Bologna Porticoes Project: 3D Reality-Based Models for the Management of a Wide-Spread Architectural Heritage Site

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Abstract. Among the actions developed in order to submit the Bologna porticoes ensemble to World heritage sites of UNESCO, there is a platform conceived for on-line accessing the huge amount of data and resources related to the porticoes. The core of platform will consist of reality-based high quality 3D models usable and navigable within the system as main user interface. The paper describes methods, procedures and best practices developed to implement the digital archive with checked uniform quality and consistency reality-based 3D digital models.

Keywords: 3D digital libraries, Architectural heritage, Image-based modeling.

1 Introduction

The system of Bologna porticoes, after its inclusion in 2006 in the Italian tentative list of UNESCO's WHS, will undergo a definitive recognition of the nomination as part of the program of the current municipal council. The nomination is aimed at highlighting the portico, not only as a high-quality architectural work, which in the past centuries has become a distinctive feature of the town, but also in its social, community and anthropological meanings, as a meeting place, a protected space. The nomination project refers to different subjects and is divided into many levels of action, with the aim to develop a platform conceived for on-line accessing the wealth of data and resources related to the Bologna porticoes system, such as historical, artistic, architectural resources, besides all those data regarding its actual management. This information system platform, bearers of specific skills, returns a comprehensive, structured and coherent semantic interpretation of Bologna landscape through shapes realistically reconstructed from historical sources and surveys, overcoming the traditional display mode.

Three institutions, cooperating to develop the whole system, integrate their perspectives within a common methodological approach [1]: Architecture Department of Bologna University is devoted to the creation of 3D models; the Municipality of

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Bologna, will operate throughout the Open Data framework, already hosting 3D data related to the history of the city[2]; CINECA [3] is developing the platform.

This paper describes methods and procedures developed for implementing the 3D repository of Bologna Porticoes with reality-based high quality 3D models usable and navigable, as main user interface, within the system. Uniform quality and consistency of our reality-based 3D digital models along the more than 40 km of porticoes was assured by a controlled, low-cost process starting from photo-modeling techniques. The core of the application will consist, in fact, of reality-based 3D models usable and navigable within a system grounded on a Web mapping [4] for the visualization of porticoes contents through a geographic platform for the Web, in order to geo-localize, not only in space but also in time, the historical and cultural heritage data related to the porticoes of Bologna.

2 Characteristics of the 3D Archive

Most of the today 3D models reconstruction available on the web do not aim to provide a faithfully and accurately representation of each building, but to render a general view of urban volumes, obtained through the use of textures gained from aerial images. The main purpose of 3D Archive of Bologna Porticoes is aimed to represent architectural shapes at the architectural scale starting from accurate 3D data capture [5]. The developed methodology is based on modeling and visualization that allow the reproduction of high-definition 3D digital models, their classification and allocation of additional information to each architectural element, besides the geometrical-dimensional details.

The core application of Bologna Porticoes will be a 3D database grounded on Web mapping where 3D models could be visualized as part of complex IS including:

1. 3D digital models representing as-built architecture;
2. 2D textual and iconographic materials;
3. Development of a new web-based architecture that allows multi-user customized access to different layer and opens to cultural and promotional cross-medial further applications.

The repository is not thought as an exhaustive set of 3D models, nor a static structure, but will be continuously updated with the advancement of studies. The application was conceived to be the preferred interface for accessing the Porticoes IS in order to give access easily and user friendly to individual buildings and to allow a direct representation of architecture whose complexity can hardly be approached and understood only through textual or iconographic documents. The repository is not thought as an exhaustive set of 3D models, nor a static structure, but as a base that will be continuously updated with the advancement of studies.

The 3D models construction pipeline, following semantic organization criteria, is based on seven different steps :

- Building's shape and color acquisition;
- 3D models production;
- Reflectance properties of the building surface texture mapping;
- 3D models semantic structure;

- 3D models multi-resolution models generation (remeshing/decimation);
- 3D OBJ file production.

3 Data Acquisition and 3D Textured Models Construction

The collection of 3D models has been thought as a system able of rendering the geometrical shape of the porticoes, which typically consists of a series of vaulted spaces, but also to ensure their faithful color survey.

For the purposes to build-up photorealistic 3D models we developed an easy, low-cost and rapid procedures able to ensure high geometrical and visual accuracy while being accessible to non specialized users and unskilled operators, with the aim that, through this procedure, almost any user can realize a 3D model of a building porch making it available to the entire community. Testing of our procedures to ensure the fulfillment of these requirements was done by group of students of the degree in Architecture and in Building Engineering/Architecture reporting excellent results in term of usability and final 3D model.

The developed pipeline, completely camera-based, essentially consists in the shapes reconstruction through computer vision techniques (i.e. structure from motion, SFM) and the rendering of reflectance properties of the artifacts surface with perceived faithfully on a consumer display. Compared to commonly used techniques, our workflow ensures camera color calibration and management using a limited number of well calibrated photos and avoids inaccuracy and multiple processing phases. It could be used inside range-based and/or photogrammetry-based pipelines and, above all, could be completely integrated in the SFM pipeline (e.g. VisualSFM [6]), avoiding the problems of data fusion from multiple sources and limited color fidelity of the final 3D model. An important requirement of our 3D models is the perceived color fidelity from acquisition to visualization. To ensure this constraint we made a reasoned review of standard methods with some customization to adapt those procedures to our case, ensuring consistency and robustness. Workflow, methods, standards and operational best practices developed - already widely and successfully used by our group in other case studies [7] - are completely device-independent; consequently, the choice of instrumentation, within certain limits, does not affect the results.

The reflectance mapping steps is aimed to solve problems that have not yet had response methods in the context of SFM, which involve camera color calibration, color management, perceived color visualization at runtime inside the rendering engine (i.e., OpenGL graphics) and the variations that arise from the use of various cameras by different working groups, which can further affect many photo-consistency-based reconstruction algorithms [8].

Recent studies [9] shown that reliability and repeatability issues are encountered when SFM methods are used for complex and long sequences; however, the performance in terms of the computed object coordinates is often surprisingly positive. We also verified that the accuracy of these software was at least that required by our case study (common architecture, not major architecture) with a series of preliminary tests in which were compared data from SFM and data from laser scanner ToF [10].

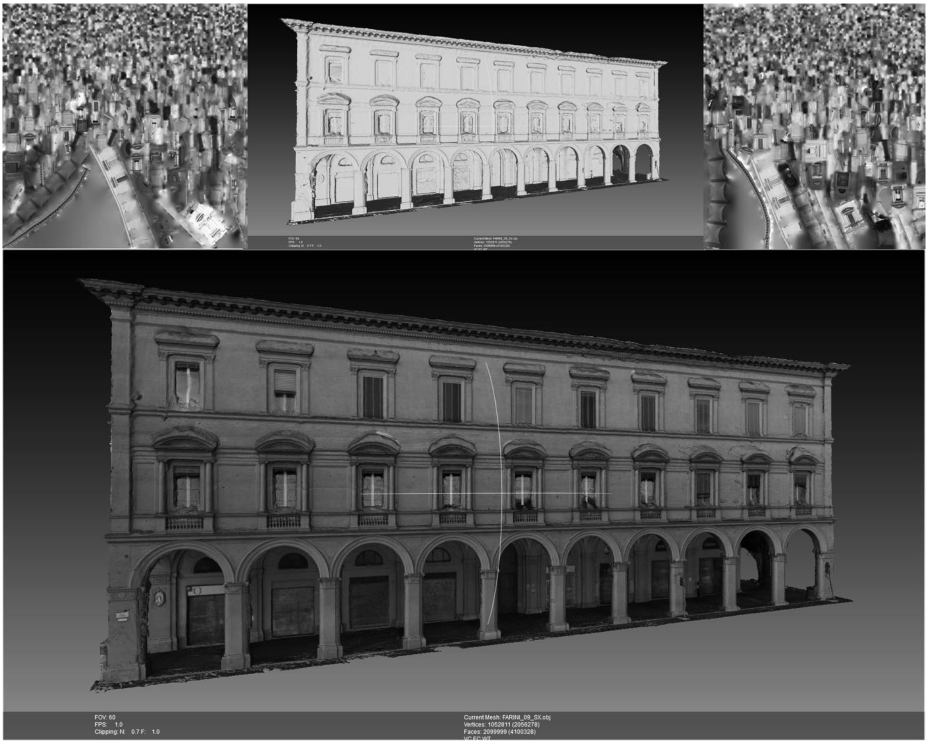

Fig. 1. Palazzo Guidotti: ‘A-level Master Model’ mesh model and related texture maps (*top*); textured model (*bottom*)

From an operational point of view, the shape and color acquisition steps is based on the use of different software free for research and non-commercial use, integrated one another: (a) VisualSFM [11; 5] for camera orientation, (b) nframes SURE for dense reconstruction [12], (c) Screened Poisson for surface reconstruction [13], and, at last, (d) MeshLab [14] for mesh editing and texture mapping. This solution, though comprising several software, is more customizable, manageable and accurate [15] than the pipeline based on the use of all-in-one commercial software. In depth on our customized SFM pipeline are in [16].

4 3D Models Standards

Within a knowledge/information system, standards and procedures are essential to ensure the consistent meaning of shared contents and to trace and record the ‘history’ of the processed data [17]. Therefore standardized characteristics of 3D models need to be defined a priori, in order enable the integration of different types of information and 3D models collected by different operators and researchers at different places and times, keeping a substantial homogeneity of representation and data quality.

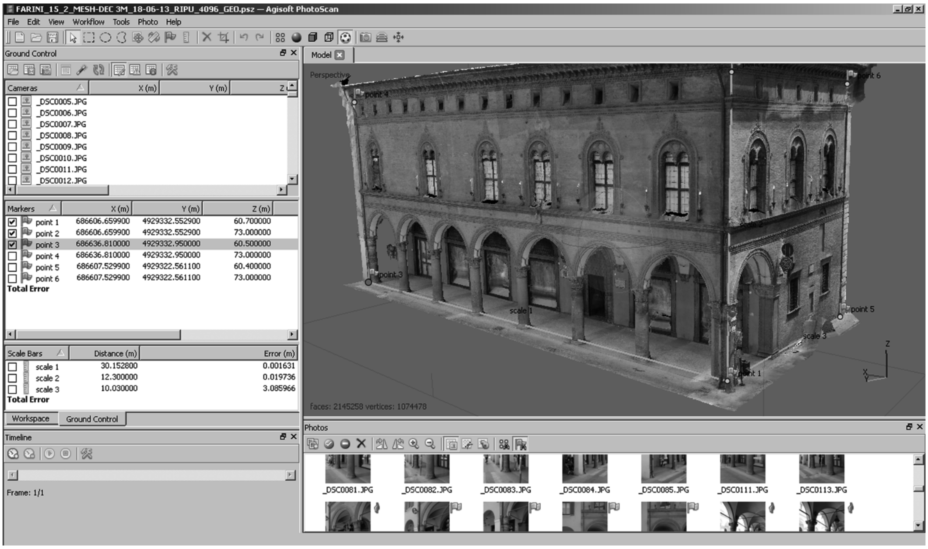

Fig. 2. The geo-referencing of Casa Saraceni's 3D model

These requirements lead to:

- the definition and use of accepted standards;
- the definition of the quality of the information according to the level of detail of the visualization;
- the continuous control of the data correspondence with the accuracies required.

Regarding the standardization of the reality-based 3D modeling process, we established a set of standards to be used by the different working groups to ensure success over time. At the core of our standards definition, we applied the concept of a 'Master/A-level model' [18] - a replica of the original object based on its intrinsic characteristics and obtained after the editing procedure of mesh - able to supply the highest quality in terms of spatial and color information content.

Following this approach in our framework, metric standards were referred to the real artifact features. The intrinsic properties of each artifact allowed us to determine the 3D data capture and modeling level of accuracy and detail to fully render each item or its single part.

Starting from the 'A-level', we defined two further different qualitative Levels of Details (LoDs) according to the different uses of the 3D models:

- 'B-level Derived models': on-site visualization for management and professional purposes (geometry simplification: 20% of the original mesh size; 50% reduction of original texture size resolution) using interpolation algorithms can be used to achieve semantic model simplification without loss of quality;
- 'C-level Derived models': on-line visualization, that can be used as 3D interfaces or included in large VR scenes (geometry simplification: 7,5% of the original mesh size; 50% reduction of original texture size resolution), could be often used as interfaces in visual 3D databases, or for dissemination purposes.

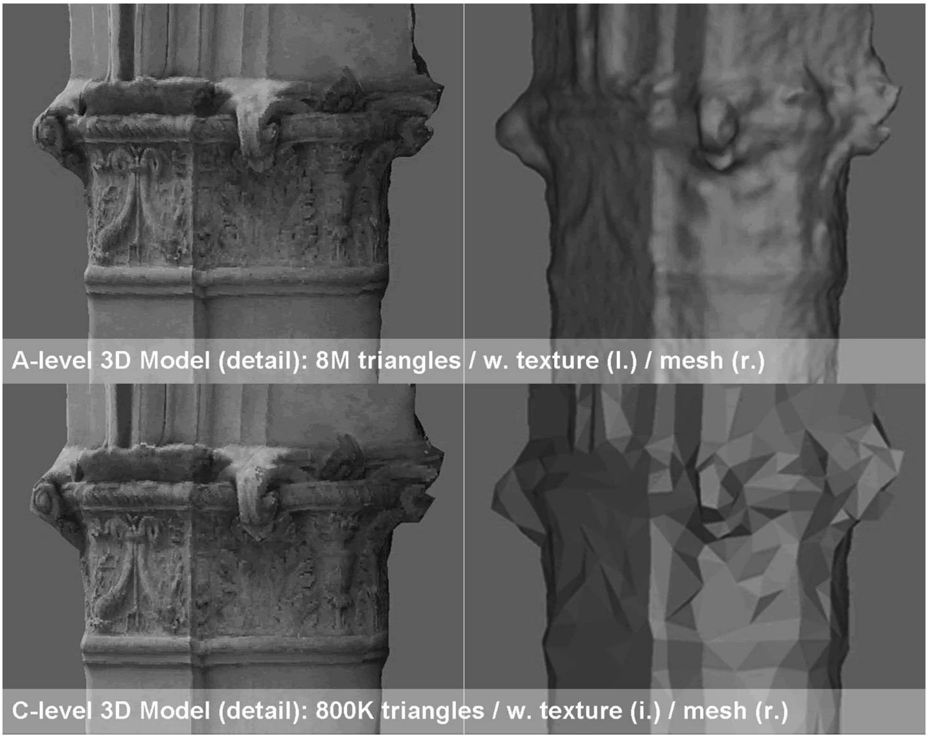

Fig. 3. Palazzo Guidotti, detail: parallel between 'A-level Master Model' (*top*) and 'C-level Derived Model' (*bottom*)

Therefore, a critical point in this procedure is related to the 3D models remeshing/decimation for multi-resolution models production. An important question, in fact, concerns the geometric and texture resolution of the 3D models.

The developed photogrammetric method allows to obtain 3D models consisting of approximately one million polygons per arcade with a photos resolution of on average of about 750mm per inch, that is, every inch of the frame are approximately 300 mm in reality. The models thus obtained, however, have to be optimized for the online platform: it is necessary to reduce the number of polygons that constitute the model tessellation; it is also necessary to define the optimal resolution of the texture. We noticed that a tessellation of about 100,000 polygons per arcade returns a good compromise in architectural quality and resolution. The difference between the original mesh and the reduced one is a negligible amount considered the scale model definition. Thanks to the computing capability of today available, we evaluated to use a texture 8192 x 8192 for a block of about three arcades, which can render an average accuracy of 1 pixel = 30 mm.

We can compare the 3D models thus obtained to a model scale definition equal to approximately 1:50. The decimated models can be implemented in the online platform without compromising their navigability online. It is important to note that the quality of the optics and the camera sensor affect the texture resolution and the scale of the model. In the above estimate is considered that the cameras and the related lens are of good commercial quality, for example the Nikon D200 + 24mm 1:2.8 lens. Another issue concerns the level of focus and the plane of the sensor that is never parallel to the planes of the object represented. Moreover, these are not fully aligned with the plane of image focus. The estimate is considered reliable for the part of the building that affects the portico floor and should be reduced to the upper part of the facade. This is due to a greater foreshortening of photographic resumptions and to a greater distance of the subject.

In conclusion, the original mesh, considering the 1:1 scale model, has an average edges length of 2 cm, while the reduced mesh model has an average edges length of 15 cm. As already said in order to obtain a model in a more detailed scale, for example, to display and analyze an architectural order, it is necessary to use a different set of photographs in which the scale of resolution pixels per inch is greater than that above. The example shows the detail of a column of Palazzo Guidotti in Bologna, Piazza Cavour (Figure 3).

5 Conclusions

The work conducted so far has allowed the set-up and solution of most of the key points for the definition of a procedure extensively applicable to survey and modeling of buildings with a porch of Bologna. It has been tested and defined the whole procedure/pipeline of data capture and production of ready to use models with a survey of about 300 buildings, they have been defined quality standards which can assure interoperability between different operators and between different steps of the supply chain and the construction of uniform and high quality of reality-based 3D digital models, it was consolidated methodology of shapes reconstruction and rendering of reflectance properties. They are currently object of further experiments and developments the solution of some critical phases of surveying and modeling procedure that characterize the typical concave-convex structure of buildings with porch (non-coplanar surfaces, homogeneous regions, distinctive edge boundaries, repeated patterns with recurrent architectural elements, textureless surfaces and illumination changes) and the development of a web-based service for an image based 3D modeling able to allow operators and city-user to update the digital library updating the city/urban transformations or simply adding not jet covered parts.

The main aim is to provide simple, well-bounded and easy to use best practices and procedures able to allow the implementation of the repository by different users, and hopefully, by unskilled operators too. Therefore, uniform and high quality reality-based 3D digital models can be implemented within the IS and become the main interface for browsing through the 3D Archive of Bologna Porticoes

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