A Journey in the Fourteenth Century. A Digital Reconstruction of Piazza delle Erbe in Verona

Fabrizio I. Apollonio, Marco Gaiani, Federico Fallavollita, Elisabetta C. Giovannini, Riccardo Foschi

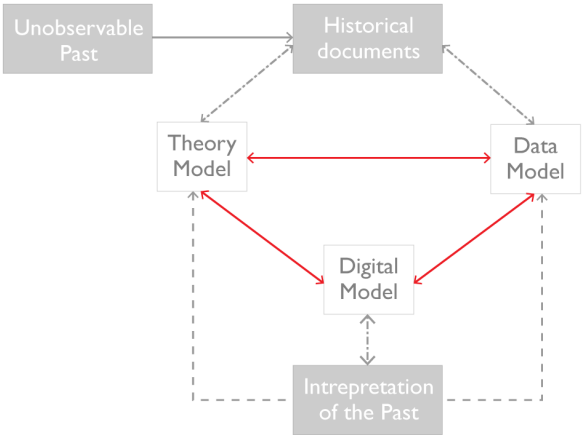
Abstract

Digital visualization as the representation of a past that no longer exists is a communicative necessity in which virtual reconstructions have become means and experience of an otherwise intangible time. The case study presented is the expression of a methodology seeking to combine informative and scientific aspects. This method aims to provide an answer to a multidisciplinary approach that characterizes the study of architectural heritage of the past where virtual reconstructions, if scientifically substantiated, can become clear and transmittable documents.

Keywords: virtual reconstruction, 3D modeling, *cultural heritage,* rendering.

Introduction

The case study is the result of a multidisciplinary work involving city historians and architects, and part of a larger research project, presented at Expo 2015 in Milan, aiming at the virtual reconstruction of market squares in some Italian cities of the Middle Ages. The paper presents in detail the case of Piazza delle Erbe in Verona between the thirteenth and the fourteenth centuries. The aim of this article is to describe in detail the methodological and procedural aspects adopted and, on the other hand, to articulate the potentialities and the criticalities of the work done within the specific field of research. The area covered by the virtual reconstruction of Piazza delle Erbe, for its extension, lies in an intermediate dimension between the reconstruction of individual buildings and that of an entire urban area, presenting the pros and cons of both scales of representation. This aspect has determined the need to model the individual buildings overlooking the square on an architectural scale, starting with the historical-documental information available, according to different levels of certainty and degrees of accuracy. In this framework, it should be specified that the work presented was entirely produced by researchers working in the field of Drawing, in close collaboration, and with effective input and comparison with the city's historians, whose contribution was indispensable for verifying and excluding the various reconstructive hypotheses and indicating reliable sources derived from historical information. The comparison was continuous and profitable and involved all phases of the project: from the study of the sources to the production of the video.



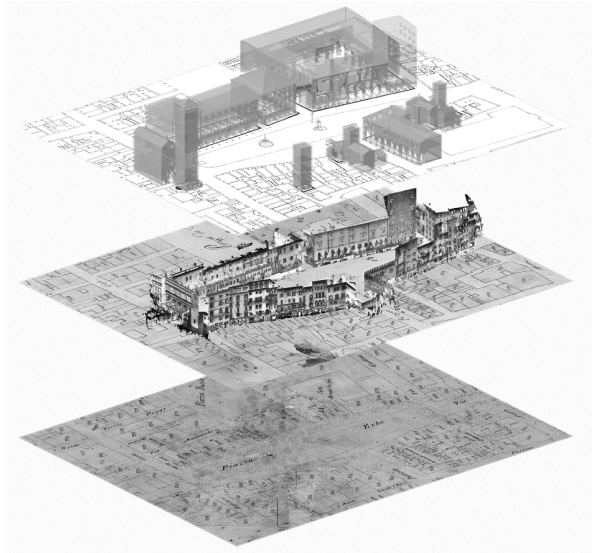


Fig. 1. Diagram of the virtual reconstruction process.

Fig. 2. Layering of procedure: historical data, survey-based data and hypothetical virtual reconstruction.

State of the Art

In the last twenty-five years the digital revolution has produced an important development of new tools and methods for 3D data acquisition, documentation and dissemination of information related to architectural-archaeological heritage. The availability of new and more effective digital technologies introduces the possibility of interchangeable media able to offer multiple nodes of access to a given term or object, and it enables a multidimensional approach to knowledge on several levels. The digital technologies propose new meanings of architectural representation, adding an extra dimension, the temporal one (diachronic and synchronic), which allows us to know an artifact not only in its evolution and transformation during its life cycle, but also through the analysis of its composition and geometric-formal matrix.
The advent of virtual reconstruction applied to archaeology introduced by Paul Reilly [1] opened the debate on the multidisciplinary approach to a huge amount of virtual reconstruction projects. There is a wide series of reconstruction works of design hypotheses and archaeological sites, as early as 1990 [2], as well as applied to architectural reconstruction of never-realized buildings [3] or urban spaces [4] that have used 3D digital modeling techniques. Koller [5] focused on the need to make visible the traceability of all additions, subtractions, and changes to 3D models, in order to make the hypothesis understandable and to display differences between 3D models and the object/artifact. One of the main aims is process transparency, that involves a virtual reconstruction and includes several problems about information management of the whole cognitive process [6]. Starting from data sources, up to the 3D model, the main issues are related to the traceability of subjective decisions and conjectures affecting the process of a certain grade of uncertainty [7] that opens the possibility to alternative options of reconstruction usually not declared [8]. The virtual reconstruction framework becomes even more complex in the case of large urban areas, where the difficulty of recomposing the overall documental framework is also accompanied by the definition and management of the different levels of certainty of the information collected and the related details of the data given back. The case study is part of the research project *Piazze, palazzi del potere e mercati del cibo nell'Italia di Dante. Progetto di ricostruzione 3D delle piazze e dei mercati alimentari di Milano, Bologna, Firenze, Verona* [9] aimed at proposing a virtual reconstruction of food market squares in some major cities of the Italian Middle

Ages, presented at Expo 2015 in Milan. The paper presents the case study of Piazza delle Erbe in the years straddling the thirteenth and fourteenth centuries. The first section provides a methodological framework concerning the virtual reconstruction of lost or never-realized architecture, with particular reference to cases of urban areas of limited extension. The following paragraphs describe the procedure adopted in the case study. The final section provides some general assessments of the experiment conducted.

The virtual reconstruction of buildings and urban areas no longer extant

Among the virtual reconstruction experiences of urban areas no longer extant, one of the largest virtual reconstructions of an entire ancient city is that of Rome in 320 AD [10]. It is a virtual reconstruction from incomplete archaeological data that utilized procedural and parametric modeling techniques to create visually compelling and detailed models [11]. In the same context, but equally remarkable for the approach, the methodology and the quality of the results achieved is the saga of *Assassin's Creed* [12] that is characterized by settings in ancient virtually rebuilt cities. The subject areas of the virtual reconstruction of Piazza delle Erbe are to be placed in an intermediate scale compared to the reconstruction of individual buildings and to entire cities, preserving the pros and cons of both scales. The virtual reconstruction of a vast urban area, such as that which characterizes a square and its neighborhood, requires, in fact, on the one hand, the collection and compliance of a typical level of detail of the architectural scale (building) and, on the other hand, the typical problems of urban scale (large amount of buildings). We need to ensure, in the virtual reconstruction process, the fidelity/accuracy typical of the architectural scale at the individual building level (not always achievable) and the complexity (in terms of the variables to calculate and the consequent degree of accuracy to guarantee) typical of urban scale. This originates the need to define the individual modeled buildings that make up the scene of the piazza at an architectural scale, confronting a scene that is already at an urban scale. Each building compounding the scene of the Piazza delle Erbe, therefore, has been rebuilt in accordance with retrievable historical information of different types and accuracy.

The reconstruction of Piazza delle Erbe between the thirteenth and the fourteenth centuries: sources, methods and procedures

Beyond the impact of emerging 3D digitalization on museological and architectural documentation, on the

Fig. 3. Point cloud obtained using a Leica C10 laser scanner (rigth) and view of the plan with the scanning stations (left).

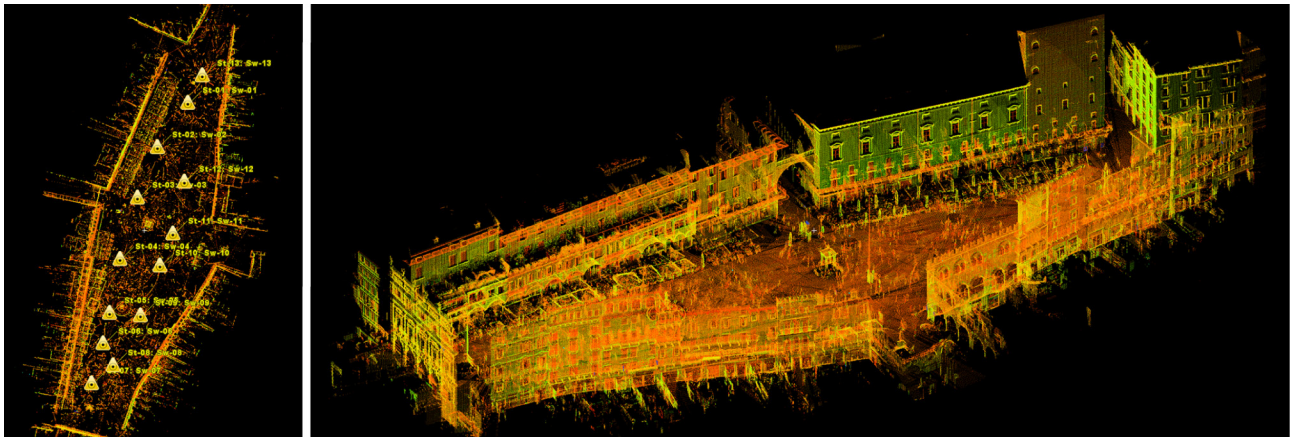
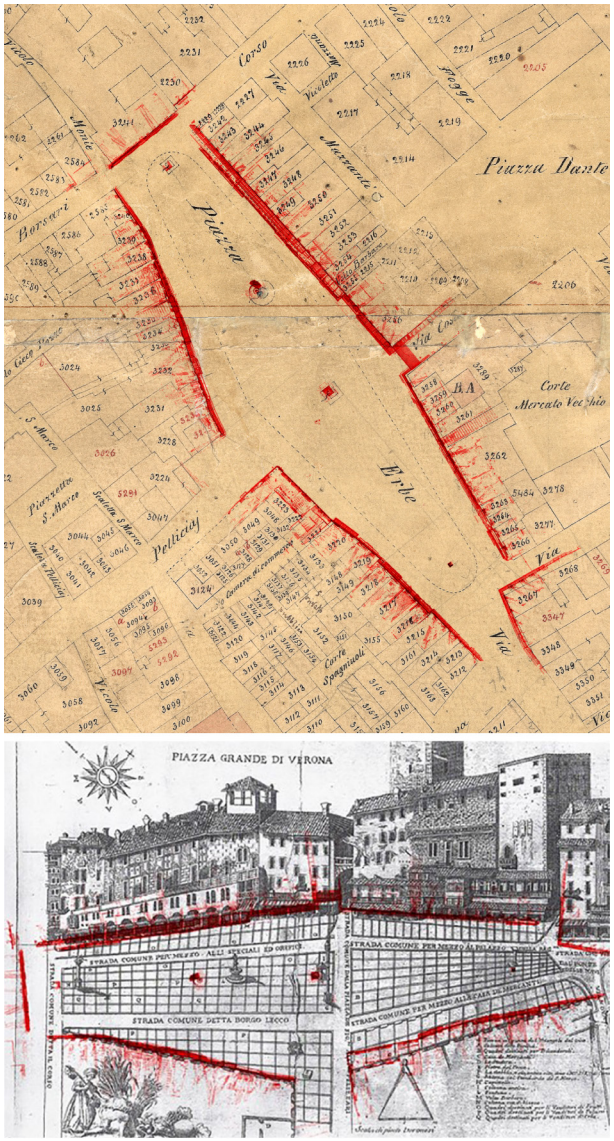


Fig. 4. The alignment of the point cloud with the historical documentation: Napoleonic Cadastre, 1807-1813 (top); Piazza Grande di Verona, 1549 (bottom).



one hand, and the consideration of referred scientific requirements on the other, hypothetical digital 3D reconstruction faces different challenges and potentials.
The virtual reconstruction includes the composition–modifiable over time–of three mutually interrelated models: the theoretical, the data and the reconstructive hypotheses; which are defined by the process of interpreting the no-longer-observable past, starting from the historical records. The virtual reconstruction of Piazza delle Erbe has been developed in multiple steps. The first step is related to historical research, which used archival, iconographic, bibliographic, photographic sources, and so on, through which it was possible to gather important information on specific or general references related to medieval architecture in Verona, in the form of notarial documents, written texts, iconography, or (from more recent sources) etchings of views of the square, postcards and historic photographs, cadastral maps, etc. [13]. In this context, the contribution and the confrontation with the city's historians, Rosa Smurra and Francesca Bocchi, coordinators of the project, were fundamental. Through their research, it has been possible to obtain various documental sources through which we have been able to derive reliable information about the conformation of the buildings and the square of that period. In addition to graphic sources, such as the historical plans [14] and historical depictions of the square or the historical cadastre [15], there were also very important written testimonies [16] describing the square and the neighboring buildings. For example, a comparison with the Napoleonic cadastral plan permitted the verification of the actual conformation of the square; while most of the written descriptions have been used to reconstruct the models of non-existent or modified buildings (see steps 2 and 3).
The second step involved the survey of the entire piazza, which with regard to the floor plan did not undergo–on the basis of historical records available–any relevant transformation since the thirteenth century. The survey was carried out by integrating active (TOF laser scanner) and passive sensor technologies (digital photogrammetry). The persistence of the square's layout was supported by comparison between existing structures and the Austrian (1843-1852) and Napoleonic (1807-1813) land registry data, which represent the first geometric-based land parcel survey of the Veneto and Friuli area, and the drawing of the piazza–albeit of a lesser metric and formal accuracy–dating back to 1549 [17].

In particular, using the laser scanner, the shape of the existing square and the façades was recorded. Thirteen stations were needed to have the exact perimeter of the entire space. From the point cloud, the sections needed for indicative measurements of the individual buildings and the space plan to be rebuilt were obtained. Through digital photogrammetry, the textured polygonal models of those elements dating back to the time of the study were rebuilt: such as the fountain and the aedicula in the square. This allowed us to obtain a correct model of the scene geometry; furthermore, from the point of view of surface textures, thanks to the use of ColorChecker, it was possible to perform a color correction of the entire photographic set before processing the photos. The finished models with the textures, have been repositioned in their original locations. In addition, a photographic campaign of surrounding buildings was carried out to obtain information on the materials and details to be reconstructed (see step 4).
The third step was dedicated to isolating the buildings with more accurate and detailed historical information and to understanding which items had remained unchanged during the centuries and which elements had changed over time, making use of the sources collected during the first step. Again, in this case the constant confrontation with the historians was crucial to validating the various assumptions and excluding the less reliable ones. From the previous two phases, it was noticed that, despite the tolerances and inaccuracies of the original drawings, the plan of the square had remained largely unchanged from the Middle Ages to the present. The plan was redesigned from the Napoleonic cadastre where the parcel subdivision of the buildings was reported. This made it possible to hypothesize what was likely the façade set before the unification of the elevations that occurred later. In addition, by cross-checking the later dataset with the previous documents (engravings, notarial acts, iconographies), it was possible to identify buildings that were almost completely unchanged in their proportions and constructive systems, or buildings that had been extensively reshaped. For example, the Palazzo della Regione, the Mazzanti Houses and the Domus Bladorum, which had undergone important modifications both in relation to its façade with the displacement and refurbishment of almost all the openings, and also regarding its volume and number of floors.
The fourth step aimed to define a variety of architectural details and construction types referable to a sort of library of architectural elements of medieval Verona [18]. This collection of architectural elements was built from architectural evidence relating to the coeval historical period, immediately gathered in Verona, or in the absence of this evidence, by analogies collected throughout the territory of Verona and from literature. This was necessary because the purpose of the reconstruction was to obtain a comprehensive skyline of the square and its neighborhood, able to hypothesize and recreate the atmosphere of that time, contextualizing as correctly as possible the medieval marketplace of Piazza delle Erbe. Subsequently, in the fifth

Fig. 5. Sketch of the hypothetical reconstruction.

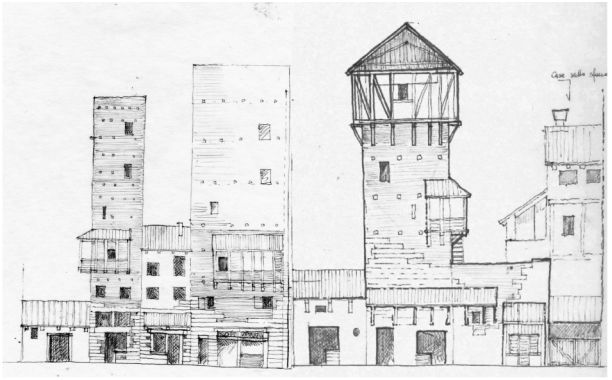


Fig. 6. Sketch of the hypothetical reconstruction.

step, we produced a set of material textures to be applied to the models. Even in this case we aimed to compose a set of photos related to buildings whose materials were comparable to those of the time interested by the reconstruction, allowing us to obtain a reality-based model able to reproduce the fidelity of color, texture, and properties of the perceived surface reflectance [19].
The sixth step dealt with 3D modeling, using as starting data those of the laser survey, integrated and implemented with historical data collected and processed in a critical manner, in order to obtain a historically correct and consistent set. It was decided to adopt both the methods of mathematical as well as numerical representation for the first phase of modeling: that is, to recreate the basic models of the final scene (Rhinoceros, Autocad and 3ds Max). The use of both presentation methods allowed greater flexibility in the formal control of the model's geometry. In this way, the model of the entire square with the neighboring buildings was obtained. An important choice at this stage was the scale of representation, or in other words, the level of detail to be adopted for the various models. Considering the expository intent and the final output of a video, we decided to use the 1:100 scale for basic geometric models. This choice allowed, through the next stage of rendering, to reach a scale of approximately 1:50. In general, we tried to simplify the models' complexity as much as possible in order to obtain a light scene in terms of number of polygons, so as to be able to populate it with goods, stalls and people.
The modeling phase was followed by texturing and illumination of the scene, trying to provide a high level of realism, applying, for example, effects simulating weathering and wear over time. The lighting setup was arranged trying to keep the "realism/rendering times" as high as possible. The setting we tried to give the most attention to was the positioning of the sun. Once the scene was correctly aligned with the cardinal directions, the sun's position was set based on the date and the specific geographic coordinates. This made it possible to have an illumination consistent with the years in which the scene was to be set. It should be noticed that the modeling phases were carried out only when it was already clear which textures would be applied and where; the geometries, to which different materials would have been applied, were divided into distinct layers. The photos taken on-site were modified to extract repeatable and correct chrome textures, to apply directly to digital models. The photos were developed with a photo-editing software to get seamless textures, and ICC profiles were generated and applied by a color profiling software to correct color aberrations at the time of shooting. As far as possible, we tried to use standard map projection systems, such as planar, cylindrical and triple planar, to speed up setting times. In some buildings, with very large surfaces with only one material, the texture repetition effect was too pronounced, and it was chosen to adopt the unwrap technique by applying high resolution textures on the entire façade as in the case of Palazzo della Mercanzia. To further enhance realism, worn and weathered effects were applied, such as leakages, moisture stains, patches of saline efflorescence.

Fig. 7. Texture layering.

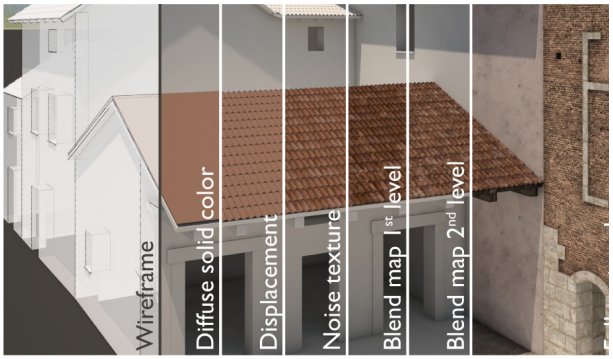
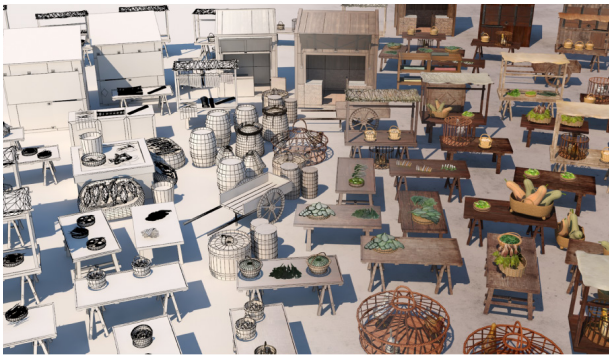
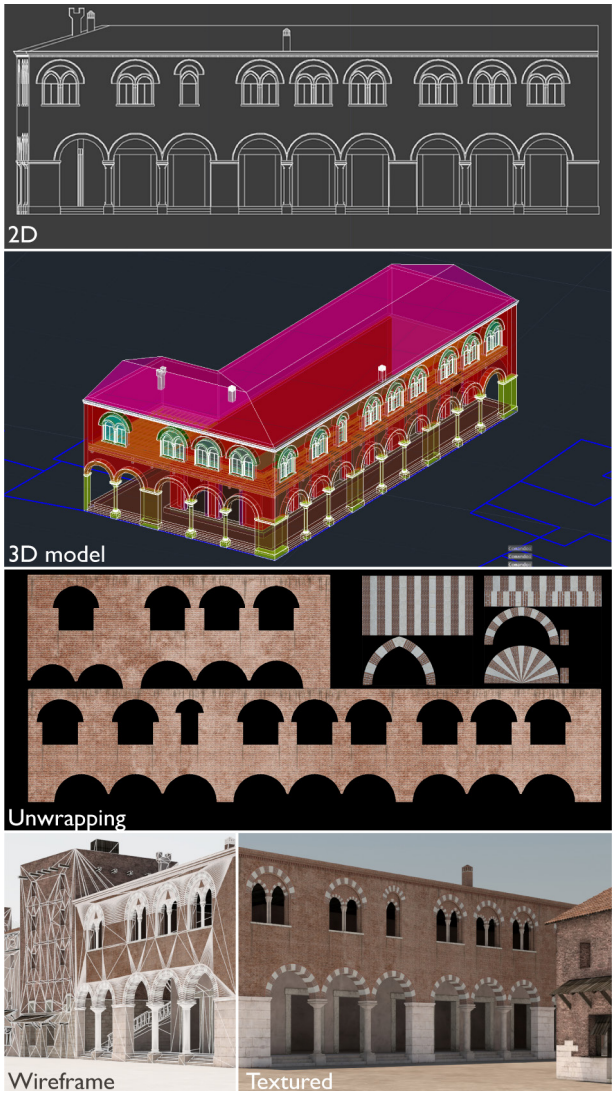


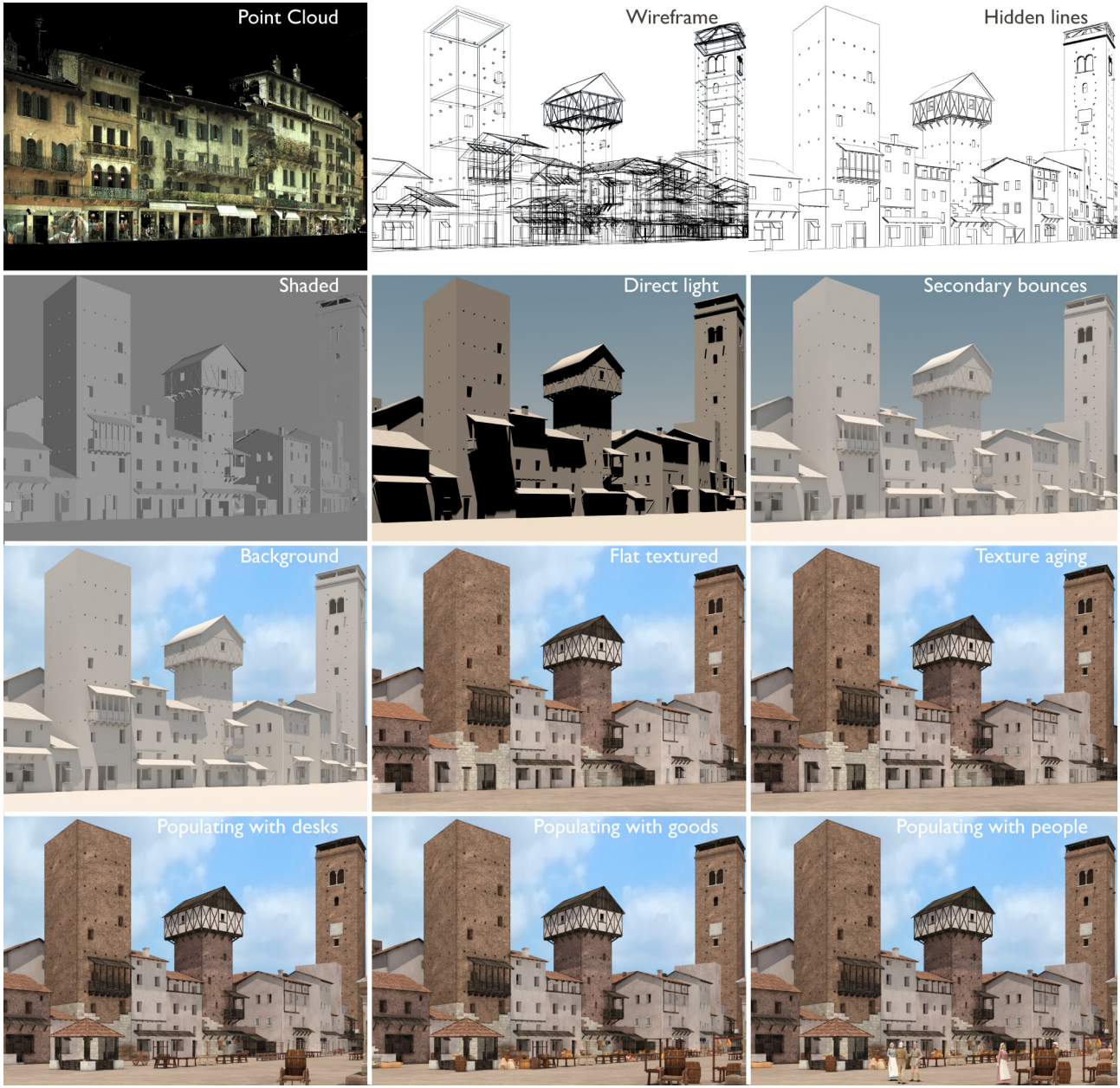
Fig. 8. Market props for populating the scene.



For the buildings on which we chose to use the textured unwrap system, it was possible to intervene specifically, by adding leakages on the sides of the window and door sills. Where instead we opted for box mapping or planar mapping, we chose to use multi-layered materials or blend materials, applying the original texture as the first layer, and as the second layer, the same lightened or darkened texture partially occluded with dirt maps in grayscale. To mask the repetition effect of the texture, the occlusion map was applied with a smaller tiling than the tiling of the texture.
A different type of dirt called VRay-dirt was used to darken the protrusions and the recesses, creating a dirt effect without unwrapping each building, decreasing the time consumption of the texturing phases. Finally, for the roof texturing, we chose to use a multi-layered material by adding a displacement map that simulated the geometry of the tiles, because modeling the single tiles would have exponentially increased the modeling time. For almost all textures, with the exception of the roofs, it was decided to integrate the roughness information, like shadows, in the diffuse channel, without the use of displacement and bump effects which would have slowed down the rendering times.
The final step was the production of the video. The camera paths were decided following a storyboard and the draft-recorded voice of the narrator. This made it possible to accurately define the rhythm of the video, and to determine the camera paths, synchronizing movements and times with the off-screen narrating voice. Even in this latter phase, the confrontation with the historians allowed us to define the scenes together with the final editing of the video. Once we decided and approved the camera paths, we populated the scene with goods, stands and people in medieval clothing [20].
The positioning of the objects, given their large quantity and great detail, was done by carefully taking into consideration the location of the cameras. At this stage, the scene was cleared of redundant geometries and buildings were added to give depth to the prospective views of the alleyways opening onto the square and that are captured by the cameras. Finally, all the frames were rendered separately using high resolution settings.
We used 50 machines, in network, for rendering, which required 35 hours of total computation. The various sequences were mounted in mp4 format and passed to professionals for the video and audio editing.

Fig. 9. Process of texturing: from the 3D model to the creation of the map using unwrapping.




Point Cloud
Wireframe
Hidden lines
Shaded
Direct light
Secondary bounces
Background
Flat textured
Texture aging
Populating with desks
Populating with goods
Populating with people

Conclusions

This case study is the result of a multidisciplinary work, where historians of the city and architects worked together with the goal of shaping a scene of daily life in the market square of Verona during the fourteenth century. The search for the historical and iconographic documentation relative to the early medieval age was flanked by a work of interpretation of that information, through which we tried to respond to the needs of scientific inquiry and the methods of modeling and three-dimensional visualization, aiming to combine informative aspects and scientific accuracy.
Digital visualization as representation of a past no longer extant today is a communicative necessity of which virtual reconstructions become means and experience of an otherwise intangible time.
The case study of Piazza delle Erbe has been presented as an expression of a methodology which had the objective of providing a possible answer to the multidisciplinary approach which characterizes the research on the Architectural Heritage of the past where reconstructions, if scientifically substantiated, become clear documents of transmittable contents. The achievement of this ultimate goal is still far away, especially where the transition from the individual building to the urban scale sector adds further degrees of uncertainty and complexity.
Therefore, from a disciplinary point of view, it is time to consider the field of virtual reconstructions as a discipline in itself. This will lead us necessarily to turn our attention towards the development of a unified methodology and comprehensive documentation in virtual reconstructions, developing web-based information systems or virtual research environments able to ensure scholarly quality. Several research groups, such as the *Digital Arbeitsgruppe Rekonstruktione* [21] established in 2014, have been working on the topic of digital reconstruction of cultural heritage with the aim of creating a common research platform within the *Digital Humanities*. The purpose is to address the issues of disambiguation, the working methodology, documentation and the preservation of digital reconstruction projects. Efforts and experiences which lead to the achievement of significant progress forward.

Fig. 10. Previous page. 3D modeling: from the point cloud to the scene populated with objects and people.

Fig. 11. Piazza delle Erbe: aerial view of the virtual reconstruction.

Acknowledgments

We would like to thank Professors Francesca Bocchi and Rosa Smurra, city historians, coordinators of the project, who led the interdisciplinary group of Michele Berretta, Silvia Bertacchi, Giacomo Brandolini, Luca Cipriani, Salvatore Corso, Filippo Fantini, Luca Grossi, Lorenzo Manzano, Andrea Notarstefano and Marco Orlandi.

Note

[1] Reilly 1990.

[2] ENSAM-IBM. 1992. *Virtual reconstruction of Cluny Abbey*.

[3] Burns, Beltramini, Gaiani 1997.

[4] Bocchi 1999; Bocchi 2004.

[5] Koeller, Frischer, Humphreys 2009.

[6] Kuroczyński, Hauck, Dworak 2014; Münster 2013.

[7] Apollonio, Gaiani, Zheng 2013a.

[8] Bentkowska-Kafel, Denard, Baker 2012.

[9] *A project from an idea of R. Smurra (planning and general coordination); scientific in charge* F. Bocchi, R. Smurra.

[10] <www.romereborn.virginia.edu> (consulted on June 13, 2017).

[11] Dylla 2010.

[12] *Assassin's Creed*, Ubisoft 2007; Hausar 2014.

[13] Among the other iconographic documents utilized, see: *Iconografia rateriana. Copy of Scipione Maffei*. Biblioteca capitolare, Cod. 106; *Piazza Grande di Verona. Engraving*, 1549; Ligozzi, P., *Verona città celeberima*. Engraving, 1630; *Prima Veduta della piazza detta Delle Erbe in Verona*. Engraving, 1747; Closs F., *Piazza D'Erbe*. Engraving, 1859; Barberis G., *Piazza Erbe*. Engraving, 1877; Austrian Cadastre 1843-1852; Napoleonic Cadastre 1807-1813, Historical Archive of the Municipality of Verona.

[14] *Prima Veduta della piazza detta Delle Erbe in Verona*. Engraving, 1747.

[15] Austrian Cadastre, 1843-1852; Napoleonic Cadastre 1807-1813, Historical Archive of the Municipality of Verona.

[16] Municipal Statutes of Verona, version dating 1276, 1327, 1393.

[17] *Piazza Grande di Verona*. Engraving, 1549.

[18] Arslan 1939.

[19] Apollonio, F.I., Gaiani M., Baldissini, S. 2011. A color processing for displaying reality-based three-dimensional digital models in RTR. In Rossi, M. (ed.). *Colour and Colorimetry. Multidiscipliary contribution. Optics and Photonics Series Notebooks*, no. 21, Vol. VIIb, pp. 260-267. Rimini: Maggioli.

[20] Human figures, shops, stalls, vegetable and animal products modeled by Michele Berretta.

[21] <http://www.digitale-rekonstruktion.info/uber-uns/> (consulted on June 13, 2017).

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