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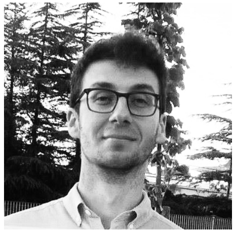

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Measurement and Historical Information Building: challenges and opportunities in the representation of semantically structured 3D content

Misura e Historical Information Building: sfide e opportunità nella rappresentazione di contenuti 3D semanticamente strutturati

The possibility of applying the BIM approach is an interesting challenge in the framework of 3D modelling and management/enhancement of historic buildings, especially high cultural and architectural value. A big challenge in reality-based modelling is to develop simple methods to get HBIM models for cultural heritage, that guarantee accuracy, precision and quality of representation compliant with the acquired data. The present work, dealing with two cases study, highlights the feasibility of a whole approach and opens the way for the development of centralized HBIM that can be used as complete data set of information on all disciplines, in particular for the heritage restoration and preservation, but also for its dissemination and exploitation. Similar methods facilitate the HBIM diffusion for the management of survey and restoration processes of historic buildings.

Nell'ambito della modellazione 3D e nella gestione degli edifici storici, soprattutto se di elevato valore culturale e architettonico, l'utilizzo del BIM costituisce ad oggi una interessante sfida. In particolare nella modellazione reality-based è utile sviluppare metodi semplici ma che garantiscano comunque accuratezza, precisione e qualità di rappresentazione coerenti con i dati acquisiti. Il presente lavoro mira a dimostrare la fattibilità di un approccio HBIM globale, presentando e comparando due casi studio. I risultati mostrano di aver ottenuto un vero collettore di dati e attributi significativi per la conoscenza e la conservazione dell'architettura storica, generandone una condivisione facilitata. Lavori simili facilitano la diffusione dell'HBIM per gestire il processo di rilievo e restauro delle fabbriche storiche.

KeyWords: semantic 3D; HBIM; quality assessment; survey data; data enrichment
Parole Chiave:*3D semantico; HBIM; valutazione qualità; rilievo; arricchimento dati*

INTRODUCTION

The possibility of applying the Building Information Modelling (BIM) approach is today an interesting challenge in the framework of 3D modelling and management/enhancement of historic buildings, especially high cultural and architectural value. BIM is widespread for new construction or even for existing one, in the case of modern buildings, ensuring to control all stages of the life cycle. An open question is rather the integration of BIM systems and databases applied to the historical and architectural heritage, to enable the creation of low-cost and interoperable systems of knowledge and 3D management.

A big challenge in reality-based modelling is to develop simple methods to get BIM models for cultural heritage, that guarantee accuracy, precision and quality of representation congruent with the acquired data. This paper aims to demonstrate the feasibility of a comprehensive approach in BIM environment, even for complex architectural forms, starting from terrestrial laser scanner acquisitions and traditional survey.

A strong point of the method is to work in a 3D environment throughout the process and to develop the semantics of the model during its construction phase. The semantic structure of the model and its parts, an essential feature for a HBIM, will be analysed in the present work by verifying existing ontologies and conversion protocols and possibly proposing specific classifications. This will allow the enrichment of the model with non-geometric data and information, such as historical information, analysis of the degradation and other drawings at levels of detail not granted by the complete model.

The paper presents similar approaches for two cases study, different for quality of survey data, for the characteristics and intrinsic complexity of the architectures but also for the nature of data to be collected.

STATE OF ART

Cultural heritage sites and our valuable and historical architectural heritage need high-resolution 3D models to achieve a significant added value from their digitization. These models are increasingly available thanks to the rapid technological progress in the field of acquisitions and methods based on laser scanner and / or photogrammetry (Barazzetti, Fangi, Remondino, & Scaioni, 2010). Some authors contributed to build a robust state of the art in laser scanner acquisition and use of laser data for architectural analysis (Bianchini & Senatore, 2011) also taking advantage of the point cloud as a complete product (Clini, Nespeca, & Bernetti, 2013). Others have been working on developing digital models for the historic architecture, especially focusing on the acquisition and three-dimensional metric control of the models in 3D geo-database (Gaiani, Apollonio, Clini, & Quattrini, 2015) or web-based platforms (Battini, 2009).

The latter perspective has opened the debate on the 3D GIS and semantics of the models: this concept, inoculated in the BIM philosophy is definitely to be strengthened when dealing search for HBIM. In fact, the use of BIM force the semantic construction of the digital model, not only as a means to generate the three-dimensional structure, but as a cognitive system (Apollonio, Gaiani, & Sun, 2013.)

Since the standardization of procedures for BIM modelling of historic buildings is considered still a challenge, many works have been recently concerned with the creation of parametric libraries for historical architecture and the validation of methods for fast and efficient modelling of facades buildings (Dore, 2014) or whole buildings (Oreni, 2014) (Quattrini, 2015). Some studies have focused on the definition of the most appropriate levels of detail (LOD) (Fai, 2014), others on the automatic extraction of features (Barazzetti L. B., 2015). In literature HBIM modelling shows in the majority several steps and two-dimensional simplifications: all the adopted workflows use different software for the necessary format conversion. Interesting developments, especially for archaeology and classical and renaissance architecture, are those obtained considering the similarities between the three-dimensional structure of a BIM and conceptual constructions (Apollonio F. I., 2012). These are particularly relevant especially for the study case related to Palazzo Ferretti, presented here.

The BIM approach is very powerful for modern buildings, being now able to monitor and manage all stages of the life of the building. A comprehensive investigation (Volk, 2014) on the use of BIM for new or existing buildings (Figure 1), demonstrates the existence of challenging opportunities that result from process automation and adaptation of BIM to the needs of existing buildings, thanks to the rapid development of platforms and dissemination of standards that guarantee interoperability.

The realization of HBIM, not only related to existing heritage but dealing with all relevant information, is allowed today by almost all of the platforms of the most common BIM authoring softwares. They ensure excel-

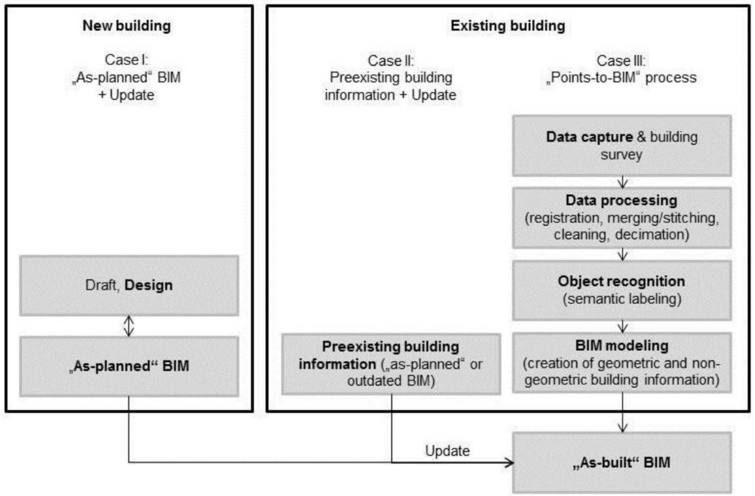

Figure 1 BIM creation for new or existing buildings, from Volk, 2014 (see reference list)

lent compatibility with all 3D formats coming from survey, enabling a phase of representation and management of components and geometries. New research and contributions would still be useful, in interdisciplinary teams, for the creation and sharing of ontologies dedicated to historic architecture in the proper identification and representation of objects that constitute the model. Several tools (owl / semantic web / xml / bimQL) are spreading that allow you to edit, write and display the data enrichment (Wiet & Beetz, 2013).
Data exchanges are possible both directly and through formats (proprietary or not). In particular IFC (Industry Foundation Classes) is the dominant non-proprietary format of industry of the buildings. It was developed to facilitate the transfer of data between software of BIM modeling (such as Autodesk or Bentley), the viewer IFC and software applications in other fields and specializations (Schevers H., 2007). Exchanges of data between the source and the receiving software and the interoperability of BIM products at different phases are still limited due to incomplete or ambiguous translations. Most of the applications are still limited to research and academic community.
In general, the horizon of research within HBIM field are the development of the whole pipeline of the management of architectural products, within a centralized and parametric single environment: from the survey and studying phase to the construction, restoration and/or maintenance phase, being able to create preconditions and drawings for communication and valorisation of the built heritage, even in virtual and/or augmented reality (Figure 2).

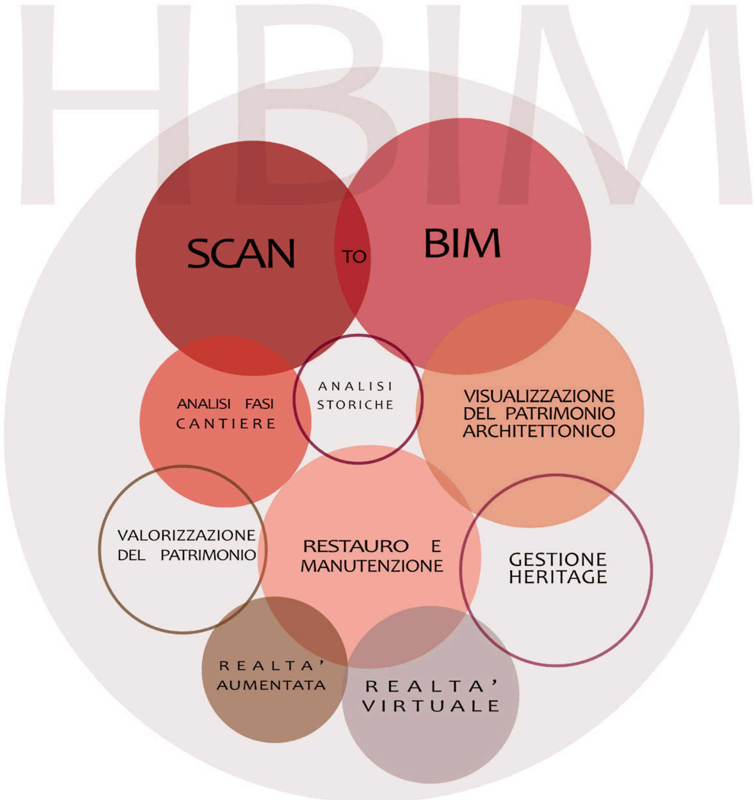

Figure 2 HBIM approach: towards a centralized management of idata from survey/analysis to modeling, conservation/valorization

FROM SURVEY TO HBIM MODELLING

The term HBIM (Heritage or Historic Building Information Modelling) means a new approach to the modeling of historical buildings, aimed at developing BIM models from survey data "remotely sensed" (Murphy, McGovern, & Pavia, 2009). This definition indicates the accuracy centrality of 3D restitution as well as the adherence to the intrinsic characteristics of the architecture that through the HBIM model you want to manage. In light of this approach, two case studies are presented and analyzed in this article: on the one hand, the modelling in BIM environment of the Church of Santa Maria di Portonovo starting from the point cloud model, on the other hand the model of the Renaissance wing of Palazzo Ferretti in Ancona, obtained in Revit from TLS (terrestrial laser scanner) documentation and previous 2D survey. In the first case, the main objective was to ensure the best geometric quality of HBIM model without losing the accuracy of the initial survey. To validate the model a comparison between the model and the point cloud was then carried out, obtaining very satisfactory results. The evaluation of the overall model quality is followed by the verification of the hypothesized ontologies in modelling phase.
The second case is represented by a classic building so, in addition to the overall coherence of the BIM model with geometric data, it enables to investigate a process of representation of classical mouldings through parametric modelling. Only in this way it would be possible to create a model in BIM environment respectful of the main features of the building and that would help enhance correctness of reading. In this case, therefore, special attention was paid to the analysis of orders and forms of decorative elements, applying geometry and hierarchy in compliance with the treatises.

THE CASE STUDY OF SANTA MARIA DI PORTONOVO

The laser scanning survey of the church of Santa Maria di Portonovo was performed with the Leica C10 laser scanner with 34 scans and 33 stations. The scans were then manually aligned cloud to cloud and through the ICP iterative algorithm to obtain a final cloud of 416

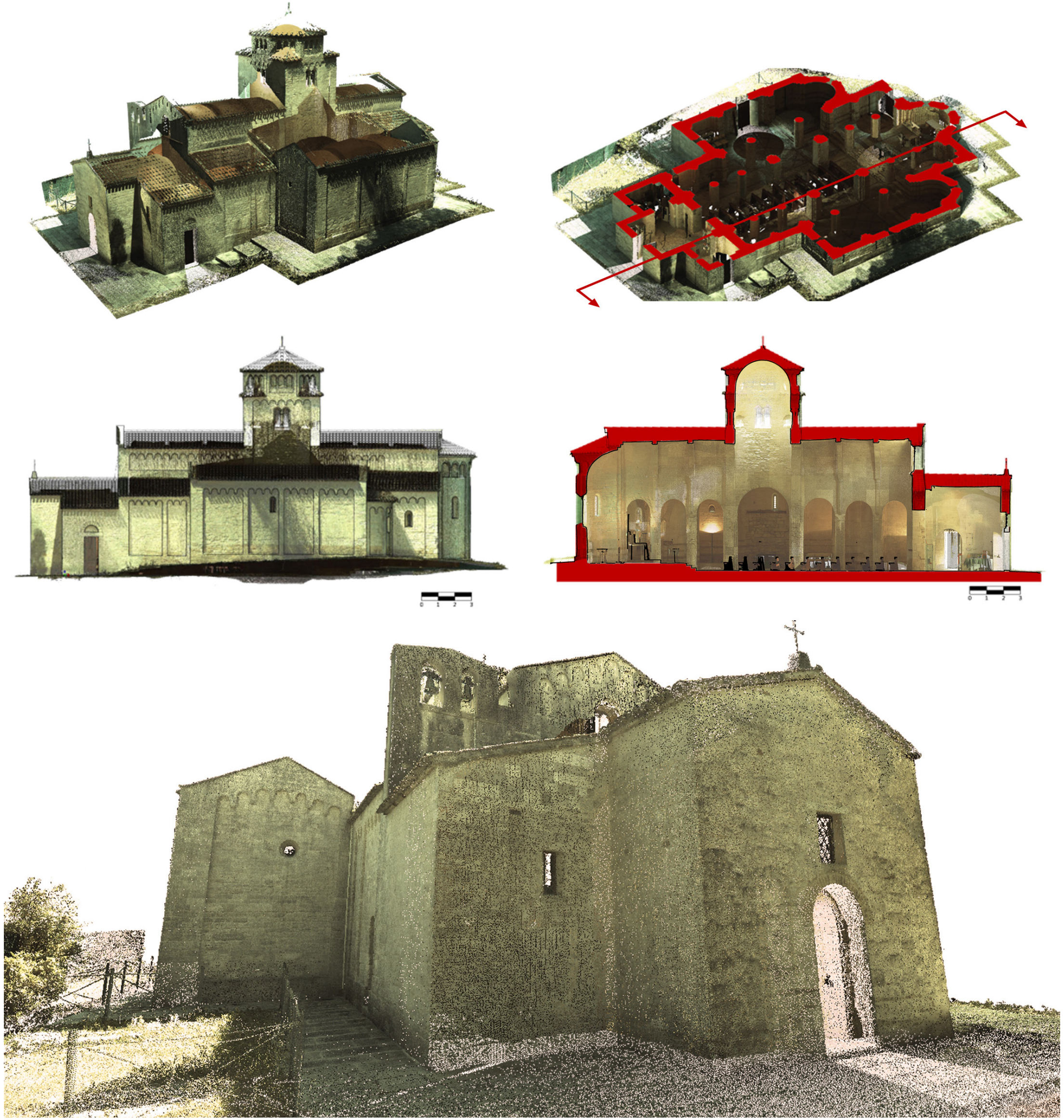

Figure 3 TLS survey of Santa Maria at Portonovo Church

mln points with a standard deviation (RMS) of 0.01 m (Figure 3).

The 3D point cloud, after the cleaning and decimation, has proved to be an excellent starting point for the case study, without errors or significant lack of data: this database is able to provide all the information (geometry, material and colour) for the further BIM development. A first challenge is to avoid an over-simplified model in relation to the actual morphology of the objects. In fact, when the components are generated from existing morphologies, remarkable abstractions in BIM models must be introduced. In order to verify the reliability and ease of use of a method for point cloud processing with high accuracy in a BIM environment, we have developed a procedure for the whole architectural complex of Portonovo in Revit 2014.

Our approach builds up the model directly in place on point clouds, minimizing the number of steps, avoiding to lose accuracy, data quality and details. Revit, thanks to the built-in ReCap tool, shows also the cloud of points in each view. In this way it is not necessary to simplify the building with slices from the point cloud (Figure 4).

Some objects are created using the basic controls of the Revit menu. Others were created externally as *rfa families and then imported into the model. The most complex elements have been modelled within the software through B-rep operations. In addition, for some elements were created parametric objects that can be reused for similar architectures.

The measures are extracted from the point cloud and the 3D model was built in millimetres, according to the coordinates system of the point cloud.

The walls are created with the “Architecture” tool. Along the outer perimeter wall there are several niches, typical of Romanesque architecture, built as a local family and obtained as hollow extrusions.

Some elements were also parameterized, for example the parameters of height, the size of the base and the stem and the number of offsets (with the relative thickness) have been assigned to the columns. This is a very important parametric element for the medieval architecture. This procedure opens a further development: the connection of the proportions between the elements already modeled. Even the basics and the torus have been shaped externally as new families.

The morphology of the capital is quite simple becau-

se it is a block cusion capital, typical of Romanesque architecture. We chose to model it with the “Pillar metric” family like a truncated pyramid with a square base to which we subtracted four balls on the corners of the lower base.
The ribbed vaults show several problems in the modelling process; for this reason we decided to split the vault and the rib and then link them with the Protégé plugin.
The arches and the ribs were modelled by “mass” family, which allowed to change the contour lines. In this way we created circular arches and vaults. The barrel vaults were obtained by “Special equipment” subtracting each other two full vaults.
A very strong point was to obtain a good geometry to described the cross vaults because they have a non horizontal generator and the directrices are not perpendicular. The algorithms that manage the intersections within the Revit software are not able to perform these irregular shapes. To solve this problem, four full solids and four subtraction solids, as cutting solids, were made, but we observe some artefacts due to errors in Boolean operation. Since we were not able to parameterize this type of vaults, they have been adapted to each span.
To create the 3D model, a first semantic partition has been made using families and Revit classes: the family refers to models with unique parametric structures and it can consist of a set of classes with different size; the single piece is called instance. In the second phase we studied the relationship between instances and classes; the relationship can be horizontal or hierarchical.
The ontology of the church, which is the conceptual system of information related to the geometric model, is a precondition for information relationship, such as the construction rules of the vaults, the types of ribs, the different decorations of the capitals. The various data were graphically assigned to each element (Figure 5).

THE CASE STUDY OF PALAZZO FERRETTI

The BIM modelling of Palazzo Ferretti in Ancona has been made possible thanks to the considerable amount of data collected in collaboration with the National Archaeological Museum of Marche , especially during the didactic activities of the Survey of Architecture course (A.Y. 2014/2015).
The entire laser scanning survey operation was carried

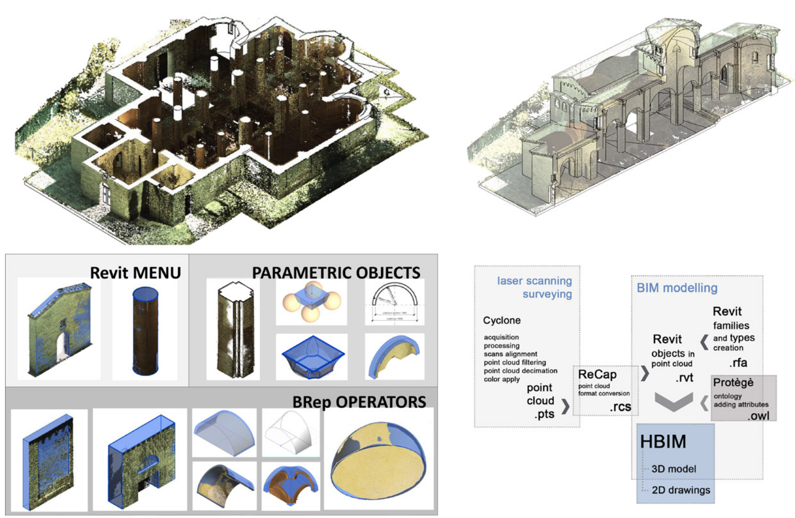

Figure 4 HBIM modeling phase in sw Revit. The object mapping in point cloud, some parametric objects and the workflow for modeling and semantic management

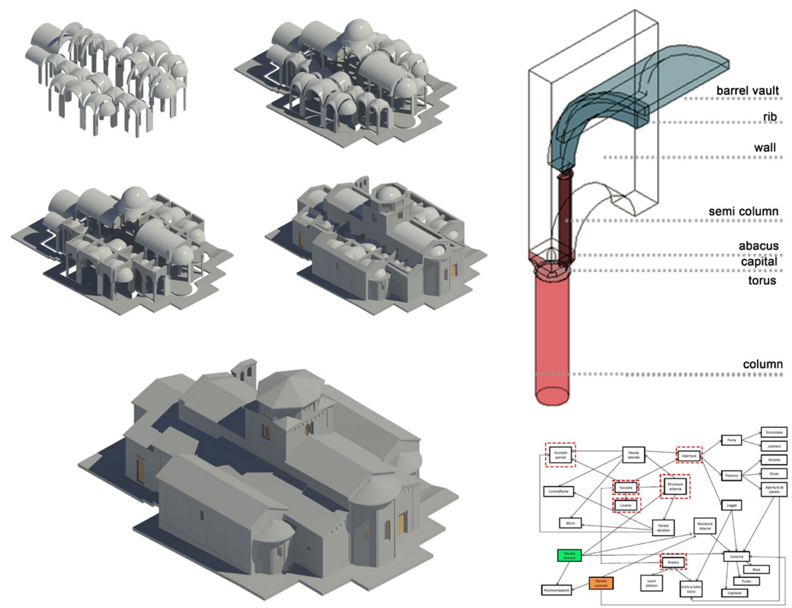

Figure 5 Semantic segmentation of HBIM about Portonovo Church

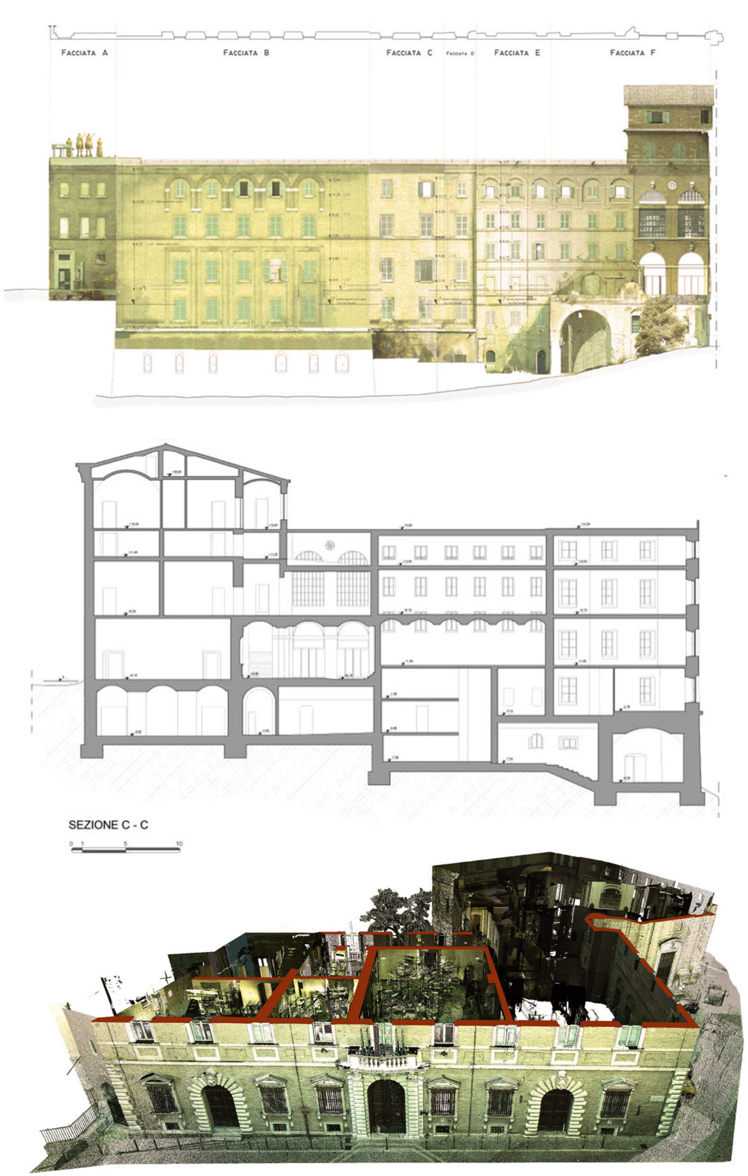

Figure 6 Survey from scanner laser of Palazzo Ferretti: ortographic view of point cloud regarding west façade, cross section and perspective from the point cloud model

out with a total of 69 stations: 49 stations (58 scans) for the external survey of the building and 20 stations and scans for the inner survey, that includes the ground floor and the first floor. These scans were set to a resolution of 1 cm at 100 m and 0,5 cm at 100 m in that parts where we decides to have a more dense point cloud to obtain a greater detail. The final point cloud obtained by the alignment of the clouds of all the 78 scans is made up of 1.2 billion points. This cloud is then cleaned of all the parts unnecessary for the survey and for the study of the building. For the alignment of the external clouds we used artificial targets for a first automatic alignment and subsequently we used surface matching algorithms, in particular the ICP algorithm (Iterative Closest Point) (Figure 6).

For the first part of modelling in Revit we chose to focus on the Renaissance wing of Palazzo Ferretti, which is the portion with the most prominent coverage by considering we had inside scans only for the Noble floor of that wing.

Palazzo Ferretti was built around 1560 on commission of Count Angelo di Girolamo Ferretti. Although the drawings seem to have been provided by the great architect Antonio da Sangallo il Giovane in 1540, the palace was built twenty years later by Pellegrino Tibaldi, who was also entrusted with the complex decoration of the building, the construction of the elaborate carved wooden ceilings and paintings. Starting from 1759 the palace subjected to massive expansion works, the design of which is due to the architect Luigi Vanvitelli. The building has undergone several restorations in the early 50s as a result of air raids and in the 70s and 80s as a result of the earthquake of '72.

In a first step we assumed to follow the same modeling procedure applied to the previous case, that would permit the control of the 3D cloud environment and without the need to have proprietary licenses for the management of point cloud formats. However, the limited computing capacity available to trainees involved in the modelling phase have forced to use two-dimensional drawings, which were at least made congruent with the global nature of the laser scanner survey.

The modelling in Revit environment to the scale of the building (Figure 7) highlighted some complexity especially in the case of not perfectly orthogonal walls and in the need to define a several reference planes, because of staggered internal levels and presence of valuable ceilings. The most onerous phase, however, has involved the mouldings of the main façades with the realization of loadable families (*.rfa) for which have been studied semantics and geometric constraints coherent with the practice of building and with the rules of the treaties (Figure 8).

ANALYSIS OF RESULTS AND METHODS

The qualitative and quantitative evaluation of the accuracy of 3D BIM of Santa Maria di Portonovo was performed with the open-source software CloudCompare, using the point clouds as reference.
The entire model was compared and has deviations lower than 9 cm for a value of 86%, reaching a level of precision with deviations of less than 3 cm for a value of 63%. These results are sufficient, considering that are included in the calculation of the average even elements without definite reference planes (such as the roofs) or noise elements (such as vegetation). In order to refine the results, we have segmented point cloud and model. Another way to improve the comparison is to set a maximum distance for the calculation, but this would not give back punctual considerations related to the semantic structure.
Then the model was divided, according to the families in which he had been constructed, in different categories (eg.: columns, pillars, cross and barrel vaults, ceilings, walls, roofs, etc.) for their focused evaluation. Columns and vaults are adequately modelled (with the average distance of 0,05 cm and 0,01 cm). The dome, having suffered deformations, shows higher deviations (mean distance 6,4 cm) than the model with ideal generatrix. This deviation may also occur in CAD modelling, if you do not use procedures of reverse modeling. The obtained analysis is also a typical pattern of deformation, able to describe structural or kinematic damages. It could be related to geometry as attribute of the instance in BIM and it could become useful for all users of the model.
The major differences are the modeling of the blind arches of the apse, due to the lack of primitive curves in B-Rep subtraction operations. The numerical results are shown in table. The overall average distance is 1,5 cm, in other words we get good quality results for a high percentage (Figure 9).
For the second case study, a qualitative assessment was again conducted within CloudCompare (Figure 10) but without expecting high precision, given the awareness of the fragmentary nature of the adopted production pipeline. The results are still satisfactory. The average distance between the BIM model and the point cloud of the entire Palazzo Ferretti is 1 cm, with a 16 cm standard deviation (σ), excluding from the calculation all the elements of the cloud not modelled in BIM environment. A further comparison focused on the east elevation was performed obtaining an average distance of 4 cm and σ of 7 cm.
At this stage, the most significant results for Palazzo Ferretti concern, as already said, the realization of parametric libraries for the external and internal building mouldings.
In fact, we have defined all the windows, the door frames and boss, the triumphant balcony and all frames, with their basic elements and semantically connected thanks to the nomenclature of the parties and to the inherent structure in Revit.
This is a first nucleus of a typical ontology for a Renaissance building at different LOD. It is also in progress the treatment of families and export to IFC (with encodings IFC 2x2 and IFC 4x4) to check the maintenance of the data structure and the compatibility with other descriptors. This will allow to evaluate the interoperability and the ontological accuracy of the model exporting to IFC format and analyzing the output file in order to detect inconsistencies or data loss when moving from different work environments. The goal in fact is to have a source file that is accessible to users of different platforms, easily editable and viewable, capable

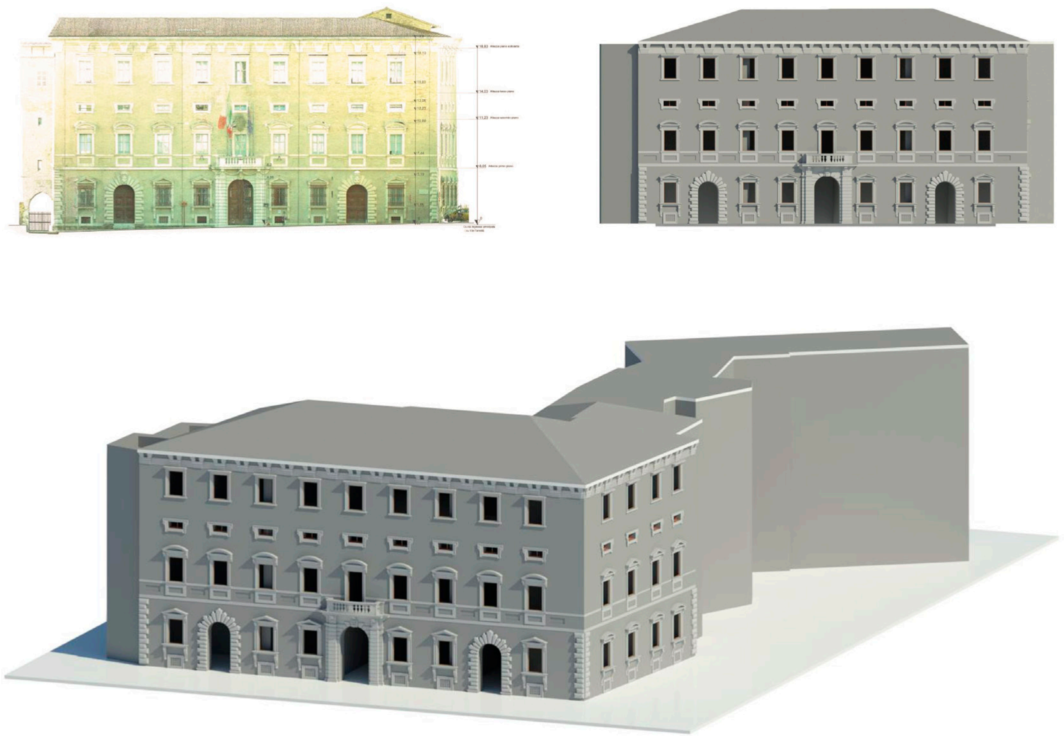

Figure 7 HBIM of Palazzo Ferretti, fronts from TLS and model, axonometric view (ray-tracing) from Revit

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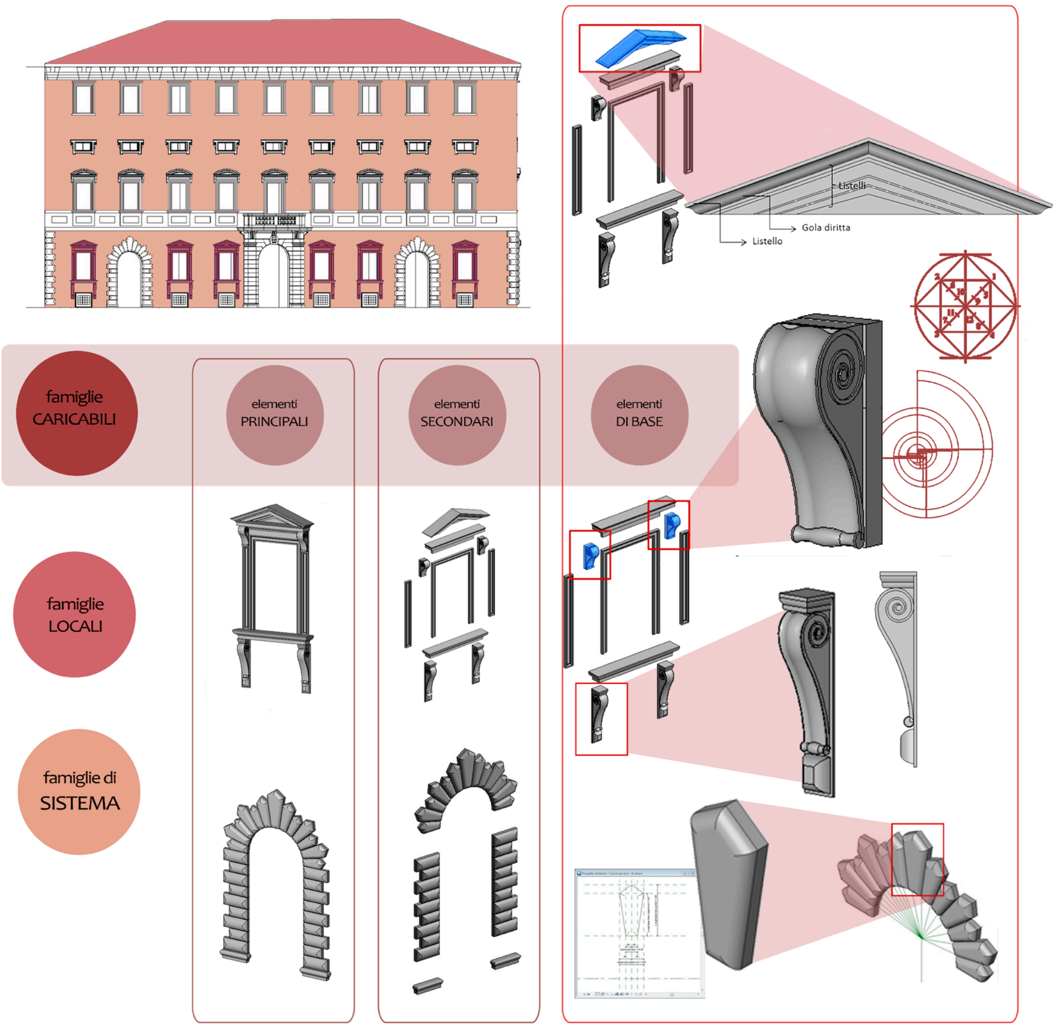

Figure 8 Parametric modeling through families: system, loadable and local.
For loadable families is highlighted the semantic structure and the compliance with classical rules

of transporting metadata (so information) enriching the same in the transition between different operators with different skills and specializations.

CONCLUSIONS AND FUTURE WORKS

The work here presented shows that it is possible to develop high-quality and semantically structured (semantic-aware) 3D models that connect data from geometric survey with descriptive thematic databases, such as those concerning historical information, maintenance and / or restoration intervention and analysis of the preservation and structural functioning of the factory. This opens the way for the development of centralized HBIM that can be used as complete data set of information on all disciplines, in particular for the restoration and preservation of the built architectural heritage, but also for the dissemination and enhancement of the historic architecture.

The semantic structure of the model in BIM environment allows multiple types of data enrichment at the level of categories, families, types and single instances. The analysis on the interoperability ensures various possibilities of the model exploitation and usability on different platforms with the long-term purpose of management of digital cultural heritage.

The main goal, to date reached in the reported research, is a high quality of the 3D model, combining efficient representation procedures through Building Information Modelling with complex levels of detail, according to the measurement and starting from knowledge-based analysis. The resulting geometric precision will also ensure the congruent output of visualisation.

The visual quality and richness of representation are essential for detailed documentation and for each management strategy in BIM environments for cultural heritage. Only once these aspects are guaranteed, it is possible to develop coherent and efficient semantic structures, from a technical/software point of view but also for the description of the building. This enables management procedures to determine the correct LOD (Level of Detail - Development) of the 3D data and model.

Our work enables the full exploitation of the accuracy of the TLS, because the objects have been mapped on the point cloud in 3D environment, without slices. A specific goal of our approach was also to minimize the

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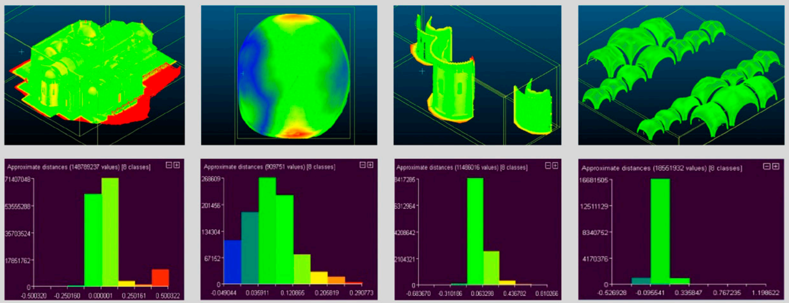
steps and format changes along the modelling process, to avoid the simplification or loss of information. The workflow obtained and validated shows some improvements compared to others in the literature.
We obtained a good procedure for the parametric modelling from laser data, verifying the adequacy and validating the process for two major monuments. The assessment of the quality of the BIM model gave very satisfactory results in both cases: either for the whole of the building that for single most significant elements. Two-dimensional drawings were also evaluated, extracted automatically from the Revit model: they are comparable to both the slice of the point cloud and to other 2D drawings previously used for restoration and documentation.
Another successful aim in our research is to obtain parametric libraries of architectural elements, starting from point clouds or from traditional direct survey.
The BIM models obtained open up exciting new challenges of research. To date they are used as a set of data that includes complete information and provides access to the management of the existing and potential simulations of various disciplines. For the future, we propose some approaches to be developed in this area:
a) the validation of the studied and realised ontologies, in application and management of interoperable environments for the semantic web, especially when we want to use linked open data semantic database for architecture and for its contents. This is the specific case of the development planned for Palazzo Ferretti model, which should allow access not only to the building information but also access to the digitized artefacts that it contains.



element	histogram		Gauss's Curve	
	D [cm]	%	D_{media} [cm]	σ [cm]
dome	-5<D<12	86	6,4	5,7
apse - niches	6<D<25	23	3,1	9,2
cross vaults	-9,6<D<12	90	0	6,7
columns	-3<D<6,8	83	1,1	7
	D<3	80	0,05	3
whole model	D<9	86	1,5	4,9
	D<3	63		

Figure 9 Quality assessment of 3D BIM about Santa Maria at Portonovo (sw. CloudCompare)

b) the development of collaborative BIM environments and augmented reality that today represents a standard for the visualisation of Cultural Heritage (CH) (Quattrini, Pierdicca, Frontoni, & Barcaglioni, 2016).
Recently, some studies are exploring the real-time communication between augmented reality and BIM environments for visualization and real time monitoring of sites and buildings. It is expected that augmented reality can perform this function effectively through the display of the BIM model in its physical context.
In conclusion, a new methodology to build a 3D model semantically aware for complex architectures has been here presented. Starting from point clouds from TLS, we got high quality HBIM models, we performed an assessment and we have created the preconditions for their semantic management. This research promotes the HBIM dissemination: thanks to the exploitation of the point cloud, BIM could easily become an environment in which to obtain technical drawings for the preservation of historic structures, including 3D documentation and orthogonal projections, but also collate all other information and analysis (Figure 2).
In general, summarizing the advantages that can be gained from BIM as those most related to the management of the building in its life cycle, although speaking of historic buildings the concept of "life cycle" is not appropriate. If we consider the dictates of the European Charter of the Architectural Heritage, in fact the cultural asset is "an irreplaceable expression of the diversity of cultures" and the aim of conservation disciplines is to "preserve the aesthetics and value of the monument" (ICOMOS, 1975). It follows that the elements that compose historic architecture are not only physical artefacts but are equipped with intangible values. These values are crucial to answer the questions "what", "why" and "how" to preserve. Necessarily we have to understand what might be an effective methodology to structure the information and which can be the information to be connect to the model and how to do this, evaluating each case. But the certain benefit of having a digitized and open system of annotation allows to get the opportunity to apply the concepts of good allocation of resources derived from an approach of "programmed preservation" (Della Torre, 2010).

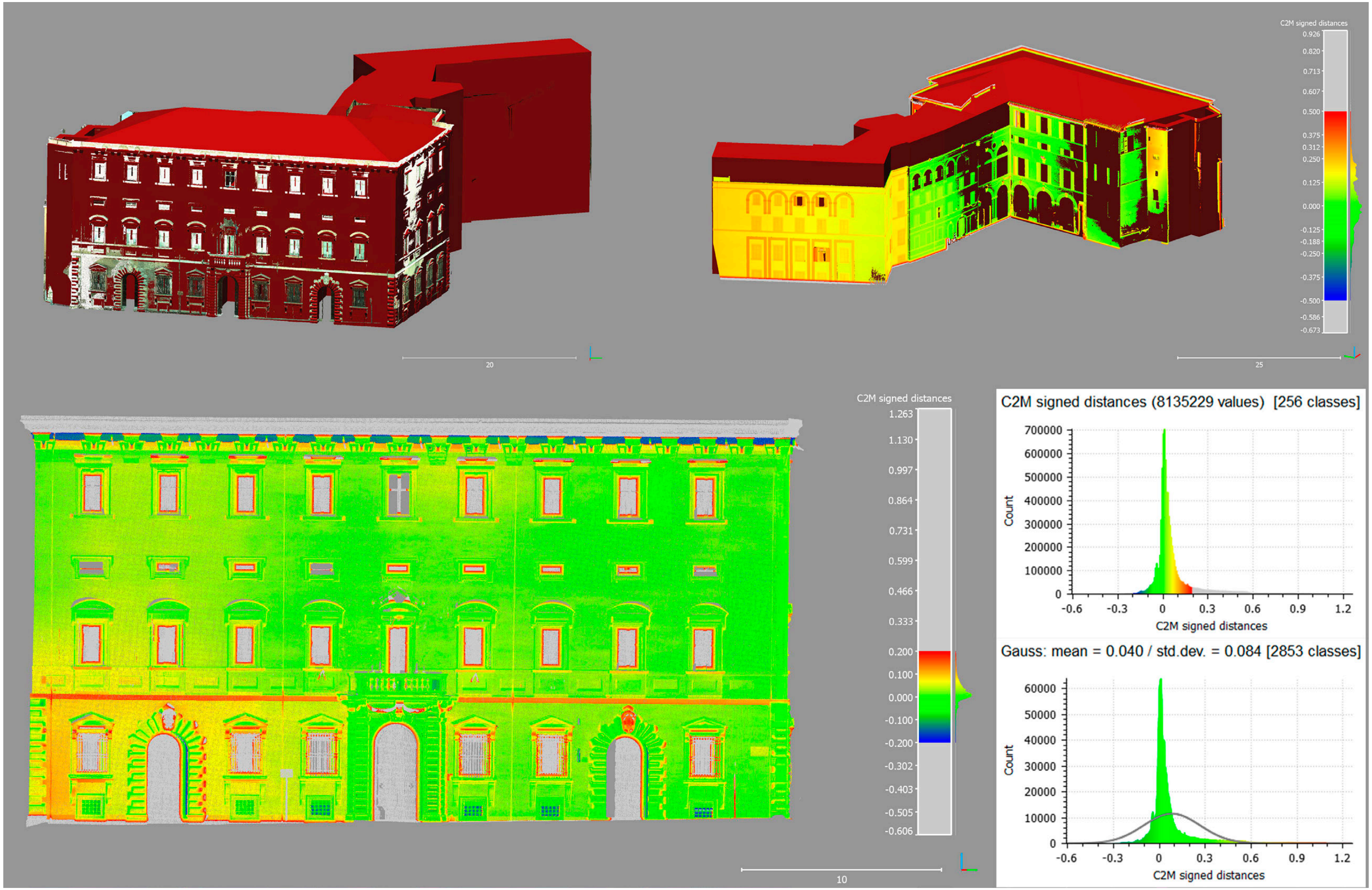


Figure 10 Quality assessment of 3D BIM about Palazzo Ferretti (sw. CloudCompare), also a qualitative assessment was carried out

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NOTES

[1] IFC is defined by ISO / PAS16739.

[2] The TLS survey was carried out in the Dep. Dicea from the technicians Luigi Sagone, Floriano Capponi and Giorgio Domenici, scientific responsible Paolo Clini. Acknowledgements are due to FAI (Fondo Ambiente Italiano) and Soprintendenza ai Beni architettonici e Paesaggistici delle Marche.

[3] The modeling phase of Palazzo Ferretti was carried out in training and degree thesis by Fides Carosi, Valentina Carducci, Vincenzo Danzi, Marco Mattioli e Maria Laura Pierpaoli, relator Prof. Ramona Quattrini.

[4] Authors we would like to thank Nicoletta Frapiccini, Director of National Archaeological Museum of Marche.

[5] Course of Architectural survey, Prof. Paolo Clini

[6] After the shapes creation, the geometries are linked to reference planes. The dimensions are connected to a label, giving the chance to add a parameter to the family. Each label can also be a formula, if you have constrains. According to the semantic, the number of parameters is decreasing if the family category is greater.

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