BIM methodology as an integrated approach to heritage conservation management

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Abstract

Building Information Modelling (BIM) is enabling the dissemination and improvement of strategies for planned conservation. Through the implementation of BIM models in two case studies, different both in terms of size and scope of restoration and refurbishment, it was possible to assess the suitable ways for collecting and managing heterogeneous data generated by various disciplines. Furthermore, the collaboration amongst various stakeholders involved in the conservation process was investigated. Issues of integration and interoperability over the phases of the conservation process were analysed: starting from the architectural survey, carried out by laser scanning technology combined with the traditional survey, as far as the management of data as a function of future maintenance phase. Using these technologies, problems related to the building information model of the current condition of heritage buildings and the information exchange between different software environments were observed. Applying BIM workflows on restoration and refurbishment projects allowed to evaluate the potential of these technologies for different stages of the process: survey, design phase, monitoring work progress and evaluation of proposed amendments and changes. It was also possible to deal with safety management. Finally, the possibility of applying the 4D BIM technology, which combines the 3D BIM model to the construction work plan, has been analysed.
Keywords: BIM, BHIMM, BIM survey, interdisciplinarity, interoperability, planned conservation, sustainability of buildings.

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1 Introduction

The implementation of the BIM methodology within refurbishment and restoration projects is becoming more and more appreciated at international level. It is the same in Italy, where it has been adopted in the conservation process of the 'Lirico' Theatre of Milan [1] and in the study of the spires of the Cathedral of Milan [2].

So far, the focus of the research on BIM for existing buildings has been set on the survey process, not only geometrical, but also aimed at acquiring data on the state-of-the-art condition. The importance given to the survey process is steadily increasing because it tackles maybe the most critical issue in the field of conservation and refurbishment: the reliability and 'objectivity' of input data. However, it is essential to realise that the targets of the refurbishment or restoration project, collected in the BIM execution plan (BEP) as result of the employer's information requirements (EIR), deeply affect the survey process. The terrestrial laser scanning (TLS) methodology itself, which is often referred to as BIM surveying, is currently one of the main matter of interest of the research. This methodology guarantees an accurate and rapid survey, but it still requires a great effort of point cloud processing in BIM environment and it cannot supply the alphanumerical information needed to enrich the so-called asset information model [3].

The asset information model has to represent the shared starting point for the development of an integrated design process, even if it may be affected by the lack of a common semantics caused by the typical fragmentation of the Architecture, Engineering and Construction (AEC) industry. Moreover, in the field of the architectural heritage it is essential to realise the importance of a maintained information model, used as common database for all the actors involved, owners, designers, contractors and facility managers. Of course it is necessary to keep the model updated, if possible also with several monitoring campaigns [4].

2 Case studies introduction

The University of Brescia is one of the academic participants at the Italian Research Programme of National Interest (PRIN) named "Built Heritage Information Modelling/Management – BHIMM", supported by the Ministry of Education, University and Research. The main aim of the research project is to introduce a new and innovative methodology, based on BIM, capable of improving the current sustainable reservation policies of the architectural heritage, including monitoring, management and retrofit. The Research Unit of the University of Brescia is involved in work packages related to methods and technologies dealing with the automated surveying, information modelling and 4D and 5D planning-related methodologies of refurbishment and restoration construction sites. In order to identify a shared workflow able to support the conservative process during the entire project life cycle, two case studies, different both for size and for scope of restoration and refurbishment, have been analysed. The former concerns the refurbishment of a typical Milanese farmstead (Case

Study 1: CS1), an architectural heritage masonry structure with wooden trusses currently subjected to a change of use and previously subjected to a not conservative restoration project. The latter case study concerns a two-floor precast concrete school built in the sixties (Case Study 2: CS2) with the aim to use the building information model of the existing building to support in the future a possible energy restoration project, figure 1.

Figure 1: State-of-the-art of CS1 and CS2.

According to the BIM requirements, the case studies have been differently approached [5]. A common requirement for both of them was to provide an interdisciplinary database, which would collect all the information scattered in several documents and would supply a base for all the phases of the conservative process. A detailed analysis of the benefits related to the implementation of the BIM methodology in a restoration process, both during design and construction phases, was needed for CS1. In CS2, the Research Unit digitalised the original project of the sixties and is currently implementing an optimised BIM to BEM (Building Energy Modelling) workflow in order to support a future energy restoration project.

The information model of the Milanese farmstead was carried out based on the traditional survey of the state-of-the-art and 2D detailed drawings of the renovation design provided by the designers. The CAD to BIM process was not easy to be applied because of an evident lack of consistency of the traditional 2D documents. BIM Surveying technologies were needed to validate the traditional survey.

In order to produce the building information model of the precast school, the Research Unit had to perform a thorough research in the historical records of the town council, owner of the building. In this case it was essential to identify the construction techniques used and to check the consistency between the project and the as-built. Moreover, in order to correctly support a future energy analysis, it was essential to characterise all the materials employed in the construction, including their thermal properties.

3 Methodology

3.1 BIM surveying

In Case Study 1, the Milanese farmstead, the implementation of the BIM methodology started with the so-called BIM Surveying. The group of Topography of the University of Brescia conducted the state-of-the-art survey with Faro Focus 3D terrestrial laser scanner (TLS). The exterior of the farmstead were detected with the laser mounted on a mobile vehicle carrying the Stop&Go mode. Subsequently scans were geo-referenced to be semi-automatically aligned by calculating the centre of point clouds over a known point by total station measurements. Static laser scanning with reference target spheres was necessary due to the vegetation that covered part of the exterior.

In Case Study 2, the precast school, 32 scans, at resolution of about 6mm@10m, were registered to survey the schoolyard, external walls, the technical room containing MEP equipment and a few classrooms on the ground floor and on the first floor. To automatically align the scans of the interiors, target spheres, carefully distributed in the survey area, were utilized, figure 2.

Figure 2: BIM surveying with Faro Focus 3D TLS.

This methodology guaranteed various benefits, like the generation of 2D measurable views comparable with the traditional CAD documentation and useful to check the consistency between the project and the as-built represented by the points clouds. Moreover, thanks to photos registered by the TLS during the scan process, it was possible to evaluate the conservation conditions of surfaces. For these reasons, this methodology proved to be a precious support to the research.

3.2 Building model preparation

3.2.1 Development of a common BIM environment

Simultaneously with the BIM surveying campaign, the Research Unit set up the parametric models in the BIM authoring tool Autodesk Revit 2014. First of all, it was necessary to create a common work environment that would guarantee collaboration between all the stakeholders. It was essential to allow everyone to work, at the same time, on a constantly updated model. Therefore a web-based 'central file' was created as distribution point for sharing work in the team and thus allowing the members to save their own local copies of the file [6]. In this way, users can work locally and then save changes back to the central file for other users to see their work. The model was subdivided into ‘worksets’, a collection of building elements such as walls, doors, floors, stairs, pipes. Users have the option of checking out entire ‘worksets’ or individual elements in a ‘workset’. All other team members may view these elements, but are unable to change them, preventing possible conflicts.

In order to simplify the information management, the ‘Project Browser’ was customised, creating different views for each discipline (such as architectural plans, sections and prospects, mechanical and plumbing views, structural plans). Disciplinary and coordination view templates were set up to easily manage the visualisation of parametric elements. In particular, all BIM objects that did not belong to the discipline of the view were made transparent or hidden, while the others were highlighted using a predetermined colour code. Moreover, a view template was carried out, which allowed the team to visualise simultaneously and clearly all the building’s elements, figure 3.

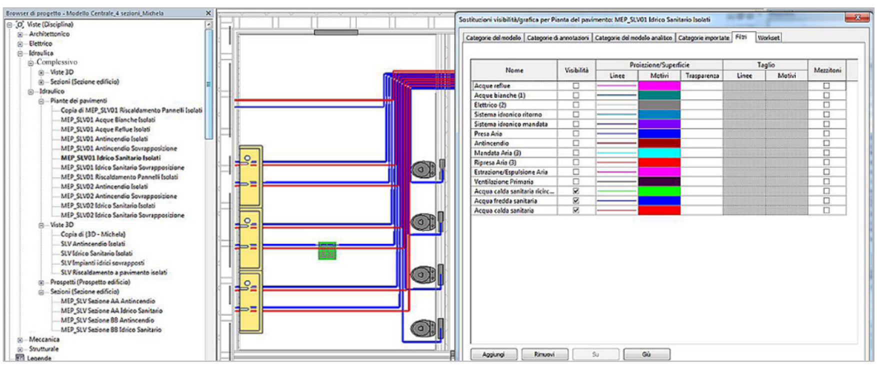

Figure 3: Project browser and view template.

According to CS1 BIM requirements, the model was enriched with layouts of construction phases and health and safety plans. Phase filters were set up in order to easily show up the components belonging to the construction phase analysed [7]. In this way, it was possible to visualise, highlight or hide the parametric elements that would be built, demolished or temporarily positioned in every phase.

3.2.2 Implementation of the alphanumeric informative content

Models were enriched, directly in the BIM authoring tool, with alphanumerical attributes. The parameters were identified thanks to an accurate analysis of the historical documentation and of the records concerning the conservative process, from survey to maintenance. These attributes, shared through the entire life cycle, have the role of simplifying the management of the project in all its phases. BIM requirements to optimise the process and to introduce a replicable methodology were defined in collaboration with the other Research Units and academic participants.

Construction and facility management phases were evaluated for the Case Study 1, the Milanese farmstead. Parameters such as ‘Manufacturer’, ‘Expected Life’, ‘Warranty Certificate’ and ‘Installation Date’ were added to the information model. Product sheets were linked to every object as hyperlink attributes to be used during the facility management phase. Moreover, the model was enriched with parameters that keep track of construction techniques and design variations eventually proposed. Parameters such as ‘Building Code’, ‘Item Number’ and ‘Bar code’ were included in the information model to ensure the traceability of elements both during construction and facility management phases. The model was also implemented with information extracted from construction health and safety plans and construction plan of work in order to define construction phases and requirements and to improve health and safety management. These settings are preparatory to the creation of a 4D model that combines BIM model with the plan of work to simulate the planned construction processes [8]. Moreover, an attributed named “Activity ID” was added to each element to automatically link the parametric object to the plan of work, created in Primavera P6 Project Management, during the 4D modelling phase.

According to CS2 BIM requirements, a link to the original documents of the digitalised project was added in order to create a coherent database. Thermal properties were defined to correctly implement the BIM to BEM workflow.

All alphanumerical attributes embedded to the BIM were ‘shared parameters’, in order to customise schedules and to filter all the elements according to the attribute values.

3.3 BIM library

At this point, the modelling phase started. First of all, it was essential to carry out a customised BIM library, indeed the software used provides a wide range of BIM objects, but they were not suitable to achieve the research targets. The issues recorded during this phase reflect the complexity of parametrising historical elements in a software developed to model new buildings. This phase proved to be very time and resource consuming, indeed the uniqueness of each element of the building involved the need of achieving a very high degree of parametrisation. In addition, the lack of information of the traditional documents used as input made it more difficult to manage the alphanumerical attributes.

3.3.1 BIM library: Case Study 1 – the Milanese farmstead

Modelling issues concerned the typical irregularities of the structural and architectural elements of historical buildings. For example, the state-of-the-art of CS1 contained structural columns which sections were not regular. It was necessary to parametrise the dimension of the angles beyond the dimension of the sides and the height. Another issue came up during the modelling of the windows that, according to the design, would have been replaced in the restoration process. Using Revit as BIM authoring tool, the model of the windows includes the openings that cut their hosts, in this way, when the window is removed also the opening is removed and the software automatically places a filler in its place. It was not acceptable in this case because it was necessary to visualise and analyse every construction phase, including the ones in which there was only the opening without the window installed. By using other BIM authoring tools it might be not a problem. In this case, in order to resolve this issue, it was needed to model two different BIM objects, one for the opening and all that would have not been removed, like the windowsill, and one for the frame, the shutters, the sashes, the hardware and the glazing that would have been replaced. Moreover, to model the splayed windows and doors it was necessary to parametrise, in the model of the openings, the angles of the splay, along with their length and height, figure 4.

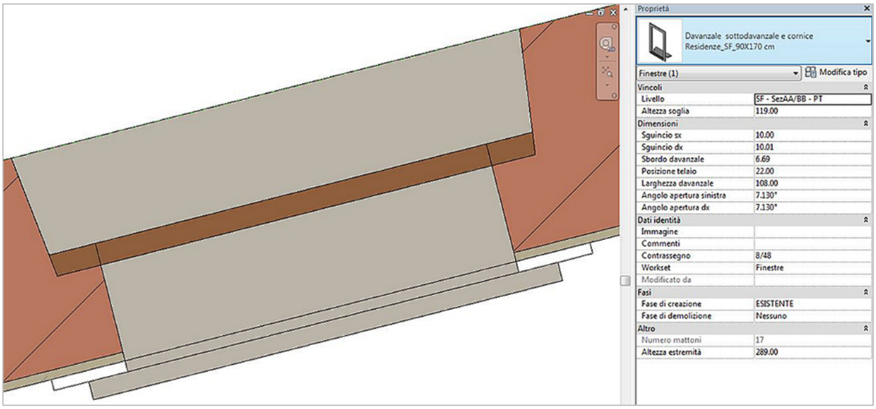

Figure 4: Parametric model of the splayed window.

Another issue was revealed during the modelling of the external tapered walls. The team identified two options to model them: either to use the ability of the architectural column to integrate itself with any wall or to model a so called 'in-place element'. The former solution combines two different elements of the model to generate the needed profile in the floor plan, but the utilised BIM authoring tool allows users to define only walls as host of windows, thus columns are not modified by the placement of the windows. While the latter option uses a particular type of Revit family, created to manage elements that need unique geometry and that the users do not expect to re-use. The use of 'in-place elements' can increase the file size and downgrade software performance, therefore they must be utilized the least as possible. Moreover, in certain cases, windows placed in these walls are incorrectly positioned and the related openings do not make a hole through the entire width of the wall. Other modelling solutions are currently studied to improve the modelling workflow of irregular elements since they are characteristic of historic buildings, an important part of the Italian cultural heritage. A BIM library for the design phase was also developed and enriched with alphanumeric attributes and 2D details to be used when high level of details is necessary.

Finally, a construction BIM library including parametric objects such as the temporary equipment that would have been utilised on the construction site, such as construction machineries, protective devices and construction offices. In order to allow the Research Unit, at a later stage, to evaluate spatial conflicts on site, specific alphanumerical parameters, like the radius of action of the tower crane and other machineries, were linked to these elements.

3.3.2 BIM library: Case Study 2 – the precast building school

Likewise, BIM objects for the school model were created, from the structural elements of the building as far as the prefabricated panel employed in the construction of external walls.

Concrete piers and beams of the foundation were parametrically modelled, as well as steel columns and beams of the structural framework. Based on the construction details of the original paper drawings, precast elements of slabs and precast concrete panels of the external walls were also modelled. The external precast panels were modelled as curtain wall panels: in this way, the external walls were modelled as curtain walls which grid was given by the dimensions of the panel, figure 5.

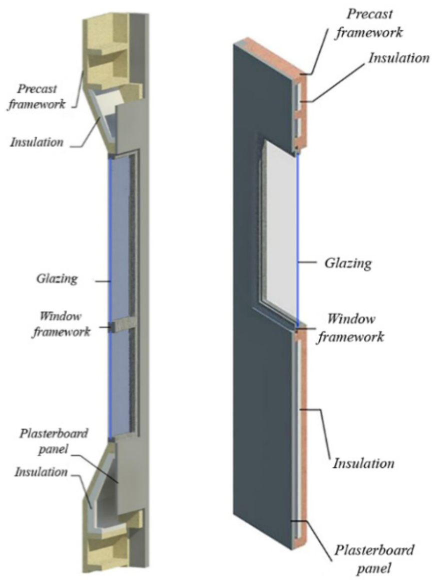

Figure 5: Parametric model of precast concrete panels.

Internal and external stairs were modelled too. In the former case, the stair object had a unique geometry and an "in-place element" was modelled. In the latter case the stair object was modelled with the proper family class.

The BIM library included all the MEP elements of the building, such as radiators, specific pipe connections, lights, electrical sockets.

3.4 Interoperability

One of the main themes of the research project is interoperability between actors involved in the project and between BIM authoring and BIM-based analysis tools, essential requirement to ensure an effectively integrated conservation process. An information model effectively exportable as IFC (Industry Foundation Classes) was created. IFC is the neutral format developed and promoted by the International Alliance of Interoperability (IAI), today BuildingSMART ensures interoperability thanks to the possibility to share BIM data between BIM tools of different software houses. Interoperability improves data flow and cooperation between stakeholders, reducing the loss of information. The alphanumerical attributes linked to BIM objects were introduced in order to be properly read, thanks to IFC format, in software for BIM-based analyses, like 4D modelling and model checking. Since the first interoperability tests, it was clear that the quality of the IFC files exported depended on the BIM authoring tools and some of them can be considered more interoperable than others. Moreover, it is essential to carefully set up the export options in order to guarantee a reliable data exchange.

4 Achieved results

Terrestrial laser scanning was used to carry out an accurate geometrical survey which allowed the Research Unit to model the as-built of both case studies and compare it with the traditional documentation, figure 6.

Figure 6: Comparison of point clouds and BIM of CS2.

It was possible to test the suitability of the chosen BIM authoring tool, originally developed for modelling new buildings, for the implementation of the BIM methodology for architectural heritage and eventually analyse its limits. A customised BIM library was successfully produced, although sometimes a compromise with the actual capability of the BIM authoring tool was necessary. Several BIM objects were created in their proper family class and they were correctly classified in the framework of the open and neutral data format IFC. Each element was carried out achieving a high level of parametrisation. In this way, most of the BIM objects could be re-used to model future case studies. A rich set of parameters that guarantees the simplification of the information management throughout the entire project life cycle was studied. The customised BIM library and the embedded parameters allowed the digitalisation of the state-of-the-art of both case studies, figure 7. The restoration design of CS1, including the design variations proposed by the construction company, was modelled. It was possible to transfer all the graphical and alphanumerical information contained in traditional documents in the BIM, generating a truly interdisciplinary database for both case studies. These parametric models would allow everyone to easily found, at the right moment, the needed information, simply querying the model instead of analysing several disorganised documents.

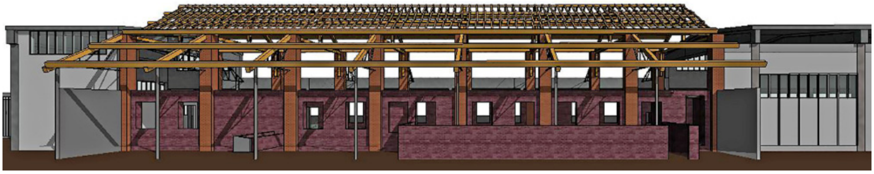

Figure 7: State-of-the-art information model of CS1.

BIM-based construction site layouts were modelled including geometrical and alphanumerical information in order to support and validate the construction phase. The dynamic evolution of the construction site layout, which often changes to satisfy the needs of the construction process could be better understood and that allows parties involved to work with more awareness and thus to be able to optimise management and to prevent several issues [9].

5 Conclusions

Building Information Modelling (BIM) is about to become a standard in the AEC industry for the entire project life cycle, from design to construction and operation of new buildings. Built Heritage Information Modelling and Management (BHIMM) is becoming an important topic as well. While not widespread, the implementation of the BIM methodology within refurbishment and restoration is more and more appreciated at international level, especially where historic buildings represent an important part of the architectural heritage as it is in Italy. The research project presented in this paper considers benefits and limits of using BIM for the refurbishment and restoration process. Modelling issues revealed during this research need to be resolved and they probably reflects the traditional processes of each disciplinary knowledge, not fully integrated with the others involved in the construction life cycle. A new design approach can be introduced by implementing the data flow thanks to software interoperability. Moreover, BIM can be used as the basis for either structural or energy future conservation and rehabilitation processes, but it also contributes to the digitalisation of traditional documentation, especially when it was produced even before the CAD era. The translation of a multitude of traditional documents into a single and coherent federated model can significantly improve the entire process.

6 Future works

Currently the Research Unit of the University of Brescia is investigating advance technologies of BIM Surveying, Information Modelling and 4D & 5D planning-related methodologies of refurbishment and restoration construction sites.

The Department of Information Engineering is studying image-based 3D reconstruction to be applied during the surveying phase. The aim is to obtain high quality 3D models directly from images captured by common digital cameras. The study aims to the segmentation of the point clouds in coherent regions in order to select by mouse parts of the model belonging to the same architectural or structural element. Selected parts have to be automatically reconstructed. Currently appropriate segmentation techniques that divide the model into consistent regions have been identified and implementation has been 90% completed [10].

Advance modelling solutions are currently studied to improve the modelling workflow of irregular elements characteristic of historic buildings, an important part of the Italian cultural heritage. The aim is to reduce the amount of time and resources spent on modelling complex parametric objects that sometimes require a compromise with the current BIM authoring tools capability.

Interoperability and BIM-based analyses are currently evaluated. BIM to BEM data flow is being analysed in order to allow the future use of the precast school information model for energy analysis. In CS2 the interoperability between the BIM authoring tool used and the most performance energy analysis tools is currently investigated. Exportation through IFC and gbXML format has been tested to translate information about thermal characteristics of materials and energy zones. The Research Unit is also investigating the benefits of 4D modelling in the management of refurbishment and restoration projects. Most of the time, this kind of projects reveal serious issues in the construction phase that can lead to the failure of the project. The research aim is to show up these unforeseen issues in the early phase of the design, when it is possible to apply cheap and effective solutions. Furthermore, the team is analysing the role of 4D BIM technologies in the evaluation and decision procedure concerning both the design and management of conservation construction site layouts. In addition, the influence of 4D BIM in the iterative process that allows the project manager to carry out the plan of work is currently analysed.

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