

HBIM Library Objects for Conservation and Management of Built Heritage

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Abstract:

The paper illustrates the possibility to shift from a 3D content model to a Historic Building Information Modelling (HBIM) in order to support conservation and management of built heritage. This three-dimensional solution is based on parametric models, suitable for industrial elements and modern architecture, that can be usefully applied to heritage documentation and management of the data on conservation practices. In this sense, the research investigates the definition of an HBIM targeted library, starting from surface surveying and representation towards the logic of object definition. In order to promote wider use and uptake of these 3D object modelling instruments, some case studies are illustrated by the paper. Vault and wooden beam floor analysis show how HBIM for architectural heritage could be implemented in order to assemble different kind of data on historical buildings, such as e.g. dimensional, geometrical, thematic, historical and architectural information.

1. Introduction

Conservation of built heritage is progressively linked to the regular maintenance of buildings, defining the preventing conservation as a real necessity in everyday practice. In this view, it is necessary to have an instrument that allows to collect, compare, share and manage all the data available concerning the geometry and state of conservation of buildings. Such data include, not only the products of surveys, drawings, thematic and historical contents, but also the information about maintenance or restoration activities and many other information.

This paper discusses the possibility to advance from 3D content models to Historic Building Information Models (HBIM) in order to support preventive conservation, information sharing and knowledge dissemination of heritage, for professionals, public institutions and experts involved in the decision making process. Paragraphs 2.1 and 2.2 describe in detail three-dimensional content models, while paragraph 2.3 gives a brief overview on the use of HBIM for built heritage, at Italian and European level, analysing the questions of modelling, data

sharing, interoperability and standards in using different software. Some case studies illustrate the use of BIM solution for the documentation and management of architectural heritage.

2. From 3D Content Models to HBIM

Surveying of historical buildings and its elements requires methods of data collection and representation able to describe buildings in a detailed manner, without arbitrarily selecting information [1]. Survey products, or better geometric documentation, represent an important instrument of knowledge and support for thematic analysis and diagnostic investigation, essential for the maintenance program and the project of conservation of the building [2]. Moreover, assessment and documentation of historic buildings require a constant integration between geometrical analysis, structural observation, decay investigation, social and economic analysis [3].

2.1. 3D data acquisition

Technological progress in recent years, especially in the fields of computer vision and laser scanning, have made the collection of three-dimensional information of environment and objects around us a fairly straightforward possibility. Geomatics engineers have now the means to reliably acquire and determine the position of millions of points on the surfaces of interest. This data acquisition may be accomplished in two main ways: either thorough (1) non image based or (2) image based methods.

Sophisticated laser technology is employed due to a wide choice of terrestrial laser scanning instrumentation available on the market, such as time-of-flight or phase shift or triangulation or structured light systems. On the other hand, structure-from-motion (SfM) algorithms and powerful computers are combined in order to extract three-dimensional information and texture from an image sequence ([4–5]).

In this context the richness of data acquired should be treated with caution, as reliability and accuracy vary a lot and they are affected by the environmental conditions, the instrumentation used, the object itself and, of course, the experience of the operator. In addition, and in the case of image based methods, qualitative information is also recorded through the digital images, a very important fact for the possible processing within an HBIM in later phases.

Availability of 3D data usually enhances the production of 3D models. Geometrical representations and 3D models must support systematic readings of all the metrical, structural and material aspects that characterize the various parts of the building, and must enable the collection and storing of other useful contributions to completely describe the architecture: Terrestrial Laser Scanner surveys and related

modelling software are progressively improving the possibilities for 3D model generations; high resolution 3D texturing models obtained from complex object image block, metric and photographic surveys, are devoted to support co-related information, such as archival, historical data, stratigraphic data, pathologies of degradation, crack's investigations and the results of diagnostic and instrumental analysis. On the other hand geometrical models must allow a continuous transition in scale between the survey of the whole architectural complex and its elements, enabling to cross data at different levels of detail and to support the next phases of information and interpretation.

The contribution of this kind of representation method does not end in a better organization and description of data survey, but it provides an important support for the planning and implementation of maintenance and conservation projects. Furthermore, it allows the control of the interactions between the various technology components of the building. In addition, a useful model could promote an easy, open and integrated circulation and use of data collected, by all those who in different ways are called to work on existing buildings.

2.2. 3D content models

The elaboration of accurate and realistic 3D content models of historic buildings is strictly related to the requirements regarding the intervention planned. In order to be really useful to the professionals in the field, the model should not only be a 3D surface model, but it must take into account the geometric laws of construction, the thickness of the walls, the materials, the organization of the elements and the different construction period of every part of the structure [6]. The investigation of the existing buildings and their constructive techniques starts from the observation of the existing parts, moving gradually through suitable surveys and towards the virtual reconstruction of the historic structures. This approach aims to generate a dynamic interpretative model, to define control alarm thresholds and to identify the sources of risk in respect to the structural and environmental stresses, in order to support analysis, simulations and retroactive control [7]. Consequently 3D content models can be integrated to traditional two dimensional representations of the built heritage.

The limit in using this kind of models in maintenance and conservation activities consists in the necessity to manually connect the shape of the elements with thematic information collected in databases. Consequently, morphological representation of the surveyed surfaces of complex elements, such as facades, vault systems, domes and slabs, needs to be integrated within the logic of object model generation [8].

2.3. HBIM for management and conservation: state of the art

HBIM is a possible solution for three-dimensional parametric representation, which enables the user to draw models and manage data on historic architectural elements, within a common software environment (IFC, Industry Foundation Classes and gbXML, green Building XML) [9]. In particular, this tool allows to combine content information on buildings with data derived from the use of survey technologies (i.e. laser-scanner point clouds, 3D models, digital orthophotos, monitoring data), in order to obtain a 3D model in the form of a geo-referenced spatial information structure [10].

The definition of BIM, as “modelling of both graphical and non-graphical aspect of the entire Building Life cycle in a federated database management system” (©Bentley), underlines the strict relation between object modelling and information involving different aspects, devoted to the maintenance process of a building. Born more than twenty years ago with the aim to manage the United States marine real estate buildings, BIM software were initially used to manage new building constructions ([11–12]). Today they represent an opportunity for heritage documentation and conservation management but they still require a methodological discussion and practice experimentation in order to obtain detailed models of irregular historical objects, that will be really useful for their preservation and maintenance activities. Critical aspects and barriers in the case of complex object modeling need to be further investigated.

Parametric models are related to data collected in a database and every change of a parameter causes a change in the shape of the elements ([13–14]); but, at the moment, a shared library for historical elements does not exist. The necessity of the libraries' implementation requires the development of methodologies and algorithms to use data survey, especially point clouds, and to model in BIM software ([15–17]), avoiding the excessive simplification of the shapes. Hence, it is essential to think about the Level of Detail and simplification process of the models which are useful for conservation projects, related to the real possibility to modify the parameters of the architectonic elements in an isotropic manner, in particular, when dealing with historical objects that are very often irregular. In this context it should be stressed that so far no standards and specifications have been proposed for the introduction into BIM environment of realistic 3D models, that could incorporate all the possible deviations of an element from its ideal model produced during the construction phase.

The literature concerning HBIM illustrates how a library of interactive parametric objects can be constructed [18], principally starting from historical dimension given by architectural pattern books ([19–20]).

One of the aims of this research is to focus the attention on the construction of libraries of architectural elements starting from their survey, using not only laser scanner data (Leica HDS6000, Faro Focus 3D CAM2) but also measurements surveyed with traditional instruments. This solution allows both to build an abacus of local constructive elements and to compare the real dimensions of the elements with the information derived from architectural pattern books. The aim of this process is to describe models in detail according to the specific situations and to use them as instruments of conservation processes management.

3. Towards a Database of HBIM Objects

Here few case studies are considered regarding the construction of HBIM applied to structural systems of historic buildings, widely used in north of Italy to cover the internal spaces of traditional architecture: in particular historic wooden beam floors, brick vaults and wooden vaults.

The survey of many of such structural elements, grouped by typology, geometries and age of construction, showed a lot of significant differences in the textures, the dimensions of the elements, the whole shape and the materials; consequently the necessity arises to use HBIM to model these structures, starting from the real dimensions, into the direction of valorization of the differences, depending from local traditional constructive technologies. In a logic of BIM construction for conservation, it is however necessary to find a compromise in modelling in order to create a shared library of those kind of elements, which general drawings could derive from historical architectural pattern. This is a kind of approach that asks a continuous change from general scale to detail, in a progressive elaboration of knowledge and management of built heritage.

The methodology followed for the HBIM construction of the structural covering systems, starting from laser scanner surveying and orthoimage generation, can be summarized in the following steps (with commands different for every software):

- 1) Definition of the macro-families "component" of structural elements, or group: i.e. slab, brick vault, wooden vault;
- 2) Definition of hierarchical aggregation of different object elements composing the family category: a) structural, b) non-structural elements, and c) decorative layers;
- 3) Definition of the object and its parameters;
- 4) Definition of the material of each object element.

In the case of wooden beam floors, following elements have been defined: the structural layers made by the principle beams and by the secondary beams, the non-structural elements, such as floorboards,

and the decorations, using the stratigraphy definition, such as the plaster and painted layers, the stuccos and so on. In the case of vault system, the structural layers made of: brick block texturing, the ties, the provisional centering wooden ribs, the plasters and stucco stratigraphy are defined.

The definition of such hierarchies of objects is the starting point for the definition of an ontology finalized to HBIMs, built on the state of art of the surveyed structures in a building and on the integration of geometry and construction technologies. Libraries of parametric object definition, coming from the manuals and guides on the historic construction technologies, can be joined to build up a diachronic repository of the different solutions and variations in respect to the chrono-types along a temporal range and across regional areas, showing the permanencies and mutations surveyed on site.

3.3. Data sharing and interoperability: IFD and IFC for HBIM

When speaking of heritage preservation and maintenance, efforts have been made to suggest best practices for recording and documentation [21], however it is still pretty hard to refer to a single methodology: survey of a site or a building requires a correct documentation and data organisation in order to obtain a Spatial Data Infrastructure (SDI), adequate for all communities dealing with heritage. In addition, the European scientific community stresses upon the need of Metadata for Architecture Context [22] and it defines concepts of “traditional content metadata and ontologies, context metadata, usage related metadata and metadata acquired through social interaction”, in the direction also of the fragmentation reduction, reliability and longevity of the data [23].

The International Framework for Dictionaries (IFD) is a mechanism that allows the creation of multilingual dictionaries or ontologies. The Data Dictionary is one of the core components of the buildingSMART technology. The dictionary, named IFD Library, is a reference library intended to support improved interoperability in the building and construction industry. IFD Library provides a flexible and robust method of linking existing databases with construction information to a buildingSMART based BIM.

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

Once progressively defined, HBIM object libraries here described and others under development [24], such as Regional Information System for Planned Conservation - SIRCoP [2], could be implemented and integrated within the H-IFD libraries in order to share common vocabularies.

In order to ensure a full exploitation, the definition of such libraries needs to provide high level of interoperability between different BIM platforms. To this aim buildingSMART open platform, has developed a common data schema that “makes possible to hold and exchange data between different proprietary software applications. The data schema comprises information covering the many disciplines that contribute to a building throughout its lifecycle: from conception, through design, construction and operation to refurbishment or demolition”. Industry Foundation Classes, IFC, are the main buildingSMART data model standard. The IFC open format is registered by ISO as ISO/PAS 16739 and is in the process of becoming an official International Standard ISO/IS 16739.

4. Towards an HBIM Library of Historic Objects: Traditional Covering Room System

For the research here presented, two different BIM software platforms have been compared, ©Autodesk Revit and ©GraphiSoft ArchiCAD, concerning the possibility to model irregular objects that constitute covering structural elements in architecture. Point Tools (©Bentley) plug in for point clouds modelling, within ©Rhino modeller and ©Leica tool for Revit has been tested in order to construct the object families starting from laser scans data. The Interoperability between ©ArchiCAD16 and ©Autodesk Revit is on course of testing in order to guarantee the existence of parametric objects, to define each Room/Zone and to reconstruct the spatial aggregation between the single object component (i.e. walls/façade object, inner walls, slabs).

Space Boundaries relational object will allow the single room unit to be related one to the other, within the whole building construction. Test of interoperability between the IFC output format file are ongoing also with software oriented to the thermal assessment and evaluation, based on object room component analysis (energetic value tools), and to structural analysis (©Midas Civil). Export tests of the geometry are aimed to verify the complete interoperability between the different software, using gbXML or IFC format file.

4.1. HBIM of brick vaults

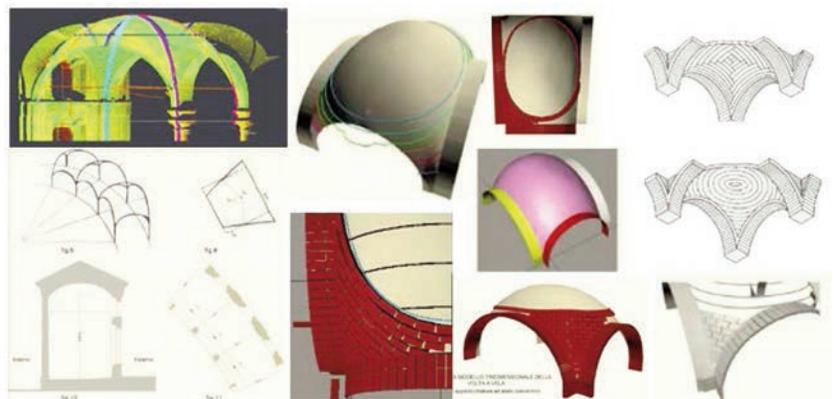
The construction of the 3D models of vaults and their brick elements requires a deep geometrical analysis and interpretation of the

shapes in order to reproduce them virtually with BIM software and to add geometric and constructive content to three-dimensional model, in particular regarding ancient construction technologies and their setting up. In this case the chain between the historical analysis of the construction typologies of the vault systems and the real assessment of each element need to be punctually considered, and it requests a high attention of a systematic analysis to verify the hypothesized structures. According to this aim, HBIM guarantees the necessary flexibility that often characterized the time-delayed and progressive phases of diagnostic analysis on built heritage through the possibility to change the parameters in function of future new investigation.

Different geometric typologies of vaults were analyzed in order to implement a local abacus of structures and to test the capabilities of the software in managing different information that is possible to add to the elements. Some examples of libraries construction, starting from data surveying, are illustrated as following.

Rib vaults cover the four principal and secondary exedras of the complex of the “Rotonda of Besana” (1713–1725), once a church and cemetery of the “Ospedale Maggiore” of Milan, dedicated to Saint Michael. Apparently they seemed related to a simple spherical implant, cut by the inscribed trapezium, as usually represented on the related historical documents; however, the analysis of the horizontal, transversal diagonal and longitudinal slices extracted from the point clouds have shown a complex ovoid shape, with different directions of the brick block disposition along the same constructive ring (Fig.1). The HBIM of the vaults have been generated on the hypothesis of the most probable brick block texture respect to the geometric shape obtained from the laser scans, because of the impossibility to access to the extrados.

Figure 1. The methodological path illustrates the geometry of the vault inscribed within a trapezium and the result of an ovoid non spherical shape. The 3D HBIM was generated from laser scanner vertical and horizontal slices, and the hypothesized texture of the brick block (©Graphisoft Archicad). Historic architectonic patterns were used to deduce information on the ideal textures and to compare it with the real geometry of the vault.



4.2. HBIM of wooden vaults and beam floors

A similar methodological approach has been applied to the research on wooden vaults, used in the past centuries to cover large rooms and to avoid the transfer of the additional weight on the side walls and on wooden beam floors. Survey and documentation can help both in transmitting skills and structural technology no more in use, and supporting activities of maintenance or replacing of some degraded elements.

Similarly to the brick vaults modelling, it was first of all necessary to analyze the interrelation between single elements in order to understand the global behavior of the structures. Secondly, the intrados and extrados of the vaults and of the floors have been surveyed where possible, in order to measure the elements with laser scanner and hands on techniques. The possibility to insert information about the metal connection or wooden elements between different part of the structure was fundamental to build a 3D model really useful for conservation planning and management.

The HBIM re-construction of the wooden vaults (Fig. 2-3) and beam floors (Fig. 4) of Palazzo Soldi in Cremona (Italy), illustrates the importance of stratigraphic analysis of elements used to identify the construction rule of each part in relation with the general structure. Information on different materials, their state of conservation and dimensions were inserted in the database but the issues on implementation of the quantity and quality of data represent at the moment a limit in using BIM for heritage.

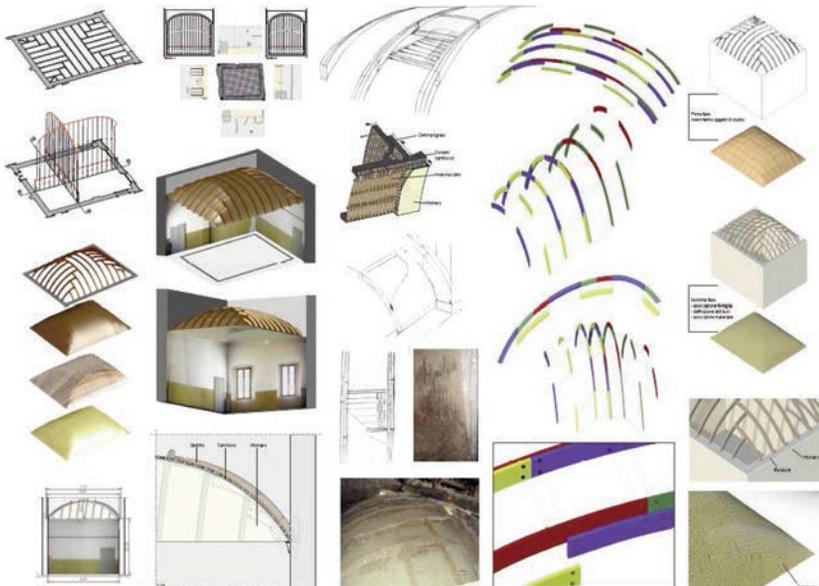


Figure 2. HBIM (©Autodesk Revit) of wooden vault in Soldi Palace in Cremona (Italy): 3D elements modelling process using laser scanner point clouds and hands on measurements. Information on materials, their stratigraphy and geometrical data of architectural elements are indicated in the database.

Figure 3. HBIM (©Autodesk Revit) of wooden vault in Soldi Palace in Cremona (Italy): information on materials, their stratigraphy and geometrical data of architectural elements are indicated in the database.

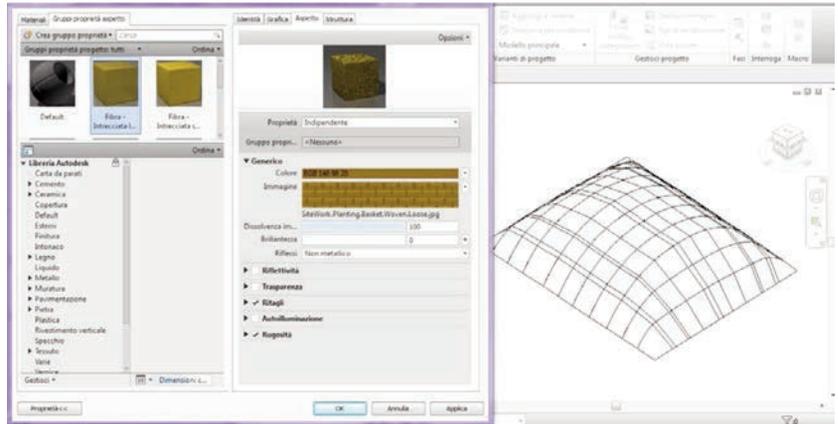
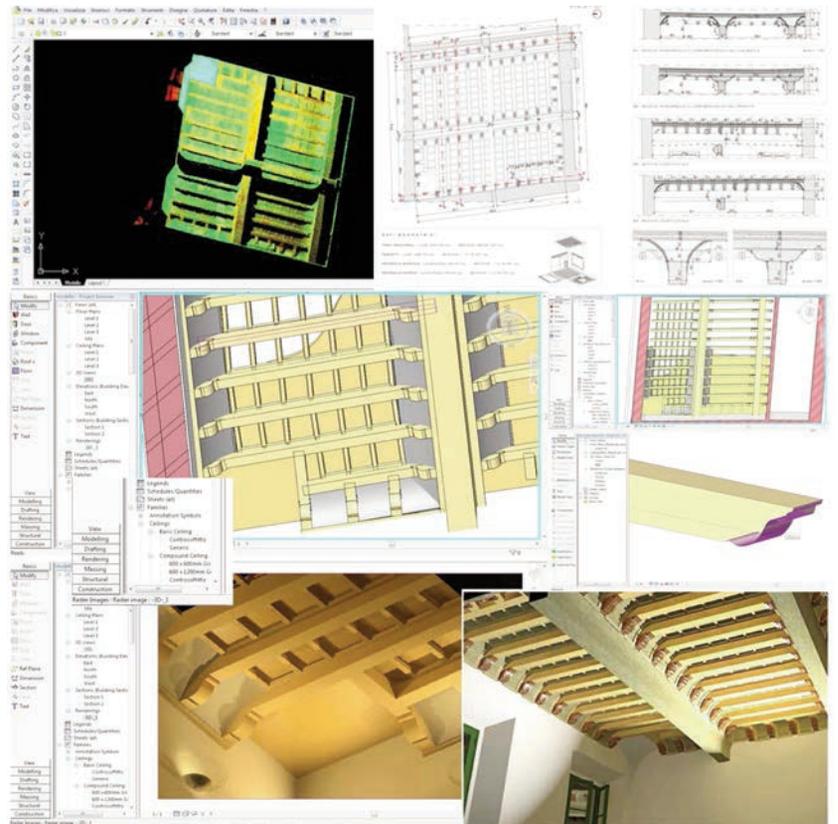


Figure 4. HBIM (©Autodesk Revit) of 15th century wooden roof in Soldi Palace in Cremona (Italy): ceiling family definition and hierarchical components. Laser scanner data and hands on dimensions were integrated to obtain a detailed 3D element model of the historical wooden structures.



5. Conclusions

HBIM is based on simplified parametric models that are suitable for industrial elements and modern architecture. However, further investigation should be done in order to apply this kind of documentation in broader heritage conservation practices.

The case studies showed how it could be possible to experiment and verify the transition from the concept of surface towards object representation. This process could (1) support enhanced comprehension of the single elements within the model information of the overall building organism, and (2) allow the connection to descriptive thematic database (constructive technologies, elements abacus), in a logic of semantic content models. These kind of three-dimensional detailed virtual models are useful instrument for improving remote access to data that could provide support to advanced programs for preventive conservation and guarantee sustainable interventions and maintenance over time. Moreover such 3D models can be able to host both geometrical - historical survey data and materials or degradation information.

HBIM libraries implementation for built heritage elements requires a wide and shared research on drawings, elaboration and interpretation activities of survey data: consequently it is necessary that this aim is pursued as much as possible between the experts in documentation and representation of the built heritage. Standards and interoperable IFC and IFD need to be deeper investigated and implemented [3]. Detailed documentation of architectural heritage should be based on a common vocabulary, taking in account the differences that characterized the heritage and on data gathered with a systematic, unified process, with increasing degrees of details. The aim of this process is, on one hand, to create significant content that is as broad ranging as possible, in line with adequate cognitive standards (not only complying with the parameters of the Italian "Istituto Centrale per il Catalogo e la Documentazione"); and on the other hand, to develop a fully implemented and interoperable tool to support conservation activities, which can be integrated with the instruments deployed in everyday planning procedures that regard existing buildings, especially those of historic importance.

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