Validation processes of H-BIM models: a case study

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Abstract. BIM is becoming one of the main methodology in the field of the cultural heritage, to create digital models, aiming to take place of the real historic buildings for investigation, analysis and simulations. However it is still an open problem the validation of H-BIM models, to ensure reliability of the archived information. In fact there are two main aspects to achieving an H-BIM model: the first relates to the process of converting geometric data captured from survey into parametric elements and their semantic modelling; the second one relates to the definition of BIM use that will heavily influence the same modelling stage. The paper deals with a methodology of survey data modelling and model validation, highlighting the need to create a database, containing geometric data and information, in order to ensure reliability and usability over time. It is presented the case study of "Morgana Fairy" fount, built by Bernardo Vecchietti in 1573 and adorned with Gianbologna's sculptures at Bagno a Ripoli in Florence. The model has been validated by a geometric comparing analysis of the deviation between the model itself and the mesh obtained with the acquired point cloud data.

1. Introduction

BIM is becoming one of the main methodology in the field of the cultural heritage, to create digital models, aiming to take place of the real historic buildings for investigation, analysis and simulations. More recently the idea of "digital twin", a buzz word in industry 4.0 sector, is spreading also in H-BIM (Heritage Building Information Modelling) procedures, meaning a "virtual counterpart" of the artefacts to enable understanding, learning and reasoning. However it is still an open problem the validation of H-BIM models, to ensure reliability of the archived information.

There are two main aspects in implementing a parametric model: the first one refers to the process of converting spatial survey data into 3D elements with the due geometric accuracy and their related semantic decomposition; the second one relates to the definition of BIM Use that will heavily influence the modelling stages. The two aspects are closely related but often present opposite needs, the synthesis of which today represents the real challenge of BIM in the field of cultural heritage. In fact, on the one hand the research for ever greater geometric precision of the digital model compared to the real building leads to address methods of implementation based on 3D Imaging/Scan-to-BIM processes, which can guarantee maximum storage of captured spatial data (point clouds); on the other hand, the simulation of building performance generally requires a simplification of the geometric model, sometimes significant, in order to allow adequate interoperability with specialized applications.

Furthermore, the semantic segmentation of a point cloud presupposes the previous definition of an ontology of objects and relations which in cultural heritage must be able to deal with the formal languages and techniques of historical architecture. The control of the information management...
process is therefore essential to guarantee the reliability of data and information achieved in the parametric model not only in the various implementation phases but particularly in the information exchange procedures between different phases. A detailed mapping of the H-BIM authoring process allows to effectively trace the information evolution, identifying the levels of geometric and informative development of the elements in each phase, and to evaluate geometric accuracy and information completeness. The validation of the process is determined on the basis of compliance with the information exchange requirements established in the goals definition phase and related BIM Uses. The "Morgana Fairy" fount, a late Renaissance work, was chosen as study case for the implementation of an H-BIM workflow, starting from spatial data capture by 3D Imaging techniques to information modelling aimed to creation of a database for documentation and restoration program.

2. State of Art
In recent years the creation of building information models from massive geometric data captured by laser scanning and 3D Imaging techniques, had a wide development, thanks to the high portability, ease of use, speed and precision in measurement of the latest generations of acquisition instruments. Based on active sensors (such as Terrestrial Laser Scanning - TSL) or optical passive sensor (such as 3d Imaging - Structure from Motion - SfM), in both cases the final output is a point cloud or a 3d mesh model that can be used as tracking reference systems for the definition of parametric elements suitable for the BIM model. The decision of choosing one of the two techniques could be done in relation to the morphology and the accessibility of the area and not secondly on costs evaluation. Laser scanners and high-resolution cameras can be equipped in unmanned aerial vehicles (UAVs - drones), which represent an emerging technologies [3].

In scientific literature it is possible to trace different approaches to the implementation of parametric models of historical buildings [7] with studies that have highlighted their potential and critical issues. Some studies have focused more on spatial data acquisition techniques in relation to the geometric accuracy requirement of the BIM model, relating the level of development (LOD) of the various modelled elements with the chosen survey techniques [2]. In other cases, it was paid attention on the modelling of historical parametric objects [5], following the path of semantic recognition of architectural forms with procedures provided with a certain degree of automation. The modeling of parametric objects referred to the classical architecture language was instead tackled by some scholars through the development of plug-ins in Geometric Descriptive Language (GDL), for the generation of the components of the architectural order codified in the architectural treatises of the 16th century [6]. The persistent difficulties in converging the parametric element modelled onto the captured spatial data, has led other authors to create hybrid environments, where the point cloud coexists with the parametric objects. These are modelled suitably geo-referenced in the various phases of the life cycle of the building, during triggering operations in the asset management such as scheduled maintenance or restoration works [1]. The accuracy check of the parametric model in relation to its stated level of geometric development is made possible thanks to semi-automated comparison procedures with the captured point cloud in the survey phase [6] using appropriate software.

However, a large part of the studies does not appear to highlight adequately the overall workflow of the H-BIM implementing process in its procedural phases articulation as an element of validation of the geometric and information quality. Even in the recent UNI EN ISO 19650 standard, the asset management of real estate through BIM methodologies is represented within a wider management system of the owner/user property, which in turn is part of an organizational quality management systems (such as ISO 9001). A change in the information management process has been suggested [8] to take into account the specific information requirements that distinguish the historical-cultural heritage differently to the new construction sector.

3. Methodology
The mapping of information flows for BIM implementation related to specific BIM Uses has long been defined in some international protocols, the best known of which is the Project Execution
Planning Guide, developed by Penn State University [9]. It is a methodology articulated in two different levels of analysis, through which it is possible to relate the BIM Uses with the information exchange requirements defined in the process. In particular the second mapping level (Detailed BIM Use Map) associates each operational activity established in the process workflow of the particular considered BIM Use, to the required information resources in order to start this activity, and the information deliveries that must be implemented to pass from an activity to the next. The BIM Uses are defined on the basis of a series of design experiences gained in various professional fields, and are described in their main characteristics, potential value, needed resources and skills.

![Figure 1 - Information process map for H-BIM implementation](image)

The process map named, "Existing Condition Modelling", is the only one that in the Penn State protocol refers to the implementation of parametric models of the historical building heritage, however the proposed scheme does not appear to adequately cover the complexity of the activities that must be developed in this area of application of H-BIM.

Therefore it was proceeded to redefine a process workflow in the information management of cultural heritage, that identified in more detail the operational phases and the information exchanges involved in the implementation of an H-BIM, aimed at the documentation and planning of restoration and conservation interventions. Referring to the diagram shown in figure 1, the implementation of a parametric model of a historic building is broken down into 6 operating phases, which identify activities and process validation checks.

1. Data acquisition - Surveying traditional techniques (metric wheel, laser distance meter) are integrated with massive data capturing techniques such as 3D imaging or laser scanning. The spatial data are properly selected and filtered to obtain a point cloud avoiding redundancies. In this phase the archive researches get information on historic transformations and ancient building techniques and materials.

2. Data selection - The big amount of data must be managed and appropriately filtered in order to identify those data strictly necessary for the creation of the model. At this stage it is to decide the purposes of the H-BIM and the BIM Uses related to the established objectives.

3. Data elaboration - The collected data are divided into geometric and informative component in order to define the level of development of the parametric objects in the modelling phase. It should be noted that the degree of geometric accuracy and information completeness must be correlated with the previously settled purposes.

4. Model creation - The creation of the digital model involves a preliminary analysis and breakdown of the building into characterizing elements, which will be modeled as parametric objects; sometimes it is necessary to resort to modelling "artifices" dependent on the software used, to create
entities that respond to the forms of historic built. In this phase the modeller skill is fundamental to guarantee the highest degree of geometric correspondence with the real building.

5. Data elaboration - The geometric model of the building is compared with the initial spatial data through deviations analysis. In this way it is possible to identify the modeling error, which is generally visualized through Gaussian distribution graphs. The reading of this error expresses an immediate evaluation of the modelling goodness.

6. Data storage - The BIM model must be stored and made accessible in a special non-proprietary open format. The IFC format can represent a valid option, however it is not yet fully compliant with the historical building items.

4. The case study: the modelling of "Morgana Fairy" fount of Vecchietti' Villa

The case study we are going to present deals with data acquisition and subsequent modelling of the "Morgana Fairy" fount, a small 16th century building located in the Florentine countryside. Designed and built starting from 1570 by Giambologna as a nymphaeum in the park of Vecchietti' Villa in Grassina, today it is almost unique in its kind and the surrounding natural landscape increases the magic atmosphere of the complex.

The fount looks like a single and isolated body, articulated like a theatrical backdrop around a small fenced courtyard. The actual nymphaeum, set in a hollow of the hill and partially buried, is placed at the center of the composition, flanked to its left by a large and slightly advanced tabernacle, while in the orthogonal direction a mighty earth retaining wall hosts two basins and a large recessed seat. On the same side, two stone basins still filled with water, were used as sinks. The nymphaeum is articulated on two levels and revolves around the large double-height main room, which also houses the only monumental access to the building. In this space, decorated by a fountain in grey sandstone, a precious marble sculpture by Giambologna depicting Morgana in the guise of a Venus was preserved until the nineteenth century. A system of artificial tunnels dug into the hill provides the water supply for the external basins, the fountain and two internal tanks for the conservation of the fishes, which were served during banquets and receptions held in the nymphaeum.
Figure 2 - General view of the complex and an internal shot of the nymphaeum
Preliminary to the acquisition of data and measurements carried on the building, bibliographic and archival material was collected in order to acquire the results of previous surveys and information about the history of the building, its possible transformations and construction techniques typical of the time. The collaboration provided by the Municipality of Bagno a Ripoli, owner and manager of the property under examination, was indispensable in getting cadastral maps and graphic documents drawn up during previous restoration interventions. Significant evidences of the original state of the building are provided by Raffaello Borghini in his text, "Il Riposo" (1584), where the entire complex of the fount was described in detail. Material composition of architectural elements and stratigraphies of the structures was instead investigated during the surveys on site.

Two surveys campaigns were in fact held, in order to be able to collect measures and to investigate all the details of the building with sufficient care. In addition to traditional techniques (metric wheel, laser distance meter, creation of eidotypes), a massive photographic campaign was also carried out to
get a subsequent reconstruction of the geometric data through the use of 3D Imaging and digital photogrammetry. Topographical targets were applied in the most complex points of the building to minimize the error in the reconstruction phase of the digital model. However, we reported the presence of difficultly accessible and poorly lit rooms.

Once the data was acquired, a BEP was drafted, in accordance with the general methodology already described, containing the guidelines to be followed during BIM modelling process.

Going back over the workflow exposed above, we analyse the various steps performed. The photographic material collected, after a first selection, was processed in Photoscan Agisoft software in order to obtain point clouds both for the exteriors and for the internal environments and some details. The strong contrast of lighting between the external facade and the internal space made necessary the creation of a specific point cloud for the central portion.

Recap Autodesk software, as illustrated, allowed the conversion of the point cloud into a format readable by Revit Autodesk and the reading of measurements not easily detectable in situ.

Once the point cloud was imported, a BIM restitution of the building in Revit Autodesk was carried out which led to the creation of a hybrid model, in which the objects were modelled and implemented
as previously discussed. The plan geometry has been reconstructed by combining the evidence of the manual survey with the profiles suggested by the section of the cloud, in order to guarantee a faithful return of the real configuration of the construction.

Modelling of details took place as families, with the exception of those elements that had unique morphological characteristics for which an “in place” creation logic was indispensable. In the following images you can appreciate the modelling carried out and the implementation of a suitably texture obtained by extrapolating ortho-photos from the point cloud. This procedure, in addition to an high precision in detecting the environmental and degradation conditions in which the building is concerned, is already an indicator of the correctness and approximation desired in the creation of the digital model.

The general model and various families underwent a validation process based on the comparison between point clouds using Cloud Compare, a software capable of providing a measure of the degree of fidelity achieved with modelling. This operation, combined with the completeness of information about materials, allows us to validate the modelling carried out. This comparison takes obviously into account a possible range of geometric error which in this case is around 3/4 cm and an almost zero error regarding the completeness of the material information, since it has been possible to trace the composition of the objects even though not knowing all their physical characteristics. The most significant discrepancies are attributable to the state of degradation of various parts of the building: in modelling it was not possible to faithfully replicate the surface alteration of the profiles. For completeness, there are significant deviations in correspondence with portions that cannot be directly investigated due to the conformation of the site (the rear part is partially buried) and the absence of data in underwater areas.

The comparison of the model with the point cloud obtained from the surveys is also very interesting to estimate the degradation of a particular element, assuming its initial conditions. Even more effective in this sense is a mockup of the decorations of the entrance portal: using a 3D printer, details have been reproduced and allow to feel and quantify the effects of degradation during the time.

Figure 5 - From point clouds to HBIM model
Figure 6 - H-BIM models with ortho-photos applied on external surfaces

Figure 7 - H-BIM model – point clouds comparisons

Figure 8 - Comparison between the real monumental entrance portal and its 3D mockup

5. Conclusions
The creation of a parametric model for the historical-cultural heritage requires the development of a complex information management process capable of including implementation phases of both geometric and information data. Many studies focus on modelling methods of massive spatial data captured by 3D Imaging/Scan-to-BIM techniques to ensure maximum accuracy of the modelled geometric data with respect to the real building. This in general contrasts with the requirements of geometric simplification, that in any subsequent phases of simulation of building performances related
to the various BIM Uses, may be achieved to ensure adequate interoperability between authorial and specialized software.

Therefore, in this contribution we have tried to pay attention to the definition of the information flows and the control of the operational phases involved in the H-BIM modeling, considering the validation of the information management process one of the most critical aspects in the model implementation, which can give rise to significant data losses in transition of phases. Through a detailed mapping of the activities, it is possible to trace these losses of information, making the reliability of these models explicit in relation to the intended uses. The case study of "Morgana Fairy" fountain aimed to develop an H-BIM model for documentation of the historical-cultural heritage, was carefully analysed in terms of conservation/loss of input data in each modelling phase, starting from the initial acquisition of geo-spatial massive data by 3D Imaging techniques. This experience confirms that to date the information management of transition of phase is still entrusted to operations highly dependent on the manual control of the individual operator, while only for some of them automated procedures are available. Furthermore, geometric accuracy is not in itself an absolute value, but must always be commensurate with the expected BIM Use. In fact the historic building parametric models are increasingly characterized as databases for the collection of archival documentation, photos, surveys, etc., ensuring structured information management not only for subsequent restoration and conservation interventions, but also for the same fruition of cultural heritage.

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