IT Procedures For Simulation Of Historical Building Restoration Site

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1 Abstract

Dealing with renovation and restoration of historical building heritage, often means facing several difficulties concerning the way of representing not only the ancient building and the design ideas, but also phases of interventions on site.

The designers have always to take into account a range of possible compatible solutions that avoid endangering the cultural significance of the historical building.

Traditional methods are often time consuming and barely efficient, because they are related to exchange two-dimensional and paper-based support information.

The Building Information Modeling may represent an answer to these problems, allowing the users to model the three-dimensional compounds of the building and to link a variety of information to it.

This work intends to propose an innovative approach to the construction management of historical building interventions, based on BIM technologies, facing different kinds of problems, such as:

- **parametric modeling of historical buildings, starting with laser scanner survey: LoD (level of detail) definition and measurement accuracy related to modeling procedures;**
- **parametric modeling of the site and the several phases of the restoration works in a fixed schedule (4D dimension);**
- **3D graphic representation of safety procedures and related tools.**

The case study was offered by the SS. Nome di Maria church (Italy), built in 1748, which was seriously damaged during the earthquake that occurred in Italy in 2012.

Keywords -

Historical Building Heritage; Historical Building Information Modeling; Building Site; Workflow

2 Introduction - Toward the Model Customization

Historical Building Information Modeling (H-BIM) is based on different hypotheseis from those used in the application of BIM for new buildings, because historical, cultural and social parameters have to be added to architectural heritage objects, considering the building's own identity. The architectural model has to answer to three main questions: “what”, “why” and “how” each part to be renewed was built (Avrani et al., 2000).

This peculiarity needs more suitable parameters, actually missing or hard to match together, and a different modeling approach, which will deals with the typical building interventions related to existing building such as maintenance, refurbishment, redevelopment and restoration.

For this reason, for each type of building a level of information has to be chosen, related to the type of intervention and as homogenous as possible to obtain a model that is easy to manage and understand.

BIM technology allows the simulation of a different types of intervention, helping greatly the designer to choose the more efficient solution.

As each change is a computational burden, the main objectives and the level of detail (LoD) have to be fixed at the beginning.

The final model therefore has to contain both physical and functional characteristics of the building, and all the processes involved to manage and communicate information among subjects at different levels.

The model uses data, produced by different building process actors, in more steps for different purposes, to ensure quality and efficiency along the whole cycle of the life of the building. Specifically BIM can help safety management by the visualization, communication, and education improvement.

2.1 Related Work

The case study of the issue analyses the real case of the restoration of a church (Figure 1) under lights of architectural modeling and management of building site and workflow, availing it of H-BIM (Historic Building Information Modeling) technology.

Figure 1. The church during restoration activity

This aim discloses some complex difficulties, and both modeling and analysis are so far to be a passive process, but they will become an integrated action including more levels of them.

It is necessary to underline how modeling and data extrapolation are still affected by intrinsic obstacles; in this issue a method to overcome them and obtain fruitful results will be proposed. The possibility of simulating, analysing and confronting in a global view all intervention proposals, allows the optimal visualization of consequences; after every change, quick data update guarantees the view of the transformation inside the project and interoperability through work sectors.

3 Methodology

The use of BIM for new designs has been a current practice for several years (Eastman et al., 2011), but we cannot find many examples of BIM applications in restoration of historical buildings, due mainly to the high effort needed in the digital conversion of the acquired data, which are often incomplete, fragmented and non-updated for a leaning modeling (Volk et al., 2012); this factor entails a slowdown in the implementation of the building information in a BIM system.

Although the historical buildings represent a high percentage of the building stock in Europe, there is not yet a chapter of BIM literature, which specifically deals with the protection of historical buildings. Moreover, some countries, such as Italy and France, do not have a legislation on public works, which compels designers to use BIM tools, consequently many professionals have only recently become aware of their advantages.

The H-BIM implementation begins with a collection of geometrical and technical data, which will be later associated with the BIM items. These can be acquired by several techniques, which involve direct or indirect contact with the building, such as different surveying techniques and invasive or non-invasive tests for obtaining properties of materials.

The accuracy of the collected information will establish the level of detail (LoD) of the digital model.

The main items, which influence in general the acquisition of the building data, are the cost and time of the procedures, the environmental conditions (light, weather, presence of vegetation, etc.), professional practice, etc. Over the last years the most commonly used technique has been the laser scanning, although it suffers from disadvantages, such as high costs and processing time, despite of a reduced acquisition time.

Behind their geometry, the elements of a historical building, however, include a good amount of heterogeneous data, due to their physical and historical complexity (De Luca et al., 2011). For this reason the collected data always have to be interpreted to obtain a useful digital model for the defined aims.

Historical Building Information Modeling intends to create a digital model that provides the highest amount of basic information for any maintenance works or renovation project and allows every updating in progress.

It is necessary to get a profound knowledge of the building to reach a suitable level of accuracy of the initial information for the digital model implementation.

The following basic steps are:

- **Step 1**: collecting cadastral documentation and existing drawings of the building;
- **Step 2**: geometrical surveying of the building;
- **Step 3**: thematic surveying related to the degradation conditions of materials and structures;
- **Step 4**: testing some real building elements to determine the characteristic parameters to associate later to the corresponding elements of the digital model;
- **Step 5**: detailing of historical building techniques.

Buildings differ according to use (residential, commercial, office, etc.), age (new, existing, belonging to the historical heritage) and ownership (public or private); these conditions, different in each case, influence the BIM application, its level of detail (LoD) and the management of the digital model (Volk et al., 2012). Also the intervention proposed will condition the model, so it is necessary to provide soon a level of information suitable for data exchange and sharing among the several specialistic analysis software and BIM tools, limiting information loss.

In particular the safety and site designer has the need to prepare a set of drawings of immediate reading to understand the construction site, by which it is possible to give operating instructions and orders related to site procedures and safety behaviours.

A great deal of work is needed to prepare this kind of project documentation, which has to refer to all the realization phases (or at least in those highlight).

Thanks to BIM technologies, these aspects have been partially solved, taking advantages of the possibility to make up a catalog of customizable parametric objects for the construction yard, such as scaffolding, cement mixers, cranes and other work tools, and to associate with them a time variable that allows one to assess their possible combinations and interferences, to obtain the optimal solution.

In the present case study, speaking of time variables, referring to the main working procedures in inteventions of restoration, implies being represented both in all macro phases of processing on site and in each stage of work.

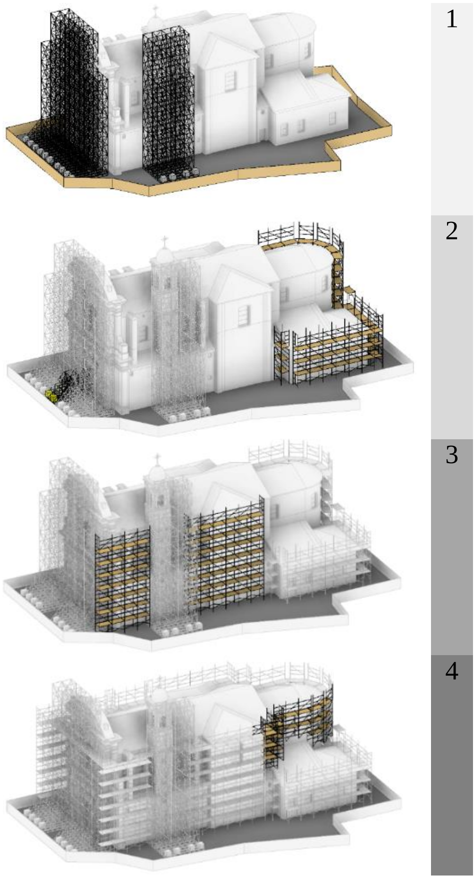

Figure 2. Sample installation of the scaffolding

The ability to view, edit, compare and represent strategic decisions is an enormous advantage for solving critical operating situations, such as delay of construction phases, cost increase and the risks involved during work phases. (Codinhoto, Kiviniemi et al., 2011, p. 44).

Moreover, the clash detection allows evaluating the right position of the elements, to highlight conflicts, verify overlaps of specific working spaces and resources flows, and, consequently to evaluate the feasibility form the technical point of view and from the working safety.

The interactive management of the elements through the capability of visualizing it with endless views achievable from the internal database, gives the opportunity to virtually compose and decompose the building as we desire.

In that way, it is possible to simulate the consequences of a particular design decision undertaken and obtain the most appropriate and meaningful images to represent and to communicate with the other professionals involved during the works, the steps needed to achieve the final result in an effective, efficient and safe way (Eastman et al., 2011).

A structured system of graphical representations is a powerful tool for the education of the workers who can visualize and simulate virtually the tasks that need to be performed. Through these intuitive representations, this task may grant also to the worker greater consciousness about the operational difficulties of both the risks and interference.

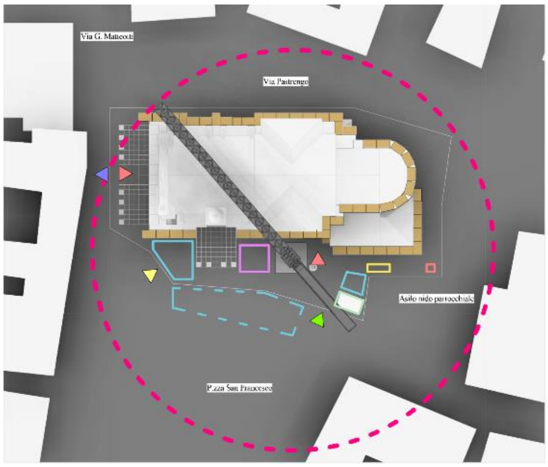

Figure 3. Construction site layout

According to Codinhoto (Codinhoto, Kiviniemi et al., 2011, p. 44) in order to increase safety during the whole construction design process, it is possible to implement BIM starting with four main steps:

1. A general safety planning based on BIM standards;
2. Risk analysis;
3. 3D and 4D visualizations with related comments and communications;
4. Other use of BIM-based to produce further drawings and information (such as floor plans or details) useful for a better understanding of the interventions (photos or additional drawings, explaining the work phases).

Moreover, it has to consider the “planning element” of the site that we report briefly:

1. The construction site, the streets and the surrounding that can be affected by its impact;
2. The site equipment, the facilities and the resources included in the construction site;
3. The material deposited;
4. The signals indicating the risks, dangers and obligations within the site.

It is always necessary to keep in mind that an easy access to information reinforces the exchange of ideas and a conscious design.

In the case of new construction, BIM-base platform allows to set the several representations in a sequential timeline (see Figure 4).

Figure 4. Logical scheme of the model for new construction building

Instead, for an existing building, as it is well known, there are many specific difficulties due to the need to include in the project the building state of preservation with its characteristics and variables.

It is different from the case of new construction for the inability to recognize chronologically the historical phases of the building according to standard steps and is characterized, however, by a custom logic case by case.

The new logical system proposes the subdivision of the existing building in several parts (building subsystems), each associated with individual interventions (see Figure 5).

Once these are grouped in a singular logical intervention, the building site must start.

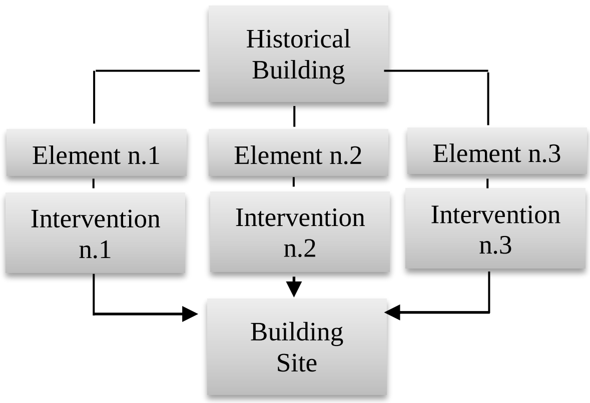

Figure 5. Logical scheme of the model for existing building intervention

From this graphical scheme representation, it is clear that this approach results more expensive in terms of time and resources. Identity of each intervention has to be considered both on a local and general level.

If we consider this difference, we must elaborate drawings and information to comunicate the individual issues contextualizing it in a broader context, both from the topographical and the chronological point of view.

Expected results arisen from the BIM model are:

a) 2D and 3D visualization of the building;
b) 2D and 3D visualization describing phases of the construction site;
c) Drawings and documents that provide information about the work to be performed, time and cost given by the use of parametric BIM-objects (often provided by various manufacturers);
d) Safety data sheets in which for each work phase the execution mode is shown, both on the local and global level of the project;
e) Alternative solutions, design variants and comparisons between them.

4 Case Study: SS. Nome di Maria church at Poggio Rusco, in Mantua (Italy)

The case study applies H-BIM axioms to the SS. Nome di Maria church in Mantua (Italy), which succumbed to permanent damage after the earthquake of 20th and 29th May 2012 that in Emilia Region.

The church is a late baroque building, and was built at the beginning of 1700 with the project of Carlo Nicolini and Paolo Pozzo, perpendicularly to the older St. Maria Alba church, which was supposed one of Matilde di Canossa churches.

The architectural system is composed of a central nave bordered by chapels, two of them, near the apse, are larger to simulate a transept. The main structure is composed of large walls of compact bricks, arches which sustain vaults and wood beams of roofing.

Figure 6. Axonometric section of the church

Bearing in mind architectural and structural elements, it is possible to start the intervention of restoration and the workflow simulation.

The model allowed to reproduce the building process phases of the intervention of restoration, which were implemented with extra data, ensuring the historical identity of the building.

The study tries to define several intervention ways applied to the church restoration, identifying the logical structures linking the building object with macro-phases of production.

For this purpose both 3D visualisation of the model and 4th dimension (the time) have been implemented, which allows to articulate the development of phases in multiple steps.

The management of operative phases, completed with the design and the progressive elaboration of building site layout, allows the simulation of the intervention and executive control during works.

Thanks to this approach, it is possible to define a general model which is able to describe the intervention, which considers at the same time design, management, and organization of the building site activity, rendering an innovative representation of works and of the general model of the construction site integrated with the building, highlighting operative, logistic and safety critical situations.

Starting from the survey, executed with the laser scanner technique, the main views (such as plans, sections or fronts) are extracted and used for the production of the BIM model of the church and the building site. A possible software for the intervention design of both new and historical buildings, which gives an answer to these integration requests, is Revit (Autodesk).

The strength of this approach is ability to coordinate each building element in a single database, giving to the user the possibility to see immediately every review result of the model, directly in associated views.

This approach to the three-dimensional historical restitution occurs in three passages:

a) Evaluation of real problems of the future 3D model;
b) Definition of the Level of Detail (LoD) of architectural heritage objects;
c) Choice of graphics for presentation of the final work.

Thanks to the modeling instruments, it is possible to obtain complex forms to simulate the building in a three-dimensional way, thinking about the real complex object like a juxtaposition of simple forms, splitting it into primitive geometries for a simpler following restitution (see Figure 7).

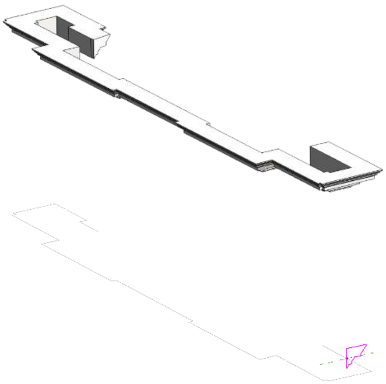

Figure 7. Section extruded forming a cornice

In fact it is possible to have a good LoD, though there are limitation imposed by nature of architectural heritage objects (see Figures 8 and 9).

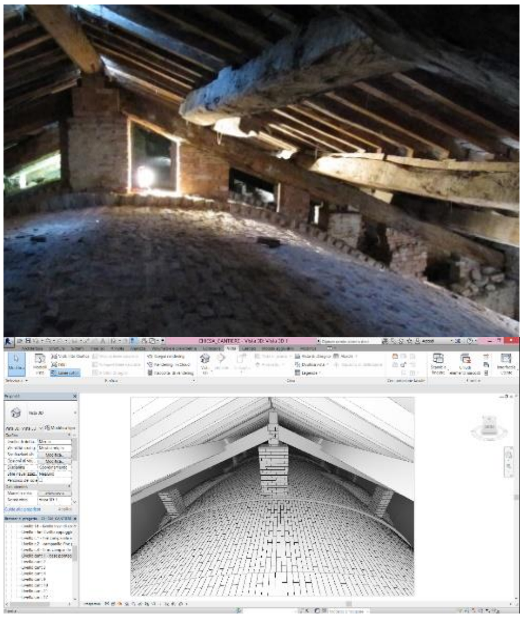

Figure 8. Photo compared to a model view

The modelling of the various architectural heritage objects was done in three different ways:

1. Creation of **“in place family”**, which are elements directly realized into the model, saved in the .rvt (Revit file format), without using .rfa files. “In place families” must be seen as a peculiarity of a single architectural model, while .rfa families are created to be used in many other projects. In place families are used for the creation of realistic walls and arches.
2. Realization of **.rfa families**, which are files external to the model. They can be separately modified and employed for many different projects. Thanks to these kinds of families, the flexibility of

the software is given by the possibility to replace in every moment of the modelling each family with another of the same category. The realization of a personalized object needs the identification in a category, which allows the transfer into the object of every desired architectural property. Elements of the same category can be interchanged to give a particular graphic result inside the design activity. This kind of family includes doors and windows.

3. Creation of **elements with auxiliary software** (in this particular case study, represented by Autocad) and following importation in the BIM model with the realization, through "surface models", of real geometries. This way vaults can be modelled.

For the modelling of the building site and work steps, BIM system can be defined as a building processor, which is able to generate a digital model including all project information.

Thanks to sequences of phases, the model really connects realized elements and logistic or operative equipment.

The experimentation found out that the system is able to follow the evolution of the building production, graphically representing work macro-phases, and single activities or operations. On BIM base it is possible to connect building objects to the logistic or safety prescriptions of the executive phase, which are requested by the project drawings.

Operative phases are connected to the building system and its dynamic evolution.

Based on methodology, the project has been initially decomposed in macro-phases. This decomposition provides a sequence of levels of description, until it is possible to read and analyse every single phase of manufacturing, examining occurring problems, such as overlapping, and considering variations, and possible compatible or alternative solutions.

Each group of phases (or macro-phase) has been included in a Gantt diagram, produced using the software Project (Office suite), which has been integrated inside project drawings.

The identification of each manufacturing follows these steps:

1. Identification of necessary interventions;
2. identification of project macro-phases and their chronological order to place them properly in a Gantt diagram;
3. Insertion of the parametrical building site objects in the model, following phase and macro-phase plan, eventually introducing variations and information (such as explicative graphs, or photos);
4. Definition of safety maintenance sheets, where there worker situation may appear with regard to his/her duties, danger faced and the necessary protective individual equipment

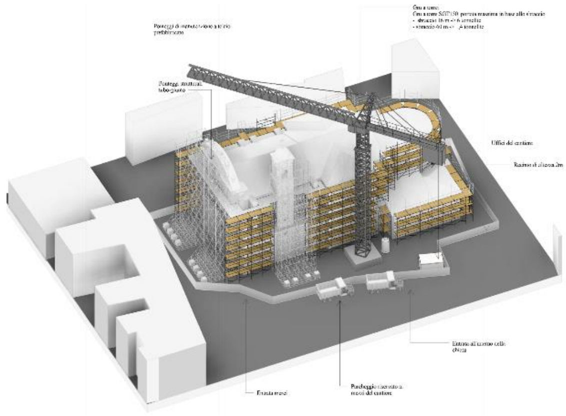

Figure 9. 3D building site layout.

The result is a graphical database, which follows a given work phase, using logical parameters inside a BIM environment. At this point, it is possible to extract efficient graphical representation to exchange logistic and safety information, with an expected LoD. A 3D-4D model allows to understand how to execute fundamental procedures and it clarifies the real boundary between the different working phases.

5 Results

The final work includes project drawings and a database, which is suitable for the analysis and design of the building site and restoration of the historical building.

It is possible to perceive two groups of results: one for the architectonical restitution, and another for the safety management of the project and development of building site, thought like the main workplace.

The first group enlightens how it is possible to obtain a BIM model of the church, decomposable in its own elements, from which limitless 3D or 4D views can be automatically generated from the BIM software (3D model, plans, sections, fronts or details).

Every view can be visualized with a preferred style, appropriate notes, photos or details (see Figure 10).

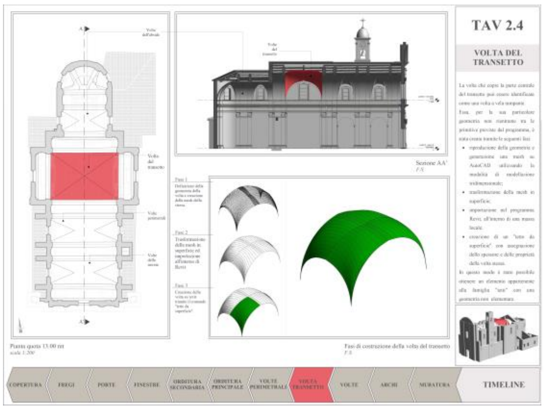

Figure 10. Graphical explanation of the construction of a vault, with modelling phases.

This is a fundamental aspect for both architectural heritage objects and the analysis for each manufacturing.

The LoD results acceptable, though for details like the intersection between elements of different categories or “in place family” objects, it is often necessary a manual re-elaboration for a realistic restitution of them.

This operation is possible either using the BIM software or exporting the specific view in a compatible software. However, the first solution is recommended, in order to automatically or semi-automatically update the detail during the development of the model.

For the construction of the building site and work phases, it is possible to obtain a development of macro-phases and phases, adding relevant views, notes, photos, abacus, diagrams and safety sheets (see Figure 11).

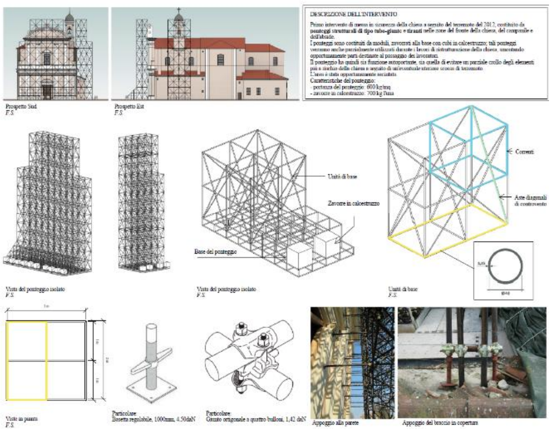

Figure 11. Three-dimensional view of scaffolding and descriptive sheet of them with notes and photos of assembling.

Model simulations allows risk analysis, and the 4th dimension of time gives the possibility to have a detailed sequence of the workflow and its weaknesses. This is a central point for the control of a dynamic environment such as the building site.

Work phases are physically and chronologically detected inside the general layout, and for each of them a descriptive table is produced and then a second one is added with a sheet including position of the workers, notes or safety symbolism.

At present this technology lacks elements, which can procure punctual provisions regarding phases and micro-phases and this crucial aspect significantly slows down the design procedure of real applications.

6 Conclusions and future perspective

Through the example of the case study, it is possible to observe how historical building heritage can be analysed in different aspects. After a laser scanner survey, obtained dimensional information allows one to realise the first BIM model, which includes both the architectural one, describing in a two- or three-dimensional way every element, and the base for the 4th and 5th dimensional approaches. This proposed case study focuses on the latter aspect, which concerns the work phases of the project, time and their cost, for a global view of various solutions.

Subsequently it is possible to verify the qualities and lack of BIM modelling for projects on historical building heritage, underlining these main aspects:

1. Digitalization of a historical building and interventions on it, after considerations on “singularity” of each element, does not allow any standard step and asks for more flexible operations to model them. Referring to the final goal of the BIM model it is possible to establish a LoD and define the acceptable error trend.
2. The model is often composed of ad hoc elements or families, which causes the increasing of the file size. At present many software houses are developing even more detailed and flexible BIM libraries, which would simplify the allow evaluation of time and costs, with a preventive view of quantities and position of manufacturing
3. Software interfaces are in continuous evolution, becoming sometimes a real obstacle for the immediate use of them.
4. Interoperability between software allows a great advantage for communication of the same basic model for analysis of historical building heritage.

Historical building heritage has an important influence on our reality, and it is often the subject of design activities and analysis: BIM technology may present a real help to pursue these goals, also contributing to maintain the historical memory of historical buildings, developing appropriate database, which can be consulted and divided in multiple levels of description.

7 Acknowledgments

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8 Reference

[1] Avrami, E., Mason, R., & De la Torre, M., (2000). *Values and Heritage Conservation.* S. Tidwell (Ed.) Los Angeles, USA: The Getty Conservation Institute

[2] Murphy M., McGovern E., Pavia S., *Historic building information modelling (HBIM)*, Dublin Institute of Technology, Dublin, Ireland & Trinity College, Dublin, Ireland, 2009.

[3] Biagini C., Donato V., *Dal modello fisico al modello digitale. Procedure integrate per la rappresentazione del progetto di architettura.* In: Borda A., Cardone V., Ferraris R., Minond E. (a cura di). *EGraFIA 2012. Gráfica del Diseño. Tradiciónes e Innovaciones*. pp. 539-544, Cordoba: Facultad de Arquitectura, Urbanismo y Diseño de la Universidad Nacional de Cordoba, 2012.

[4] Codinhoto R., Kiviniemi A., Kemmer S., Essiet U.M., Donato V., Tonso L.G.., *Research Report 2 - BIM - FM - Manchester Town Hall Complex. Manchester City Council.* Univerist of Salford (Manchester), 2013.

[5] Volk R., Stengel J., Schultman F., *Building Information Modelling (BIM) for existing buildings – Literature review and future needs*, pp. 109-127, Elsevier, 2013.

[6] Saygi G., Agugiaro G., Hamamcioğlu-Turan M., Remondino F., *Evaluation of GIS and BIM roles for the information management of historical buildings*, Dokuz Eylül University, Faculty of Architecture, 35160-Izmir, Turkey, 3D Optical Metrology (3DOM) unit, Izmir Institute of Technology, Faculty of Architecture, 35430-Izmir, Turkey, Bruno Kessler Foundation (FBK), 38123-Trento, Italy, 2013.

[7] Bertaccini B., *Stanta Maria del Fiore Dome behavior: Statistical Models for Monitoring Stability*, Dipartimento sdi Statistica "G. Parenti", Università degli Studi di Firenze, Novembre 2013.

[8] Brumana R., Oreni D., Raimondi A., *From survey to HBIM for documentation, dissemination and management of built heritage – the case study of St. Maria in Scaria d'Intelvi*, Politecnico di Milano, ABC Department, POLIMI, Lab GIcarus, 2013.

[9] Brumana R., Oreni D., Georgopulos A., Cuca B., *HBIM for conservation and management of built heritage: towards a library of vaults and wooden bean floors*, Politecnico di Milano, Laboratory of Photogrammetry della School of Rural & Surveying Engineering della National Technical University of Athens, Cyprus University of Technology di Cipro, Settembre 2013.

[10] M De Luca Picione, G. R. Dell'Osso, *Simulazione e modellazione, con il Building Information Modelling, del cantiere edile negli interventi di recupero sul costruito*, Università degli Studi della Basilicata e Politecnico di Bari, Ed, ISTeA – Italian Society of Science, Technology and Engineering of Architecture, 2009.

[11] Simone Capocchin e Andrea Torre, *Recupero edilizio e restauro*, Il Sole 24 Ore S.p.A., Milano, 2010.

[12] Markku Kiviniemi, Kristiina Sulankivi, Kalle Kähkönen, Tarja Mäkelä & Maija-Leena Merivirta, Kopijyvä Oy, Kuopio, *BIM-based Safety Management and Communication for Building Construction*, 2011.

[13] Biagini C., Donato V., *Building Object Models (BOMs) for the Documentation of Historical Building Heritage,* in Barba S., H.C. Lomonaco (a cura di), "EGraFIA. Revisiones del futuro. Previsiones del pasado", Actos V Congreso Internacional de Expresión Gráfica en Ingeniería, Arquitectura y Carreras Afines, Rosario (Argentina) 1/3 Ottobre 2014, CUES, Rosario 2014, pp. 442-8.

[14] Eastman C., Teicholz P., Sacks R., Liston, K., *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, John Wiley & Sons, Inc., seconda edizione, New Jersey, 2011.

[15] Finnmap Consulting Oy, Gravicon Oy, Olof Granlund Oy, Lemminkäinen Talo Oy, NCC companies, Pöyry CM Oy, Skanska Oyj/VTT Technical Research Centre of Finland, Solibri, Inc., SRV Rakennus Oy, Tietoa Finland Oy, *COBIM,* Common BIM Requirements 2012.

[16] Anna Osello, *Il futuro del disegno con il BIM per ingegneri e architetti/The future of drawing with BIM for Engineers and Architects*, Dario Flaccovio Editore, 2012.