HBIM for Documentation, Dissemination and Management of Built Heritage. The Case Study of St. Maria in Scaria D'Intelvi

by
Raffaella Brumana, Andreas Georgopoulos, Daniela Oreni, Anna Raimondi and Angeliki Bregianni

Reprinted from

International Journal of
Heritage in the Digital Era

volume 2 number 3 2013

HBIM for Documentation, Dissemination and Management of Built Heritage. The Case Study of St. Maria in Scaria d'Intelvi

Raffaella Brumana[1], Andreas Georgopoulos[2], Daniela Oreni[1], Anna Raimondi[1] and Angeliki Bregianni[2]

[1]Politecnico di Milano, ABC Department, Milan, Lab. GICARUS, Italy, 31,Via Ponzio - 20133
(raffaella.brumana, daniela.oreni)@polimi.it, anna.raimondi88@gmail.com

[2]National Technical University of Athens, NTUA, School of Rural & Surveying Engineering, Section of Topography, Lab. of Photogrammetry, Athens, Greece, 9, Iroon Polytechniou -15780
2drag@central.ntua.gr, 2aggelikh@msn.com

HBIM for Documentation, Dissemination and Management of Built Heritage. The Case Study of St. Maria in Scaria d'Intelvi

Raffaella Brumana, Andreas Georgopoulos, Daniela Oreni, Anna Raimondi and Angeliki Bregianni

Abstract:

The research presented here is carried out within the INTERREG EU project framework, which aims to the valorisation and dissemination of the role of the Church of St. Maria di Scaria (Como, Italy). It mainly focuses on the Carloni's intervention (XVIII century), a local family of craftsmen, famous across many European cities and regions contributing to the construction of monuments and their rich decoration apparatus.

The laser scanning and photogrammetric surveys have been integrated with the on-site stratigraphic analysis and with the scarcely available historical documents, in an attempt to focus on the reconstruction of the main transformations and chronological phases: BIM approach has been experimented as a way of transmitting a piece of the history of the church life to the local people and for tourist purposes.

A Historic Building Information Modeling (HBIM) has been developed while investigating the potential of an object library specially generated to illustrate the structural elements, the construction technologies, and the decorative layers, along with the critical aspects faced by standard BIM in a complex geometry shift from surface approach to object modeling. The research contributes to the explanation of the sequence and construction technologies adopted for the vault system, the first two vaults of the nave, with respect to the vault covering the altar and the apse. The HBIM approach development is analysed to help the generation of a vocabulary and an abacus of elements to be geographically referenced across Europe to disseminate typical construction elements and skills.

Key words: 3d modeling, HBIM, built heritage, survey, laser scanner

1. Introduction

1.1 Historical notes

The church of St. Maria is placed in Scaria d'Intelvi, a little settlement of Lanzo d'Intelvi, in the province of Como (Italy), next to the Italian border with Switzerland, on the road to Central Europe. Its importance is connected to the Carloni family, native of Scaria: this family belongs to the workforces of craftsmen and artists, hailing from the Intelvi valley, that were taking part in the decoration of many monuments and palaces, for the most important courts and personalities of Europe.

The church has probably romanic origins, but the first documentary information about it date back to the XV century. The church underwent a huge transformation during the XVIII century, that involved the addition of a new apse and the modification of its general arrangement, with a rich complex of baroque ornaments. The promoters and authors of this transformation were the brothers Diego and Carlo Carloni, sculptor and painter respectively.

The renewal of St. Maria can be considered like a present of the Carloni brothers for their homeland. After becoming successful and rich, while working over Europe, they transformed it into a little jewel of baroque art.

The survey of the church, using laser scanner (Leica HDS6000) and photogrammetric instruments, have been integrated with the on-site stratigraphic analysis and with the available historical documents; the aim was to focus on the transformations of the church during the centuries and on the different chronological constructive phases, by using BIM approach for dissemination and data management of this little unknown jewel of architecture.

At the end of the research it has been shown the potential of HBIM in Building Performance Analysis (BPA) to support Life Cycle Management (LCM) and energy efficiency goals in the case of an historical building.

2. State of Art of BIM for Built Heritage

2.1 The project of dissemination and management of data surveying

A little local museum is planned to be realized near the church, co-funded by the EU Interreg programme, devoted to the exhibition of the apparatus of the sacred vessels and precious furnishings donated in the past. The construction of a three-dimensional object model of the building is finalized to be exposed in the multimedia section of the museum, in order to transfer the information on the transformations and on the decoration of the church in an easy way, with the aim to facilitate the readability of the history of the monument.

Historic Building Information Modeling (HBIM) aims to a three-dimensional parametric representation of the built heritage, enabling the user to draw object models and manage related data on architectural elements, within a common exchange format (IFC, Industry Foundation Classes, and gbXML, green Building XML), in order to support a full interoperability between different software (Cooperative Research Centre for Construction Innovation, 2009), strongly supported by the smartBuilding open platform. The paper describes the effort to combine content information on buildings (i.e. material, decay, stratigraphy) with data derived from the use of different survey technologies (i.e. laser-scanner point clouds, digital orthoimages), in order to obtain a 3D object representation in the form of a geo-referenced spatial information of a structured hierarchical set of families (structural elements, such as wall, vault, roof, and decorative elements) (Pauwels, P., 2008).

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.
BIM software, initially used to manage new building construction (Lee, G., 2006) (Eastman, C., 2008), today may represent an opportunity for heritage documentation and conservation management (Hichri, N., 2013). Nevertheless their use 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 (Oreni, D., 2012). Critical aspect 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 (Boeykens, S., 2011) (Boeykens, S., 2012); but, at the moment, a shared library for historical elements does not exist. The necessity of a libraries' implementation requires the development of methodologies and algorithms to use data survey, especially point clouds, and to model in BIM software (Murphy, M., 2013) (Chevrier, N., 2010), avoiding the oversimplification of the shapes. As a consequence, it is essential to think about the level of detail and simplification of the models useful for conservation projects (Garagnani, S., 2013), related to the real possibility to modify the parameters of the shape of the architectonic elements, in particular of historical object that are often irregular, in an isotropic manner. The literature concerning HBIM illustrates how a library of interactive parametric object can be constructed (Tang, P., 2011), principally starting from historical dimension given by architectural pattern books (Fai, S., 2011) (Fai, S., 2011). According to this aim, the individuation of shape grammar and stylistic rules can be used to build a first library of historical elements of built heritage. But it seems to the authors that the high potentials in BIM library generation is to share, in an easier way, tools and functionalities samples, in order to support different analysis of other specific cases, avoiding the risk of an uncritical use of objects with no relation with the real shapes. The attention to the strictly connection between geometry and construction technologies is the only way to guarantee a real 3D model of the built heritage.

Due to the complexity in generating objects, for example a vault, beginning from accurate laser scanner survey till to 3D texturing, the generation of sample parametric grip object can represent a valid support in modelling of similar objects. In addition, a library of spatially referred objects can support, in the future, abacus of objects and a geographic history of the skills and techniques across European regions, that are now substantially unknown to the public or to the specialists, due to the lack of relations between them.

3. The Survey of the Church and Data Interpretation

3.1 Surveying methodologies toward object modelling logic

In the field of Cultural Heritage nowadays it is common practice that geometric documentation of interesting objects is performed in three dimensions. The creation and development of 3D models of heritage buildings, conveying information essential for both to reconstruct the geometry and to interpret the monument itself, requires the implementation of a multitude of advanced surveying methodologies.

The methodology used for such projects usually involves, among others, laser scanning surveys. Contemporary equipment can offer a high level of accuracy and reliability, while capturing the details of an architectural form. The geometric information that defines the shape and the spatial relationships of the objects can be extracted

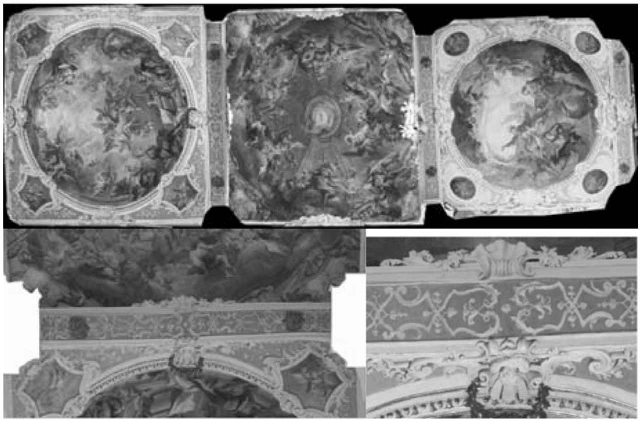


Figure 1. Orthoimage of the three spherical vaults that cover the nave of the Church and details accuracy of 3D texturing.

either directly from the point cloud or from 2D drawings designed with it as a reference. Moreover, surfaces (DSMs) like TINs can be produced based on the point cloud, creating in this way 3D objects form 3D points.

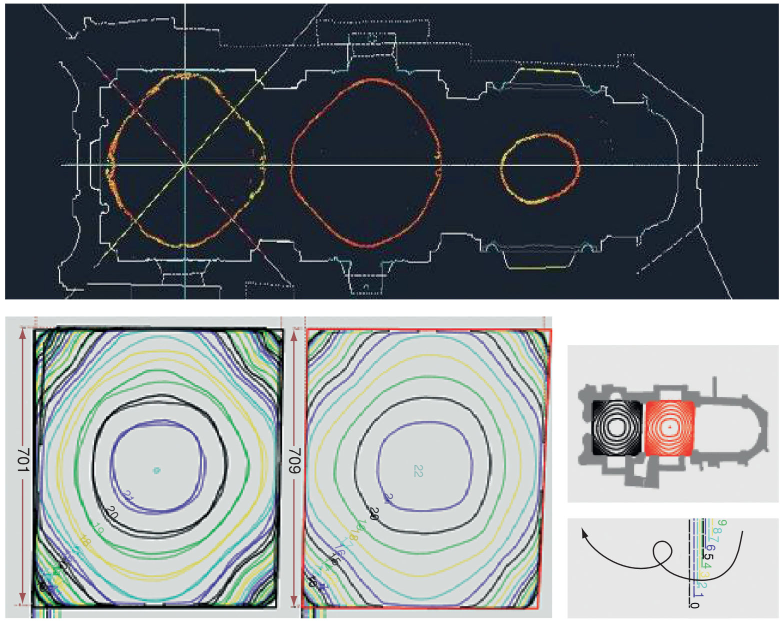
On the other hand laser scanning surveys can also be integrated with image-based techniques, providing a more complete result. Images can be used for additional measurements of details or degradation elements. This requires the creation of orthoimages from the images acquired, using the appropriate photogrammetric software (Vaiopoulos, A. D., 2012). Moreover, images and surfaces can be combined and fused, thus generating 3D texture models, providing in this way a far better virtual representation of the objects. It is strongly recommended that 3D data acquisition, as described above, should be carried out within a rigorous reference framework established by accurate surveying techniques.

Given that the GCPs were used with an accuracy of less than ±1 cm and based on the image orientation results, the accuracy of the final orthoimages is estimated to be in the order of 1 cm. Finally all orthoimages were combined together to form the orthophotomosaic of the vault system.

A critical point, which calls for special care, is the creation of the DSM from the point cloud. The removal of the noisy data and the editing of the TIN where necessary, in cases e.g. of flipped triangles and holes due to occlusions of the laser beam, are absolutely necessary for obtaining orthophotos without "floating" pixels, especially when the object has complex surfaces, such as the stucco decorations, with many different reference planes.

The vaults are also unique as far as their construction is concerned, as the first two of them have a mirror shape and the third one is positioned lower than the other two and has a different shape, as shown in Figure 2.

Figure 2. (Up) Horizontal section of the laser scanner points cloud; (down) symmetrical horizontal level curves of the two vaults that cover the nave.



3.2 Geometry and shapes analysis of the vaults to interpret the construction technique

The accurate 3D survey of the entire church allowed to analyse and interpret in detail the geometry and the morphology of the structural elements, focusing in particular on the three spherical vaults that cover the nave. Because of lacking of historical data related to the exact age of construction of the vaults, apparently coeval, a detailed structural analysis of their shapes could help in the identification of analogies and differences between them and in the validation of historical phases of construction. Those information suggested hypothesis on the different period of construction of the three vaults, all decorated in the same period (XVIII century), concealing the different shapes and dimension of them.

The three vaults are spherical vaults, geometrically originated by ellipses with their foci close together (Figure 4). The ellipse that generates the vault in the chancel is different from the other two, confirming that this part was added in a different historical phase (XVIII century) compared to the nave (probably XVI century); in fact we know that the chancel was added during the Carloni's transformation in XVIII century (Vincenti, A., 1975) (Monti, M., 1895), together with the addition of the decoration and paintings of the three vaults.

In particular it's possible to observe a significant similarity between the shape of the first and the second vault of the nave: both of them present very recognizable deformations along the longitudinal and

Figure 3. Contour lines extracted from laser scanner points cloud of the two vaults with the indication of the bricks texture (square disposition).

cross sections, that at a first glance appear mirrored in the two vaults (Figure 2). Also while extracting from the point clouds the contour lines, this deformation is recognizable as a kind of stretching of the curves in the cross direction. It is interesting to observe that the curves approximate both a circle and a rectangle, but they are not sufficiently defined by any of these shapes. Rotating the lines of the second vault for 180° and superimposing them on the lines of the first vault, is possible to notice that they follow really similar curves, as visible in Figure 3.

These considerations support the hypothesis that a single centring was used for both the vaults: after the realization of the first one, it could have been removed, rotated and placed in order to build the second. This could explain the symmetrical disposition of the deformations in the vaults.

Observing directly the extrados of the vaults, even if they are covered by a thick layer of mortar and rubbles, it was deducible the arrangement of the bricks. They unload their weight on the arches and walls, and the courses of bricks meets along the diagonals, behaving like a cross vault. Such texturing explains the strange shape obtained by the laser scanning contour lines (a mixed circle-square), not perfectly fitting on a circumference, even if they are spherical vaults (Figure 3). The deformations of the vaults could find their origin in this peculiar way to arrange the bricks, or in a deformity of the centring, caused by an executive mistake. It is significant to notice that the decoration apparatus, created by the Carloni (Figure 1), followed a logic that goes against the architectural one: the frescos and stuccoes are repeated in the same scheme in the first and third vault(schema A-B-A), while the second presents a different style (Colombo, S., 1997).

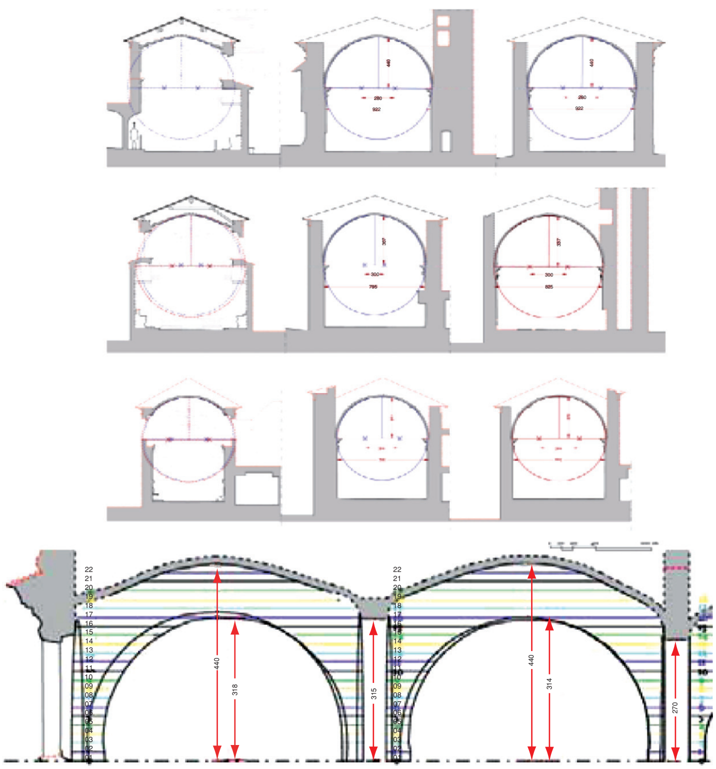


Figure 4. Geometrical analysis of the three vaults using cross vertical sections.

This kind of decorative solution could be interpret as an attempt to stylistically modernize the oldest plan of the church, according to new architectural manner of eighteenth century.

3.3 The construction of the 3D model

The BIM model of St. Maria in Scaria has been faced as the last step after the various analysis, following the survey and the historical research. From these analysis many considerations were sprung, especially focused on the achievement of a stratigraphic study that considers the changes undergone by the church though the centuries (Figure 5). These transformations involve the architectural structure as the finishing layers, and their studies are still open and liable to be deepened.

The BIM logic has been considered appropriate to comply with this request of representation flexibility, in order to be constantly implemented and updated, satisfying the demand of continuous transformation of the model. In fact, the logic of the object-against the cad one, made of lines and surfaces - can keep in a single representation a stratification of information that go from the materials to the structural or energy aspects. That requires the object to be divided into its different structural and functional parts; for example, in the Figure 7 it is possible to notice that the intrados of the vault (blue colour) must be filtered from its decorative stuccoes, in

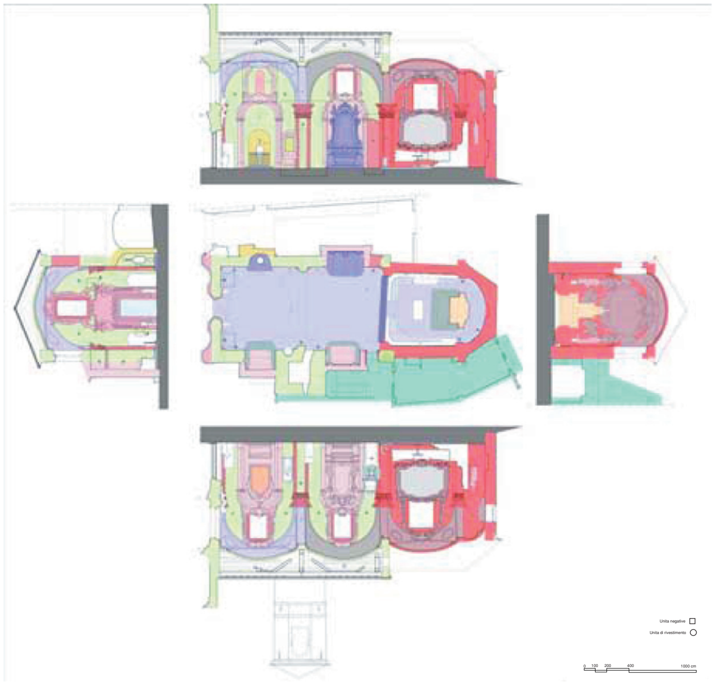


Figure 5. "Box system" representation of the different constructive phases of the building (stratigraphic analysis).

Figure 6. Historical transformation of the church: the different colours represent the different constructive historical phases.

Cent.XV	?? First fresco cycle Bell tower?
Cent.XVI	?? second fresco cycle
1593	Pastoral visit of Como's Bishop
1599	First statement about baptistery's recess
Cent.XVII	?? cloister in the facade? Main altar
1635	Statement about the presence of Genovesi's chapel
1708	Start works in the choir
1710-11	End building new walls + choir's roof
1718-20	Start works in the sacristy
1721	Start nave's walls works
1724-26	Chancel's decorations
1741-46	Facade decoration, statues' positioning
1740-50	Chancel's transformation
1752	Still not relized painting in the chapels, chancel's walls frescos, decorations in first and second spans
1753	Completed church's floor,realized vault's frescos in first and second spans
1754	Completata baptistery's floor, end works in Crocefisso's chapel
1757	Chancel's step and balauser
1764	?? end "Virgin's coronation" frensco (second span)
1772	Roof completed, marble steps placed at the altars, main altar and bapistery adjusted
1775-1800	End of works: roof, facade, sacresty, wooden door finishes, pulpit adjusted
Cent.XIX	Genovesi's chapel and baptistery's gates
1963	Demolition old parish house + built new one
After 1975	Latest restoration interventions

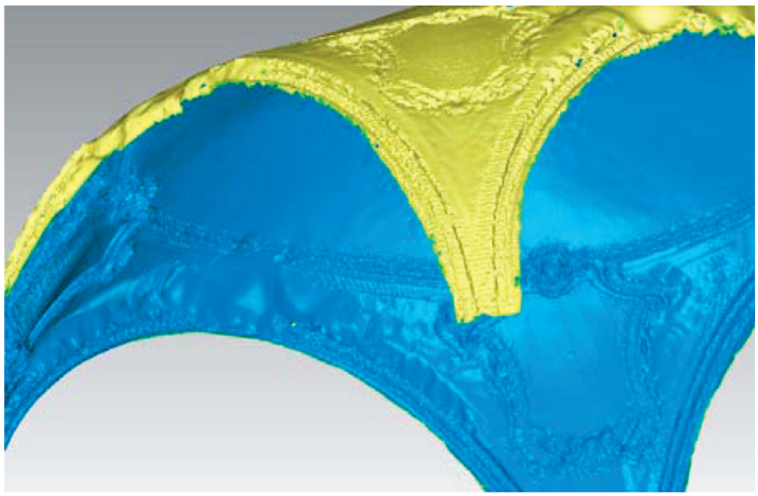


Figure 7. Vault dtm extracted from laser scanner points cloud.

order to obtain the geometry of the masonry and to generate the different model object.

An example of the possibilities offered by the BIM model could be the future Museum of Scaria, next to the church, to which the model can be offered to show to the visitors, in an immediate and intuitive way, the complexity of the little church: the BIM, availing its object, characterized also by the historical phases, becomes a divulgation and knowledge tool, suitable for all. The choice has been the object modeling with families, subdivided into structure and decoration apparatus, to consider the differentiation of the various elements.

3.4 The model for historical data interpretation and dissemination

In the matter of the obtained results, we show the examples of the vertical bearing and the horizontal pushing structures: the families of irregular walls, vaults and trusses have been generated. The church, as the most of the historical buildings, is composed of not regular masonry, rich of many different stratigraphic parts. Excepted for the frescos, that were considered at a later stage, there were some old opening now closed (i.e. a window in the apse, a window over the baptistery, a closed arch next to the Crocefisso Chapel), juxtaposed walls (i.e. the walls of the Crocefisso Chapel) and parts of walls built in different period.

Because the database library of Autodesk Revit are lacking of walls suitable for the needs of this church, and there are not direct

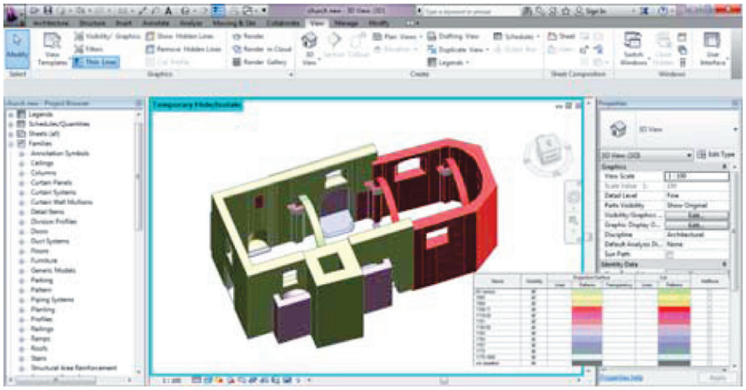


Figure 8. HBIM of the church with stratigraphic data related to the singular object.

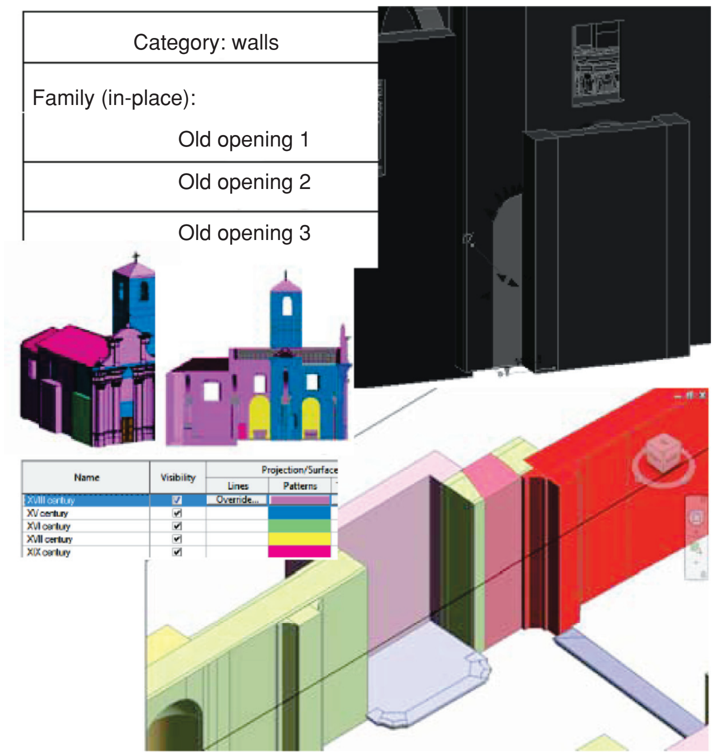


Figure 9. Details of stratigraphy represented in the HBIM of the church.

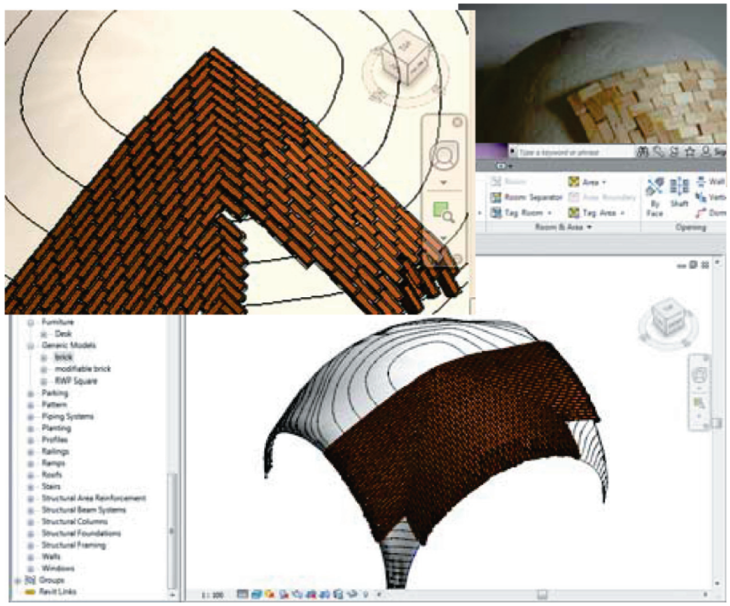


Figure 10. The disposition of the bricks on the spherical shape extracted by points cloud.

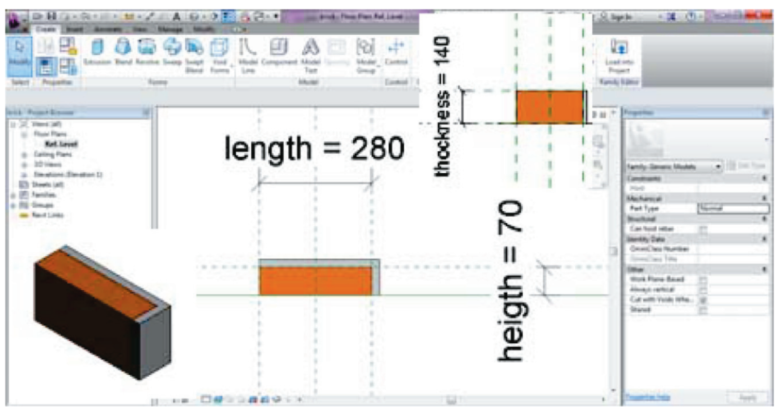


Figure 11. Creation of the bricks family an unit block.

commands for modeling non regular walls, it has been necessary to combine a regular wall of the project families with an irregular "layer", attached to it, that would consider all the deformations and openings (topographic surface generation tools are available but it doesn't generate a full object updatable by info). Every stratigraphic element has been modeled separately, in order to be characterized with the phase it belong, that can be visualized in the proprieties tab, as it is selected. It has been possible applying graphical filters, created *ad hoc*, that automatically change the colour of the objects, as the desired phase is inserted into the properties. The result is a representation that, through the colours, offers immediately the perception of the different transformation phases.

The information correlated to the object library can be changed in the future along with the growing of the historical research.

3.5 The model of the constructive technologies of the vaults

The modeling of the vaults had to face the irregularity of the geometry: a geometrical simplification to regular forms and the modeling with automated commands has not given a satisfying result. Firstly, working with the point clouds, has been necessary to clean the geometry of the vaults from the decoration apparatus, to obtain the horizontal and vertical sections with which to create a mesh. Over such surface, it has been arranged the bricks, modeled in its own family, with the dimensions surveyed on the extrados, with the aim to study the patter. The "vault" family, not directly modeled, identifies itself with the "brick" one that, through the parameters, can modify its dimensions, allowing, for example, to change easily the thickness of the vault, once measured by means of suitable tests.

3.6 The wooden roof object construction

Finally the roof has been modeled beginning from the vertical sections and plan represented (Figure 12).

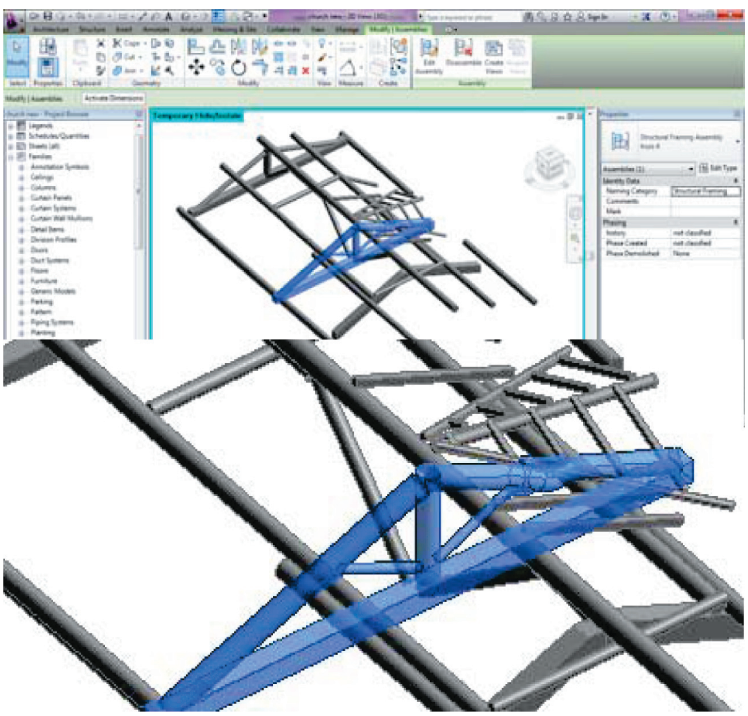


Figure 12. HBIM of the different wooden elements of the roof.

The trusses that constitute the roof has not been directly surveyed, but have been hypothesized after their simple observation. In addition to the trusses, the beams, the rafters and the purlins, the roof hosts some stiffening elements that are placed in correspondence to the centre of the vaults, connecting the beams and the trusses one to each other.

There is also a connecting element between the bell tower and the top of the roof, that allows the access to the attic. The timber pieces constituting the elements are irregular and often deformed: it is common to find expedients to fix the discontinuities, realized with little wooden pieces.

Moreover the trusses, in both the analysed cases (the only visible), present different characteristics. The trusses are the central one (between the vaults of the nave), and the one over the arch connecting the nave and the chancel.

Although the aim was not to show the ideal functioning of the roof system, but a representation more close to the reality and to the complexity of the roof elements, a simplification was required, at least about the regularity of the beams and the elements of the trusses, which deformations have been represented just in the main cases.

The parts (i.e. struts, diagonal beams) have been modeled as autonomous families ("structural framing"), after combined one to each other. Every modeled part presents variations of the geometry or cuts that have been obtained through void forms, and, where possible, the objects have been parameterized, in order to obtain the different types to be applied to the various situations (Figure 13).

The walls, the vaults and the trusses are clear examples of the cases in which the parameters and the project families, despite their utility and the advantages they give in modeling, are not enough to satisfy the complexity of the real structure, even if simplified.

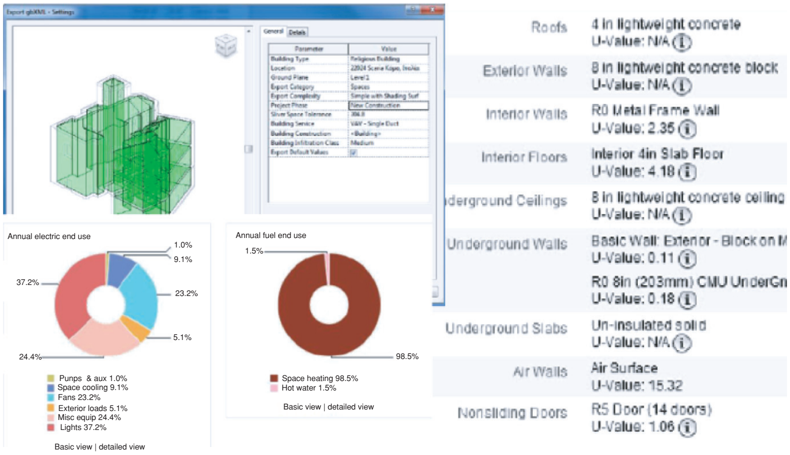


Figure 13. Model spaces and some parameters of the BPA, the related U-value and one of the Charts of annual electric and fuel end-use on the volume calculation.

4. HBIM and Building Performance Analysis for Energy Efficiency

One of the major advantages of BIM, that has affected significantly the way AEC industry works, is its ability to produce models that can be analysed from the standpoint of building life-cycle and energy efficiency. BIM and interoperability potentials can be applied to energy efficiency simulations of architectural data (Osello, A., 2011). With BIM it is possible to iteratively test, analyse and improve a building design. This procedure is called *Building Performance Analysis* (BPA). As it has been already mentioned, the BIM models contain both geometric information and semantic characteristics of the structure. Therefore it is possible to estimate life-cycle energy costs, annual consumption, but also potential energy savings by using design alternatives (Diaz-Vilarino, L., 2012).

One of the aim of the research was also to evaluate the potential of BIM models for energy analysis, using the appropriate tools for life-cycle building management and energy efficiency. The BPA performed in the case study of St. Maria church is a simulation with a lot of parameters, taken as assumptions just to start the process (Figure 14) (Figure15). This first energy analysis was performed with the integration of Autodesk Revit 2013 and Autodesk's web-based energy analysis software Green Building Studio (GBS), through *gbXML* format (Green Building Extensive Markup Language). GbXML is an open schema that facilitates the transfer of building properties, stored in 3D building information models, to engineering analysis tools (gbXML Organization, 2000).

The concept of making simplified model is based on some "rules" for the components that describe the Revit physical model, so that it is exported correctly like an analytical model. First of all the volumes of each room/space had to be properly determined with the appropriate *levels,* as well as their use: if i.e. a room was a rest room or a corridor and their occupancy. Then the materials of each element

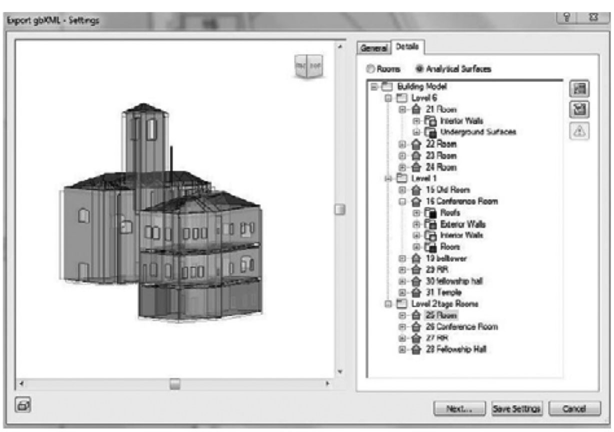


Figure 14. Preview of the model's Analytical Surfaces.

and their thickness were applied. In this case it was also decided to handle the church and the parochial house as a "building system", so this process was performed for both of them.

This simplified Revit model of the church and the parochial house was imported into GBS. There the location, the building type (Religious Building) and the schedule (i.e. working hours of the facility- worship) were determined. GBS offers many and different results, like annual costs and consumptions, end-use charts of water or electricity and potential facility to work with alternative resources (i.e. natural ventilation or photovoltaic).

That kind of results indicates the transition in connecting the "architectural" BIM models with the "engineering" ones, in an attempt to support and improve the decision making process in Cultural Heritage Management.

5. Conclusion

In conclusion, HBIM, in its deeper meaning of an interoperable instrument of geospatial Object/Data library, can represent a challenge with an high potential to be further investigated to strengthen a multidisciplinary approach in the historical building domain. Such approach, mandatory for the architectural heritage documentation and assessment (Stylianidis, E., 2011), is nowadays fundamental to avoid wasting all the precious information acquired during the surveying phases and gathering them - through BIM data structure - toward different design and management purposes: among all planned conservation, structural assessment and behaviour analysis. The logic model here obtained is progressively based on the generation of an HBIM object model obtained by the increasing potentials of laser scanning, photogrammetric surveying, and multimedia 3D virtual models (Remodino, F., 2009), adding the effort of generating them strictly related to the information taking in account, as an hub, construction technologies, materials texturing, relationship between the hierarchical object families and their elements, transformation, decay process, energy strategies and tailored energy efficient solutions for renovation of historic buildings.

According to this aim, when applying BIM to historical building (HBIM), some limits and barriers needing to be deeper investigated in the next future, with respect of the state of art of tools and exchange format.

Different level of simplification need to be better analysed to support structural finite element approach and geometric behaviour analysis (i.e. anomalies in the geometry of the vaults, irregular walls). This requests a more flexible functionalities by the BIM software, in the modelling of complex elements, not to lose the info-correlation capability of a true BIM object: infact, generating mass object based on the clouds thorough "Topographic surface" command, the output model is not a true object model, so no info can be related to it. To overcome such limits, many experiments are on course to model complex shapes, beginning to the profiles extracted by the points clouds (Pointools plug-in/Rhino, or Leica/Revit), in order to export more complicated historical elements, generates as real 3D objects. The process of importation of them within BIM environment (Revit, Archicad), without losing info on materials and texturing, volume calculation and so on, is quite complicated but it is necessary in order to obtain real parametric objects.

In the end, the research has shown the potentials of HBIM content modeling for the dissemination, to a non-expert public, of the information related to the history and the transformation of the church during the past centuries; one of the aim of the project is infact to make known the life of this unknown baroque church, within an European frame of skill exchanges (as is the case of Carloni's family of Scaria), that represents also a demonstration of the capabilities of *Magistri Comacini*.

Last, through the BIM objects libraries generated (Oreni, D., 2013), a territorial historical abacus can be progressively implemented, by the different users, on different case studies, allowing diachronic and synchronic analysis (i.e. the construction typologies, materials, texturing, location), through historicized geography atlas, within BIM-GIS environment.

6. References from Journals:

Chevrier, C. (et al.), 2010. Parametric documenting of built heritage: 3D virtual reconstruction of architectural details. *International Journal of architectural Computing*, 8, pp. 131–146.

Garagnani, S. (et al.), 2013. Parametric Accuracy: building information modelling process applied to the cultural heritage preservation. *ISPRS Journal of Photogrammetry and Remote Sensing*, 5, pp. 87–92.

Hichri, N. (et al.), 2013. Review of the "AS –Built BIM" approaches. *ISPRS Journal of Photogrammetry and Remote Sensing*, 5, pp. 107–112.

Murphy, M. (et al.), 2013. Historic Building Information Modelling. Adding intelligence to laser and image based surveys of european classical architecture. *ISPRS Journal of Photogrammetry and Remote Sensing*, 76, pp. 89–102.

7. References from Proceedings and Books:

Boeykens, S. (et al.), 2012. *A case study of using BIM in Historical Reconstruction. The Vinohrady synagogue in Prague,* Proceedings of the 30th International Conference on Education and research in Computing Aided Architectural Design in Europe, Prague, Czech Republic, 2012.

Diaz-Vilarino, L. (et al.) 2012. *As-Built BIM with shades modeling for energy analysis*, Proceedings of International Conference on Virtual Systems and Multimedia (VSSM), Milan, Italy, 2012, NJ, USA 2012, pp. 353–359.

Colombo, S. (et al.), 1997. *I Carloni di Scaria*, Fidia Arte.

Cooperative Research Centre for Construction Innovation, 2009. *National Guidelines for Digital Modelling*, Icon.Net Pty Ltd., Brisbane, Australia.

Eastman, C. (et al.), 2008. *BIM Handbook. A guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*, Jonn Wiley & Sons, Hoboken, New Jersey.

Fai, S. (et al.), 2011. *Building Information Modelling and the Conservation of Modern Heritage,* Proceedings of the 24th World Congress of Architecture (UIA), Tokyo, Japan, 2011.

Fai, S. (et al.), 2011. *Building Information Modelling and Heritage Documentation*, Proceedings of the 23rd International Symposium, International Scientific Committee for Documentation of Cultural Heritage (CIPA), Prague, Czech Republic, 2011.

Monti, M., Atti delle visite pastorali diocesane, vol. II, Como, 1895, p. 291.

Oreni, D. (et al.), 2012. *Towards a Methodology for 3D Content Models. The Reconstruction of Ancient Vaults for Maintenance and Structural Behaviour in the logic of BIM management*, Virtual Systems in the Information Society (VSSM), Milan, Italy, 2012, NJ, USA, 2012, pp. 475–482.

Oreni, D. (et al.), 2013. HBIM for Conservation and Management of Built Heritage: Towards a Library of Vaults and Wooden Bean Floors, (accepted for publication), CIPA 2013XXV International Symposium, ISPRS Annales 164, 2013, pp. 1–6.

Osello, A. (et al.) 2011. *Architecture Data and Energy Efficiency Simulations: BIM and Interoperability Standards*, Proceedings of Building Simulation, 2011.

Pauwels, P. (et al.), 2008. *Architectural Information Modelling for Virtual Heritage Application, Digital Heritage*, Proceedings of the 14th International Conference on Virtual Systems and Multimedia, Archeolingua, 2008.

Remondino, F. (et al.), 2009. *3D Virtual Reconstruction and Visualization of Complex Architectures*, 3rd ISPRS International Workshop "3D-ARCH", Trento, Italy, 2009.

Stylianidis, E. (et al.), 2011. *Introduction to Heritage Documentation - Best Practices and Applications*, CIPA XXIII International Symposium, Prague, Czech Republic, 2011.

Vaiopoulos, A. D. (et al.), 2012. *Comparison of 3D representations depicting micro folds: overlapping imagery vs. time-of-flight laser scanner*, Proceedings of SPIE, Earth Resources and Environmental Remote Sensing/GIS Applications III, 2012.

8. References from Other Literature:

Boeykens, S., 2011. Using 3D Design software, BIM and game engines for architectural historical reconstruction, CAAD Futures, Liege, Belgium, 2011.

Lee, G., 2006. Specifying parametric building object behaviour for a building information modelling system, Automation in Construction, Elsevier, 2006, 15, pp. 758–776.

Tang, P. (et al.), 2011. Automatic reconstruction of as-built building information models from laser-scanned point clouds. A review of related techniques, Automation in Construction, Elsevier, 2011, 19, pp. 829–84.

Vincenti, I. (et al.), 1975. La chiesa di Santa Maria a Scaria Intelvi in Arte Cristiana, 616, 1975.