described by the architectural survey. The LODs identify the degree of depth of the various information concerning the model. The term LOD represents the "Definition level" (or "Development level") that the objects present in the BIM model must assume in the various phases of the design. Furthermore, according to English law, the client is required to draw up the EIR (Employer's Information Requirements), a document containing the basic requirements to be included in the design. Issues related to LODs are addressed by many regulations that differ depending on the country that produced them. In the United States In the American context, the American Institute of Architects (AIA) has published the AIA Protocol G202-2013 Building Information Modeling, in which the term LOD refers to the level of development necessary in relation to the contents of the model elements; the choice to use the definition "level of development" instead of "level of detail" is motivated by the fact that an element, although it may appear visually detailed, could actually be generic. The legislation also distinguishes the degree of development in the BIM modeling of a building by dividing it into five levels ordered by hundreds, from the LOD 100 in which the element is represented in a generic way, to the LOD 500 where the element faithfully reflects reality. In the Italian context, on the other hand, the UNI 11337-4: 2017 STANDARD provides for an articulation of LODs in alphabetical sequence, but with the same concept of trend from general to particular. For heritage
restoration interventions, the most interesting LODs are the LOD F, where the planned management, maintenance and/or repair interventions are defined for each element, and the LOD G, which instead concerns the representation, in the useful life cycle of the building, of all those elements included in the maintenance and restoration of the property. The qualitative and quantitative characteristics are also updated. The possibility of integrating the attributes of the LODs of some objects with 2D representations or information attributes has also been included within this legislation if the modeling is not necessary or economically/technically unsustainable.

5.1. Level of Development and Level of Detail

Within the BIM software it is possible to model elements with different graphic detail, from a schematic view up to greater detail levels. Thus, there seems to be a close analogy between LOD and detail levels and it may be easy to believe that it is enough to increase the level of graphic detail to switch from one LOD to another. This concept is completely wrong, as we know that by modeling a wall element it is possible to define different LODs that concern not only the geometric components but also the informative ones. In fact, the difference between the level of detail and development is precisely this, that is, the information attributes that are applied to the LOI modeled geometries. In fact, the modeling of elements with advanced LODs cannot help but have a whole range of information that accompanies the geometry, while the level of detail is applicable only to the geometric attributes of the element.

5.2. Vitruvius and modelling of Levels of Detail

Having clarified the distinction between the two levels that accompany the definition of the BIM model, we reasoned about the conceptual similarity between the term parametric and the concept of modularity in architecture. Parametric modeling refers to the definition of existing relationships between the elements that are modeled, allowing the management of changes and coordination; in the mathematical field, the numbers that govern these relations are called parameters. Using the parametric modeling in BIM, modifying a parameter allows you to extend this modification to all the elements that are governed by that parameter. The same concept is applied to historical architecture, where the elements are coordinated by the module. In the digitization of existing heritage this affinity between the two concepts helps the modeling process. In fact, since ancient times, the concept of architectural order has inherent in the concept of repetition and series, as tools for reading the architectural system as harmony that can be re-proposed using the module.

Vitruvius in the third book of *De Architectura* refers to the commensurability of all the elements that make up the temple according to a proportional scheme, through the use of the same unit of measurement or *commodulatio*, which for the ancients corresponded to the diameter of the column. The procedure of successive partitions used by Vitruvius to discretize the architectural order can be divided into three levels, as observed by Riccardo Migliari [6], and referred to the Vitruvian triad of *firmitas, utilitas* and *venustas*: a constructive level, characterized by the distinction for large masses and proportions; a functional level, in which all the partitions of the elements are identified and each element takes on a specialized function; finally a decorative level, where each element is completely modeled thanks to the insertion of moldings. We have thus examined the possibility of applying this same distinction by levels to an articulation by layer of the level of detail. Within the platform it is already possible to view the elements according to different levels of graphic detail, Course, Medium and High. In fact the usual passage in the modeling of an architectural order is always from the general to the particular, from the large masses to the functional and finally decorative elements. Therefore, a model could be generally characterized by the representation of these three levels for all the elements of the model, expressing a sort of distinction in the graphic scale of representation of the parts. This model, as well as the representation of the LOR (objective reliability level) [7] and the LOE (representation of the building phases of the monument) are defined as Thematic Levels (Fig. 5) applicable to each HBIM model according to the different outputs of the model itself and the objectives set.
Fig. 4. The three levels of detail in the construction of the Doric order of Riccardo Migliari in comparison with a Revit model of a podium.

Fig. 5. Redefinition of data flow in digital process through the LOD. On the left graphic representation of some thematic levels: LOD of a pedestal elaborated by the author; LOR of the Temple of Divo Claudio taken from ATTENNI, M., 2019, LOE of the Casa dei Cavalieri di Rodi taken from TACCHI, G. L., 2014.

6. 3D modelling

Starting from the decomposition of the architecture, we have moved on to a phase, so to speak, of meta modeling in which the elements of the model have been classified and distinguished according to two macro categories: the replicable elements, or those that could be repeated within the model, and those not replicable as they represented an isolated episode, such as some fixed furnishings or decorative elements. Clearly, different modeling methods have been associated with the two categories: internal modeling of the software for replicable ones, external modeling using other modeling software and subsequent import into the BIM platform for the unique ones. A further distinction was then made for the types of families to be used in internal modeling: system families for structuring elements such as walls and floors, loadable families for elements that can be replicated in this or other projects, and local families.

The first step involved importing the point cloud into Autodesk Revit having first registered it and exported it to Autodesk Recap. Subsequently, the geolocation, the orientation of the project and all the reference planes useful for anchoring the architectural elements were set. The external envelope was modeled as a mass system
family, an operation that allows you to select the faces and simply apply wall or floor system families to them, defining the stratigraphy of the elements at a later time through the property tables. Specifically, the masonry stratigraphy was modeled starting from the information found in recent published surveys and studies, while the positioning of both the envelope and the load-bearing elements took place directly by drawing the imported and previously segmented point cloud by dividing the external scans from the internal ones in order to make it easier to view in Revit.

All repeatable elements such as windows, columns, doors and moldings have been modeled as loadable families [8], i.e. families that are modeled in Revit but in a different project browser, and subsequently imported. These elements were modeled by importing the CAD profile into Revit and then parametrically extruded to allow future reuse in other projects (Figg. 6 – 7).

A large amount of information can be managed in the property tables of the individual modeled elements; in the specific case, the focus was on information about the materials and the construction phase. Within the platform, an attempt was made to make the textures of the materials as similar as possible to reality, sometimes enriching the layer with appropriate descriptions. As for the construction phase of the individual elements, we worked with the setting of the phase filters.

These filters allow you to enter information about the construction period of the single object by setting the single phase previously loaded in the phase management database (Figg. 8).

It is therefore possible to apply the same temporal logic of new constructions to existing buildings, working on phase filters. This is how an is architectural model is defined which also includes the diachronic analysis of the construction phases.

**Fig. 6.** Modeling of Corinthian pillar. Extraction of all profiles of the pillar from the point cloud, drawing and modeling in Revit as a parametric model.

### 7. Conclusion

The research presented here has tried to clarify first the identification and terminological distinction of the different Levels that are part of the BIM field, aiming for a systematization starting from current legislation. Furthermore, we focused on the development of an operational methodology, divided into different phases, for the realization of BIM models for the historical heritage built, using an important historical building as a case study. The growing use of these modeling processes not only for architecture requires the research and coding of operational methodologies for the application of these procedures also to the field of restoration and documentation of existing heritage. It is evident that there are limits and criticalities in the application of BIM processes for the modeling of historic buildings, nevertheless the research must go in this direction as the BIM platform offers great potential in the integration of heterogeneous data and interoperability of the system; all advantages that can be very useful in the field of Cultural Heritage.

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Fig. 7. Mass modeling from the point cloud.

Fig. 8. Application of phase filters to a window. View of the exterior of the Baptistery model.

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