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SEMANTIC DESCRIPTION OF THREE-DIMENSIONAL MODELS OF BOLOGNA PORCHES

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Abstract

The study is part of a broader search coordinated by the Department of Architecture of the University of Bologna, the Cineca and the city of Bologna for the nomination of the city porticoes in the UNESCO World Heritage Site. The study describes, first, the problems and the methods adopted for the survey, the numerical modeling and visualization of the arcades models. In addition, the paper aims to describe a method for the semantic studying of the porticoes architecture and the segmentation of the models. The goal is also to establish an integrated approach to the semantic cataloguing of the Bologna arcades based on historical, material, formal, dimensional and theoretical data, and to make this information easily readable and communicable.

Keywords

Digital photogrammetry, 3D digital model, semantic structure.

1. *Introduction*

The representation of the Bologna arcades through 3D digital models offers several ideas for research on survey methods, taking care of the construction of architectural models, the structure to give them and the ways in which we can use them for informational and knowledge purposes. We can define, therefore, those methodologies and identify those technologies that allow the best and most effective use of these models and of the contents associated with them.

A *model* is an idea of the object, real or imaginary, that we want to represent[1]. In this sense, we can consider any two-dimensional or three-dimensional representation a model. Nowadays, thanks to information technology the possibility of model construction have expanded, surpassing also the scale limits of representation that were imposed by the drawing traced on paper. Compared with two-dimensional drawings and physical model, today you can combine three types of digital models: the parametric model (Apollonio, 2012), the numerical model and the mathematical one. Within the Bologna's Porticoes Project we used, especially the latter two types: the numerical model, a digital model consisting of polygons and vertices; the mathematical model, the model consists of continuous surfaces. The two models differ not only in the intrinsic qualities, namely the first is a discrete model and approximated while the second is a continuous pattern and accurate, but for methods which characterize them (Luciani & Migliari, 2009) and for the potential that they offer[2].

In the specific case of the Porticoes Project the numerical model is the result of a photogrammetric survey process, which is an interpretative model representing reality as objectively as possible (Migliari, 2004). The lower the degree of approximation and the closer the model will be to reality. This model, however, will always be an i*nterpretation* of the author. In a survey project it is, therefore, important to document as accurately as possible the method used and describe the data acquired. This will enable the scientific community to verify the data and re-apply the method described.

The mathematical model is generally used in applications where you want to design an object of industrial design or architecture or you want to

[1] Regarding the idea of the model as a prototype cfr. (Gaiani, 2004).

[2] About the applications of the mathematical representation method in the study of surfaces cfr: (Fallavollita, 2009).

Fig 1: Axonometric view of the numerical model of Palazzo Felicini

reproduce an ideal model[3] or normalized model of an existing building. The mathematical model reproduces an existing object through the modeling of its essential characteristic, discretizing the data used to define it, such as the rules of composition, proportion, etc. The construction of a mathematical model allows studying the proportions, the shapes and the design of architecture, looking for compositional and geometrical rules that have been adopted to build the architecture and have guided the design and the construction. Secondly, it allows establishing the knowledge base for the analysis procedures, labeling and segmentation of 3D models based on machine learning methodologies.

The study deals with (a) the issues and methods related to the construction of the numerical model through digital photogrammetry (fig. 1), (b) the problems and methods for studying the semantic architecture of the arcades and the criteria of assessment used. Please refer to future studies for the issue of how to form a numerical model that reproduces a real object, with all its singularity, exceptions, defects, you can get an ideal model.

2. *Method for Photogrammetric Survey of the Porticoes and the Construction of the Numerical Model*

For the research, we took into consideration the following case studies: Bonasoni Palace, Caccialupi Palace, Felicini Palace and Grassi Palace. These four buildings were chosen because they are very different from each other by structure, materials, architectural order. The work was carried out according to the following points: formal analysis and historical research; choice of survey method and execution of images data set; generation of the 3D model with texture; scaling and segmentation of the 3D model following a semantic structure.

2.1 Formal Analysis and Historical Research

In this first phase we collected all the bibliographic and archival data easy retrieval concerning the buildings examined. Moreover, where possible and necessary, we have investigated similar cases within the city of Bologna as a benchmark to frame the stylistic influences that have affected the design of the

[3] About the idea of a model cfr. (Baglioni, Fallavollita & Salvatore, 2013).

building or interventions posthumously. The analyses regarding the study of the architectural orders and the size ratios of individual architectural elements of the façade are part of the historic and formal research too.

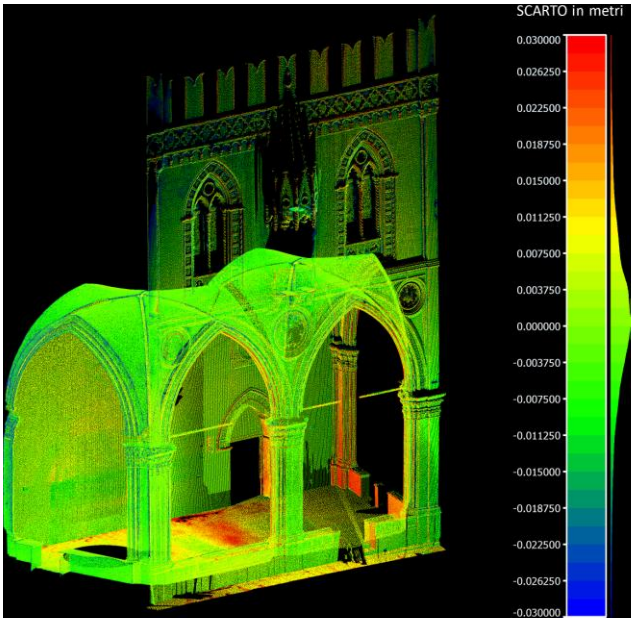

Fig 2: Comparison metric between the two mesh: one obtained from the laser scanner and the other obtained from digital photogrammetry

2.2 Digital Photogrammetry as Survey Method

In order to survey the porticos buildings we performed a comparison of all methods of digital survey. After a first general analysis, we focused on laser scanning and digital photogrammetry. To compare the strengths and weaknesses of the two methods we considered two porches in the Piazza della Mercanzia, one wooden and one lithic, performing for both a survey with laser scanner, assumed as reference, and a survey through digital photogrammetry. In this way, it was possible to analyze the error generated by the point cloud obtained by photogrammetry compared to that obtained with laser scanning, showing a standard deviation of 1.4 cm in the former case and 1.0 cm in the latter, with lows and highs blocks between 3 cm regardless of the shadow areas (fig. 2).

Based on the data collected we analyzed advantages and disadvantages of digital photogrammetry for the specific case of the arcaded buildings, achieving the following considerations. As regards the defects of photogrammetry in relation to instrumental survey with the laser scanner. The survey operations are longer and more difficult for the arcades typology than isolated objects or buildings without porches, because of frequent changes in the concave façade. Currently digital photogrammetry does not allow a refined control on the accuracy of the survey, especially in fine details. It requires always a comparison with other instruments more accurate and precise as the use of a laser scanner.

The numerical model is not a scale model, so you need an auxsiliary instrumental survey to put it in the right scale. The method presents problems in the construction of reflective surfaces and monochrome surfaces, especially if white. The surveying operations are slowed by low light conditions, as it is necessary to use a tripod to get pictures with good resolution and low noise. Finally, the survey operations are strongly influenced by weather conditions, by the ambient lighting conditions and by the space of maneuver around the building to detect.

As regards the advantages of photogrammetry compared to the use of laser scanner we can state the following considerations. You can get a finished model with texture in less time than other methods. You have better control over the quality and reliability of the colors of the texture than other methods. This method is low cost, both as regards the software and the hardware required.

The method does not require sophisticated instrumentation, fragile and difficult to handle, since it requires only a good commercial camera. It is also applicable to multiple people at once without having to buy expensive equipment for everyone.The surveying operations are easier in terms of traffic and crowds. The method is simple to apply and learn because it presents a high degree of automation. It allows you to capture many more points in three dimensional space compared to the amount of points may be captured by the best laser scanner available on the market. Finally, the method allows for greater flexibility in the choice of software for post-production than the other methods.

Considering the objectives of the research, that is the cataloging and the semantic description of the Bologna arcades, we chose the photogrammetry method as more suitable, cheap and easy to apply (Apollonio, Gaiani, Felicori, Guidazzoli, Virgolin, Liguori, Fallavollita, Ballabeni, Sun, & Baglivo, 2013).

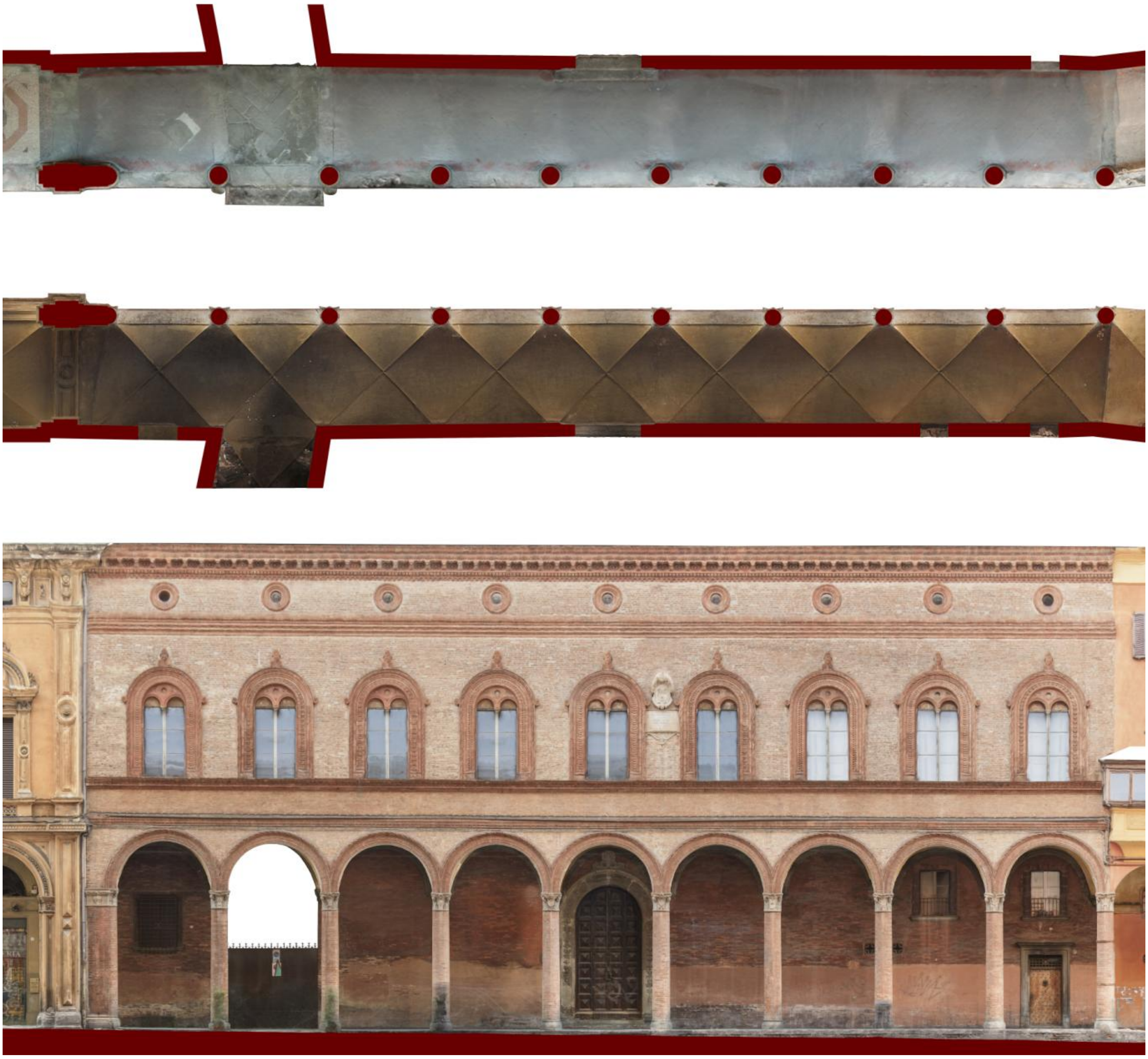

Fig 3: Plan and elevation of Palazzo Felicini obtained from the numerical model

2.3 Execution of the Images Data Set for the Acquisition of Point Cloud

It was necessary to take photographs of the buildings paying particular attention to the control of the perceived color by splitting the set into subgroups: the facade, columns/pillars outside, columns/pillars inside, porch, ceiling/vaults and floors. We extracted at least one profile ICC for the chromatic correction from each subgroup with the aid of a ColorChecker and the software Profile Maker (Apollonio, & Roberto, 2012; Apollonio, Gaiani, & Baldisisni, 2011).

During image capture, it is important to keep the exposure for each subgroup constant and correct. The noise, due to the excessive ISO set, should not be present. The focus must be optimal paying attention to the exposure times. The focal length must be constant and must prevent deformation due to the wide angle. It is also important to plan the shooting operations in advance for optimizing set with a good number of photos/result. For a deepening on the method used, please refer to the following studies (Apollonio, Fallavollita, Gaiani, & Sun, 2013).

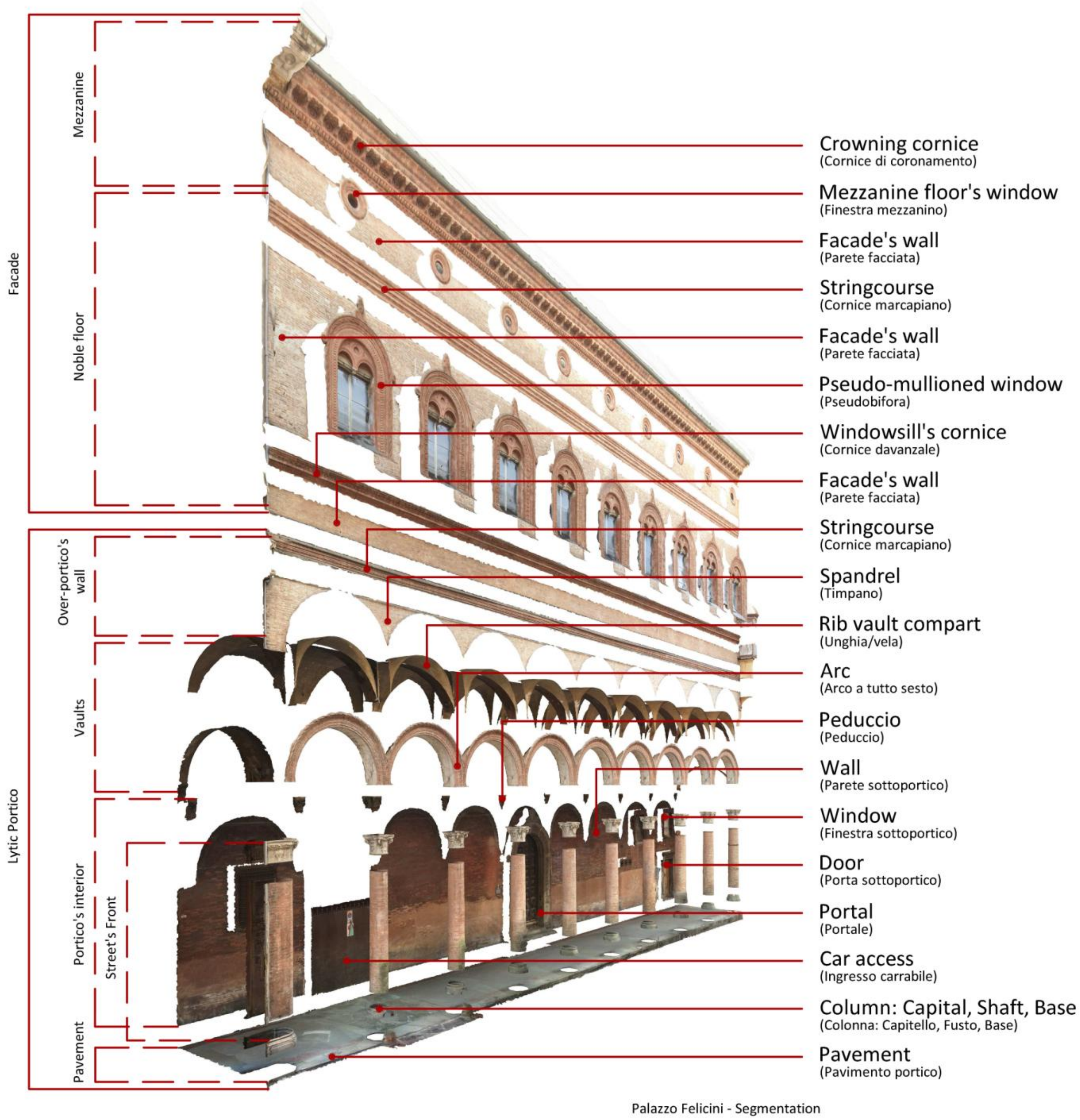

Fig 4: Semantic Segmentation of Felicini Palace

2.4 Constructing and Scaling 3D Numerical Model with Texture

Following the acquisition of the photo shoots, the photographs were processed using a commercial software (Agisoft PhotoScan), which works through algorithms of stereo-photogrammetry, vision and interpolation of homologous points, resulting a point cloud. From the point cloud we generated a mesh, namely a numerical model. To get a good 3D model with correct texture you must perform, after each step, a control and a correction of the results of each calculation. In particular, it is necessary to clean up the dense cloud from the points obviously incorrect, to correct the resulting mesh from errors of geometry, holes or self-intersections errors, to correct the color and to mask the disturbing elements in the foreground that could be erroneously projected on the surfaces. The model obtained by photogrammetry, as mentioned, is not a scale model, it is therefore

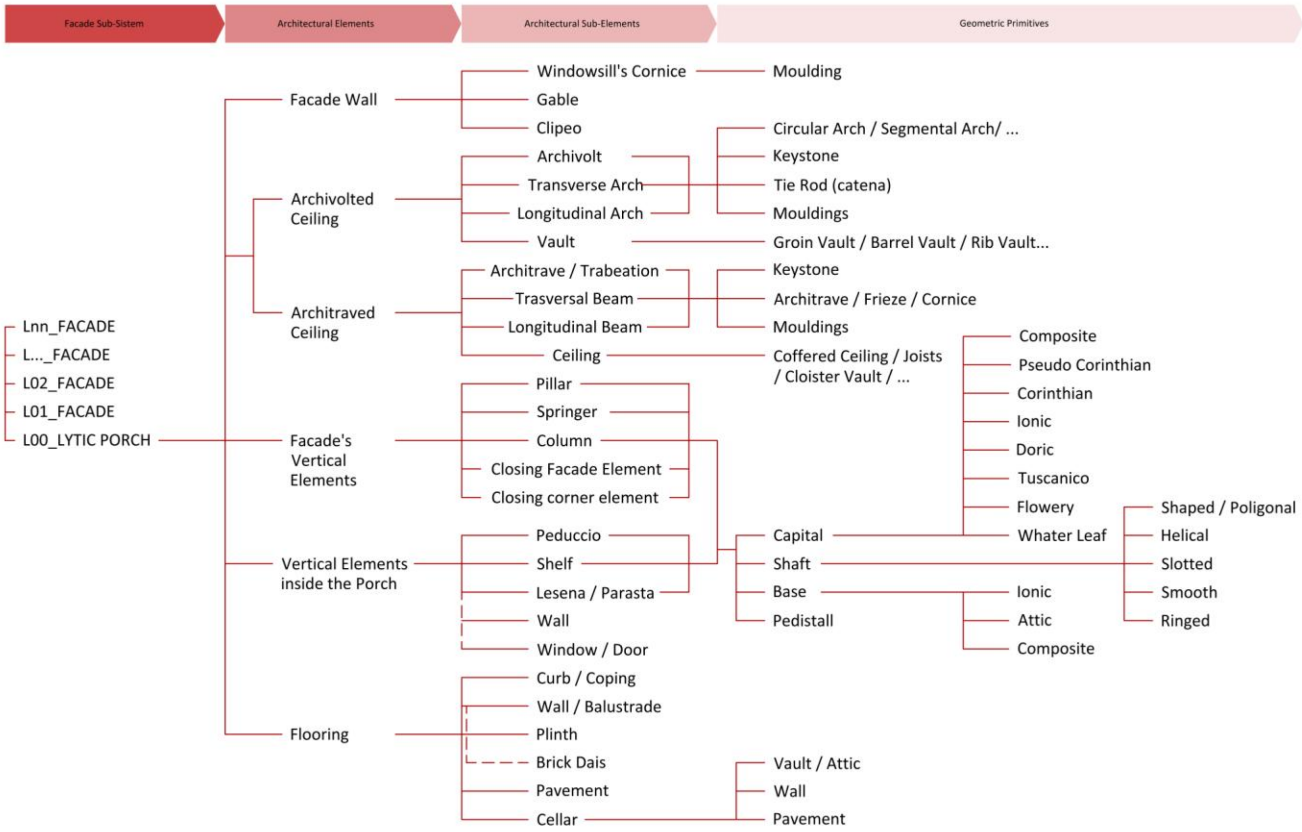

Fig 5: General Scheme. Smantic Segmentation of lytic porch

necessary to scale it through the support points obtained with instrumental surveys. In our case study, we used a Total Station to get some points on which to place and scale the 3D model.

3. *Semantic Structure of the Digital Model*

The numerical model thus obtained can be segmented and organized as a *Cognitive Architecture System* (CAS). It can be described as a collection of objects hierarchically organized, which are identified by a specific architectural vocabulary.

The segmentation of the model into sub-elements can be based on the analysis and the formal composition and structure of architectural objects, organized in hierarchical levels and classifications of aggregation. The hierarchical organization of the elements requires a special attention as for the ways in which objects are assembled from a typological and morphological point of view. To be useful, the segmentation must subdivide a particular model in parts (eg. the limbs and torso of an animal), or in ways that meet criteria of different nature (eg. each piece is bounded by edges which meet certain geometric characteristics, such as radii of curvature, continuity, etc.).

The segmentation of a model is an important step for its analysis and understanding. A wide variety of applications benefit from a process of pre-processing that uses a segmentation method efficient and reliable. In the field of *reverse engineering* of CAD models, for example, the segmentation plays an important role in the subdivision of a model into parts. Each part can be characterized by a single analytical surface (Várady, Martin, & Cox, 1997). In the field of computer graphics segmentation can be applied in various areas, such as simplification of procedures in different meshes (Zuckerberger, 2002), in the collision detection (Li, 2001), the morphing (Shlafman, Tal, & Katz, 2002; Zuckerberger, 2002) and animation skeleton-driven (Katz, & Tal, 2003).

The approach used under the Porticoes Project, divided into three steps mutually connected to each other (modeling, segmentation and display), has been defined and implemented as general as possible, testing architectural objects

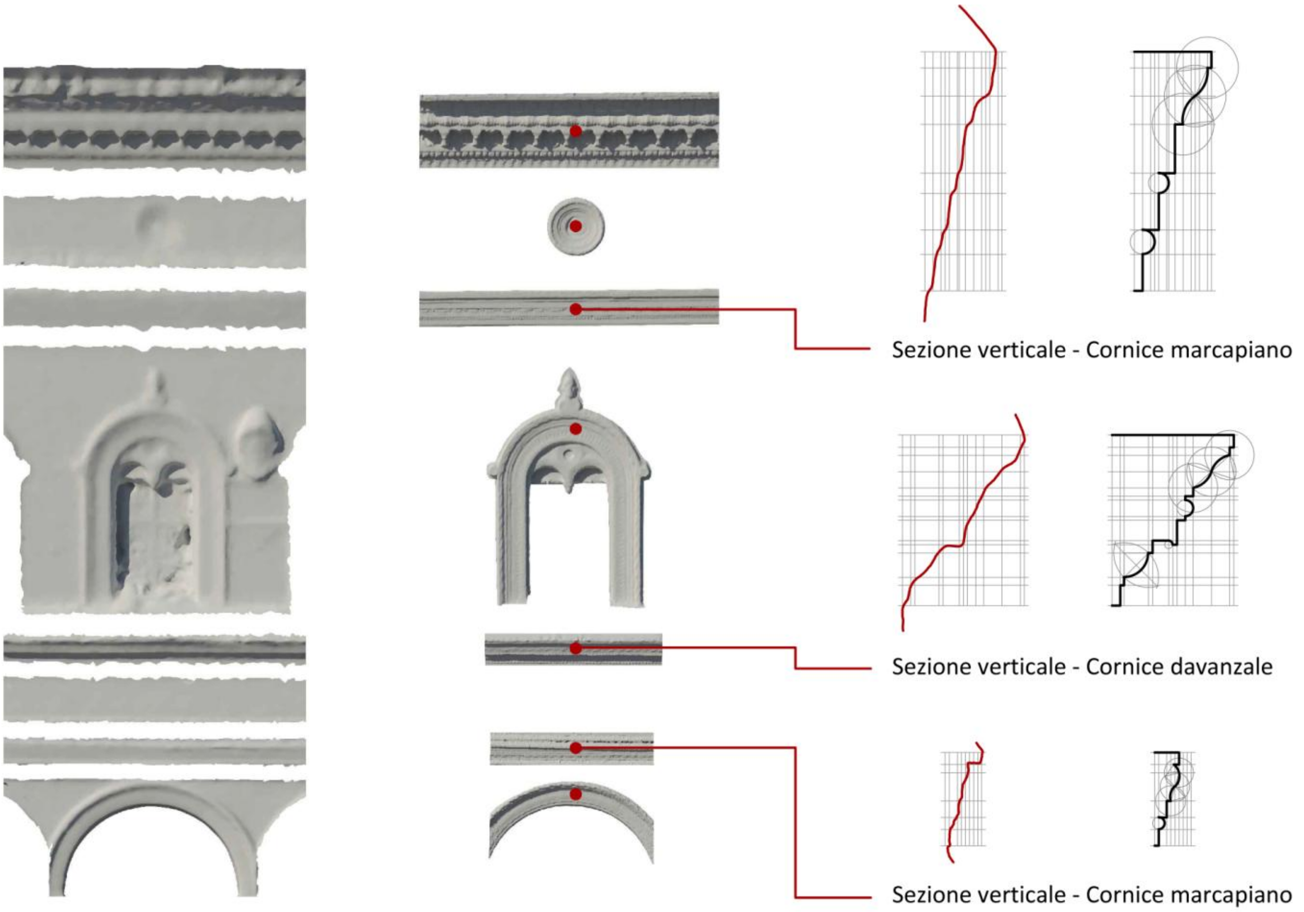

Fig 6: Extraction and construction of the moulding ideal profiles from the numerical model

characterized by different and specific characteristics and using different modeling procedures, in order to cover a sufficiently wide typological range of case studies.

This method makes it possible to achieve three outcomes:

- construct 3D models high-resolution photorealistic *reality-based*;
- classify them in three different *Levels of Detail* (LoD);
- assign at each architectural element additional information with respect to the geometric properties and surface quality.

The method provides that the 3D models, after completion of the production process, are divided into their component parts, based on libraries of morphological elements and/or of geometric primitives.

Each significant portion of the artifact, or any element of the corresponding digital model, is connected to a series of information that have been specially collected, created and organized with the aim to facilitate the process of their recovery in a context based on semantics, as it may be for example a *web based* interface.

The structure of the 3D models developed for the platform dedicated to the Bologna arcades have been conceived as a prototype/model for implementations that can be made in the future. We designed it in such a way as to follow the criteria and methodologies to ensure the identification of individual buildings, of individual artifacts, of single elements that compose them and of resources (text, images, 3D models, etc.) related to them, as elements connected directly with the 3D geometry. The singularity and uniqueness of the multiconvex schema typical of the arcades has led both in the definition of the parts, which define a building with portico, both in the name of each item and the corresponding unit typological/morphological in which the building is divided, to a specific study.

The system of the Bologna Porticoes is the result of a centuries-long process of construction,

Fig. 7: Perspective section of digital models

transformation and planning of urban structure that led to the creation of the specific conditions for the realization of this exceptional and unique structure. The structures used over the centuries and still present at Bologna for the construction of buildings with a porch can be traced, therefore, in three types:

- wooden trilithic structure or piers and architraves;
- lithic structure which can be both in archivolt or trilithic;
- mixed structure with piers and arches of brick or stone, and horizontal elements, beams and floors, wood material or reinforced concrete.

The classification adopted in the Porticoes Project refers to the methods defined in the classical architectural treatises (Vitruvio Pollione,.1556; Barozzi, 1562; Palladio, 1570; Serlio, 1560; Serlio, & Scamozzi, 1600) and principles of reading and typological analysis applied to building structures (Caniggia, & Maffei, 1979). The components of building objects are split according to the five terms: elements, elements of structures, systems, structures, body system (Caniggia, & Maffei, 1979, p. 73). As has been said, due to the range of epochs, to the building techniques, as well as to the linguistic peculiarities characterizing Bologna porticos, we cannot refer only to a single source that defines a glossary of architectural terms[4], but we must refer to other dictionaries (Dizionario Enciclopedico di Architettura e Urbanistica, 1968;

[4] S. Art & Architecture Thesaurus della Getty Foundation, http://www.getty.edu/research/conducting_research/vocabularies/aat/

Pevsner, Fleming, & Honour, 1982; Koch, 1985) and historical-critical specific sources[5].

From an operational point of view, in the case of the porticos system we refered to (Apollonio, Gaiani, & Sun, 2013) determining a structure based on four hierarchical levels:

a) sub-façade systems (distinguished by the level at which they are placed)
b) constructive/architectural elements;
c) constructive/architectural sub-elements;
d) geometric primitives.

At the first hierarchical level, therefore, we can report the segmentation of the system of the facade in sub-elements that identify the different levels/floors.

The result of the semantic segmentation process is expressed in the combination of the different sub-elements, declined in their turn according to the manufacturing system used (wood, lytic, mixed lytic / wood, ect) and according to the styles that characterize the different epochs, give rise to the form of a graph that characterizes each specific building portico. 2D geometric primitives (profiles, sections, generating lines of each architectural details) are extracted from the elements at high-resolution.

The degree of detail of the mesh detected is not always sufficient to accurately reshape all profiles.

Therefore, to audit the reliability of the reconstruction, we compiled a *scale of uncertainty* (Apollonio, Gaiani, & Sun, 2013) divided into 8 points regarding the sources taken as a reference for the redesign of geometric primitives. Once we extract the geometric primitive, we linked this to the respective architectural element in the *schematic view*.

4. *Conclusion*

With the segmentation of the model into elements and semantic structuring, you can get geo-objects easily readable, communicable and navigable. In this way, you can connect within the same file information of all kinds, such as texture, color, architectural, but also semantic information, of geometric nature or historical nature. Once the models have been organized according to this system, we can insert them in a *database* accessible through search engines, possibly online. In this way anyone can know how many and what are the buildings that have a specific characteristic. The search can be filtered by architectural details, such as: mullioned window, number of floors, type of column or capital, size, construction materials, architectural order, etc. It will be possible to know, about each item, the size, any links with similar elements of other buildings, the placement within the architectural system of the building providing a very useful tool for the study and knowledge of the Bologna porticoes.

The study showed also the different possibilities for further development that include the construction of mathematical models and the benefits that this type of structure can provide in terms of effective use in many areas of digital 3D models. In future local communities and tourism can benefit from these models to study the history and the formal aspects of the Bologna arcades; while the community of scholars and architects can use the same models for managing research projects and for the protection, conservation and restoration of the architecture of the city.

[5] In addition to the contribution contained in this volume of Francesco Ceccarelli, the semantic structure has drawn inspiration from the rich bibliography on the Bologna porches in particular by: (Bocchi, 1990; Bocchi, 1997; Vianelli, 1988).

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