The Scale Model of Mirafiori Castle: AR Applications for Inclusive Enjoyment of Cultural Heritage

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Abstract. The research project on Mirafiori Castle, funded by the European project proGIreg, results from an agreement between the Department of Architecture and Design of the Politecnico di Torino and the Municipality of Turin.
The castle, once one of the out-of-town residences of the Savoy family, at the present time no longer exists: this is the reason why the early stages of the research produced an augmented reality experience, supported by an information panel placed in the surroundings of the castle ruins, aimed at the localization and visualization of the castle in its heyday.
The most recent phases of the work, currently in progress, see the research team engaged in the creation of a scale model of the castle through digital fabrication processes, as a media of inclusive fruition, with which to associate AR contents that enrich the model with various information, geared toward understanding the artifact in relation to the cultural context in which it was built and its stages of transformation, historical events involving the royal family, and the customs and amusements of court life.

Keywords: local promotion; cultural heritage; scale model; AR.

1 Introduction

The research project results from an agreement between the Department of Architecture and Design of the Politecnico di Torino and the Municipality of Turin to realize an augmented reality simulation of Castello di Mirafiori and cultural accompaniment for citizens funded by the European project proGIreg (Productive Green Infrastructure for post-industrial urban regeneration). The castle, once one of the out-of-town residences of the Savoy family, at the present time no longer exists: it was converted into a manufactory in the second half of the eighteenth century and later abandoned and underwent a slow and inexorable decline that caused its gradual disappearance.

Earlier phases of the work saw the research team engaged in digitally reconstructing the castle compound morphology in the period of most extraordinary splendor and hypothesizing its location. The realization of the digital model comes from the interweaving of information derived from historical documentation and enables the implementation of AR experiences aimed at making the results of documentary research and digital reconstruction accessible to a broader audience.

2 Structure of the research and methodological approach

The history of the castle and gardens, reconstructed through documentary analysis, was described in Vittorio Defabiani's (1987, 1990) [1] [2] and Chiara Devoti's (2014) [3] essays.

In the earlier phases of the work, the research team was engaged in digitally hypothesizing the castle and the garden's location and reconstructing their morphology in the period of most extraordinary splendor. The creation of the digital model comes from the interweaving of information derived from historical documentation (texts, design drawings, survey drawings, pictorial views).

In particular, a photogrammetric survey was carried out of the cryptoporticus' arcades that still exist in the form of ruins, and an on-site survey of the courtyards of the auxiliary buildings of the castle, which show, in the masonry enclosures, traces of the main gate to the city and a side gate halfway along the western side of the original enclosure.

The so-called 'Carta della Caccia' (pre-1762) and several later cadastral maps, the French cadastre (1805), the Gatti cadastre (1820-1830) and the Rabbini cadastre (1866), contributed, together with these surveys, to the location of the ancient artifacts on the current numerical cartography and served to reconstruct the gradual dismantling of the architectural and environmental complex.

At the architectural scale, among the various iconographic documents, emerged for their importance:

- the 'Tippo del Castello e Beni di Millefiori' (mid-18th century), which testifies to the deviation of the Sangone stream in favor of the triangular conformation of the garden to the south of the castle,
- Carlo di Castellamonte's ground plan for the enlargement of the palace for the wedding of Vittorio Amedeo to Maria Cristina of France (1619-1620), which allows us to recognize the realized parts of the building and gardens,
- the one-point perspective view of the castle by Giovanni Tommaso Borgonio (1655), showing the elevation and gardens towards the Sangone,
- the survey drawings of the castle on the occasion of its transformation into a tobacco manufactory (1741), particularly the longitudinal section showing slabs and openings, both original and newly built.

The last three drawings show extraordinary geometric and metric consistency. The Castellamonte plan and the elevation in the Borgonio view appear to coincide in their vertical alignments, while the latter, when compared with the longitudinal section, shows the correspondence of slabs and windows.

The acquired data do not allow reconstructing the service bodies along the southeast side of the castle, while the shape of the roof of the central body has been assumed to be analogous to Sebastiano Serlio's Ancy-le-Franc Castle, one of the sources of inspiration for Mirafiori Castle.

The west wing of the castle, marked in the plan as being in design, appears never to have been built.

Reconstruction through documents reveals that the two celebratory views of the complex, from the north and the south, contained in the Theatrum Sabaudiae (1682) [4] that in the collective imagination represented the splendors of the castle, show several parts that were never realized: the wide exedra towards the city, the doubling of the side pavilions of the central body, and the west wing of the castle.
Therefore, the 3D model reconstructs the external structure of the building, including the decorative apparatus and the complex of the gardens, schematized according to the findings of the documentary analysis (Fig. 1).

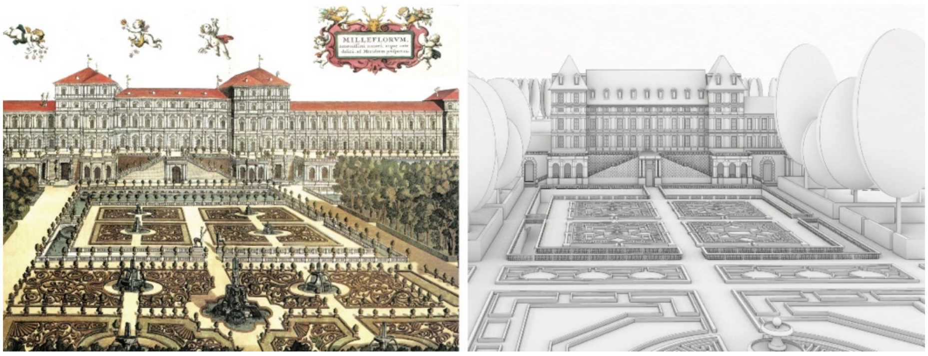

Fig. 1. Comparison between the view of Mirafiori Castle in the Theatrum Sabaudiae, meridional facade, (Bleau 1682, I, 35) and the reconstructive digital model of the built complex (Modeling: R. Spallone, M. Vitali).

This model enabled the implementation of an AR experience aimed at making the results of documentary research and digital reconstruction accessible to a broad audience, starting with an information panel placed near the castle ruins. A subsequent phase of the work, involved the creation of physical reproduction to scale of the digital model of the castle through digital fabrication processes, as a function of inclusive fruition, with which to associate AR contents that enrich the scale model with various information, geared toward understanding the artifact in relation to the cultural context in which it was built and its stages of transformation, historical events involving the royal family, and the customs and amusements of court life. The realization of the scale model of the Castello di Mirafiori primarily uses the digital reconstructive modeling already completed, implying the adjustment of some essential aspects: on the one hand, it involves a qualitative reshaping of the elements (necessary simplifications), and on the other hand, require a quantitative discretization of the components through which design the assembly of the model.

3 Physical model construction

The procedure for the digital fabrication of Mirafiori Castle's model is based on engineering the previously realized reconstructive digital model [5].

The adopted representation scale of 1:250, as a result of many complementary evaluations, both regarding the effective model footprint (800x1740x220 mm), the transportability, the user perception, and the simplification operations in terms of geometric complexity which the digital model was subjected to be physically fabricated, was confirmed as a proper compromise (Fig. 2).

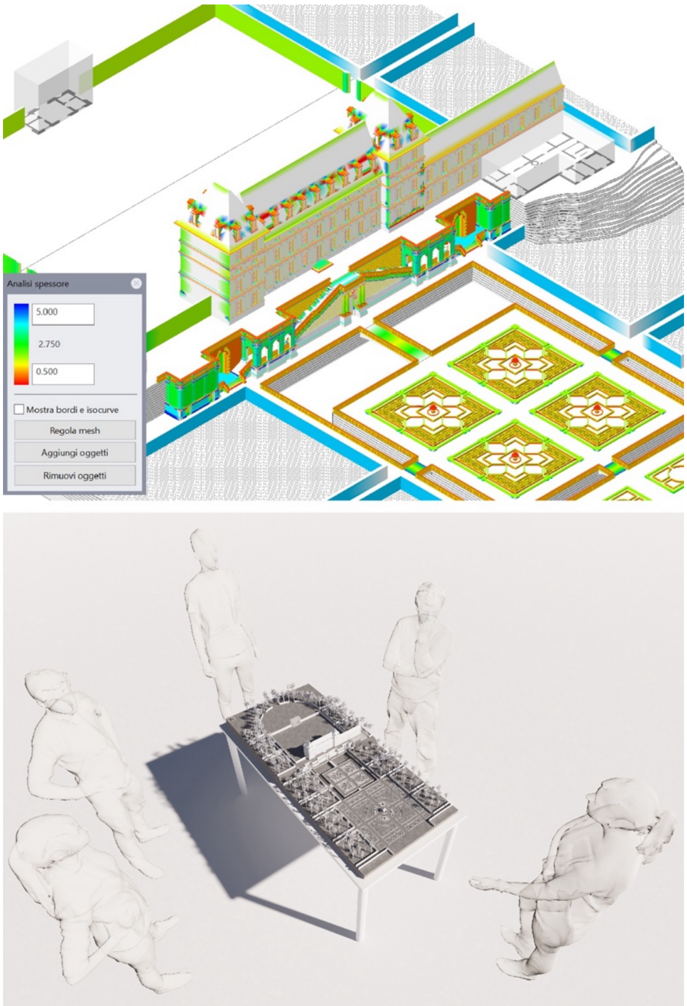

Fig. 2. The analysis of the thin parts to be produced by 3D printing (top) and the visualization of the model in the display space (bottom) (Graphic elaboration: E. Pupi).

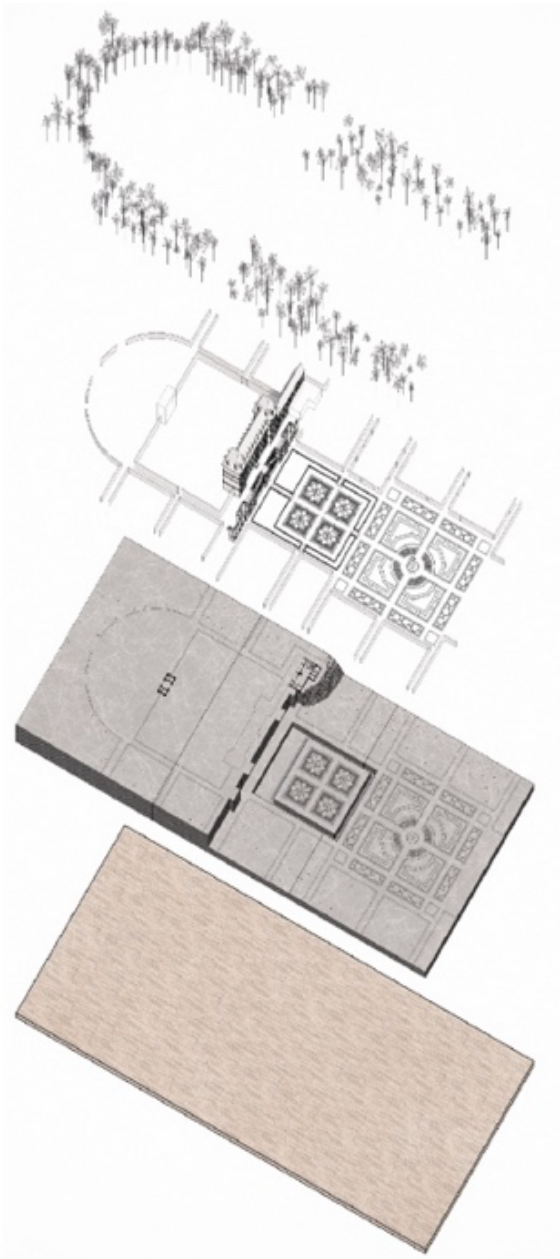

Fig. 3. Subdivision of the building components of the physical model (from below): basement plane made of plywood, greyboard panels, PLA components obtained by 3D printing and natural trees (Graphic elaboration: E. Pupi)

The digital fabrication techniques adopted make use of the machinery supplied to the MODLab Arch model laboratory of the Department of Architecture and Design of Politecnico di Torino: a laser cutting machine (Trotec Speedy 400) with a working area of 1000 x 600 x 305 mm, and an FDM 3D printer (Ultimaker S5) with an active area of 330 x 240 x 300 mm.

About the used materials, the model design provides for their division into four main categories addressing the further assembly stage (Fig. 3):

- A basement plane, upon which assembling the components, conceived to give stability to the physical model, consisting of a 15-mm-thick plywood panel, the dimensions match the footprint of the model (800x1740 mm)
- greyboard panels with a thickness of 3 mm, subjected to engraving and cutting by laser machine, overlapped to restore the height differences between the honour court and the gardens
- detail elements, meaning railings, fountains and hedges, the body of the Mirafiori Castle, the cryptoporticus, and the stairs leading down to the gardens, made by additive 3D printing process, using white PLA spools
- tall vegetation, widely spread in the castle surroundings, consisting of natural Noch 23100 trees (composed of *teloxis aristata* and between 5 and 10 cm tall), painted with opaque white spray varnish.

Preparation for digital fabrication of the components is done according to the production available volumes (Fig. 4): the laser cutting process was prepared by extrapolation of the vector drawings directly from the digital model, paying attention to any overlapping or excessively close (d<1 mm) cutting/engraving lines.

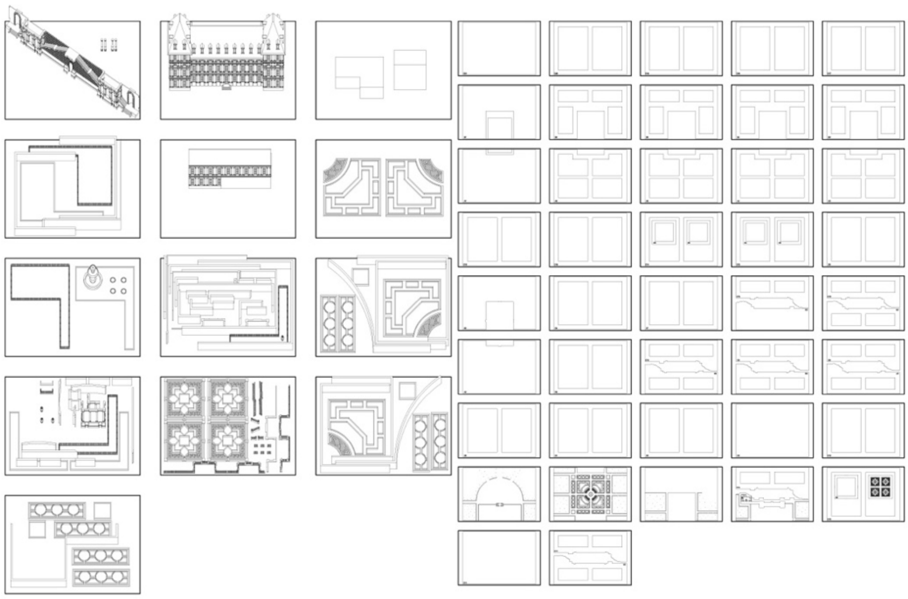

Fig. 4. Cataloging and organization of components produced by 3D printing (left) and laser cutting (right) (Graphic elaboration: E. Pupi)

This resulted in the use of 42 sheets of 3-mm-thick greyboard. At the same time, for 3D printing, the process was optimized by organizing the components into 13 printing plates, 12 with single extrusion of white filament and 1 with natural filament (without pigment). In both processes, precise and accurate cataloguing of the elements is important to speed up subsequent assembly operations. In this regard, in 3D printing, the parts were labeled with an identification code, while in laser cutting the codes were engraved directly on the panels.

To reduce the overall model weight, the panels made of grayboard were emptied and lightened to create the height differences. The resulting parts, as far as possible, were used for the placement of small elements to optimize the use of the material.

The digital fabrication required two weeks of work for the physical production of the elements by 3D printing and laser cutting, while the assembly phase took about ten days of work, during which the components were prepared and fixed using UHU Extra glue (Fig. 5).

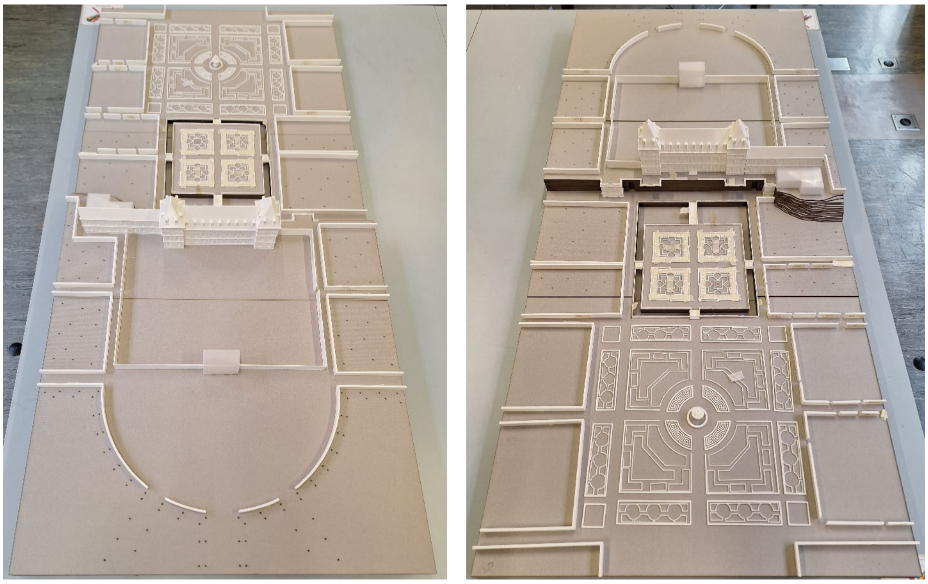

Fig. 5. Assembly phase and preventive check of the correct positioning of components preparatory to final fixing (Model: E. Pupi)

4 AR content applied to the scale model

The storytelling of architectural heritage today requires an increasingly interdisciplinary approach, also supported by Digital Fabrication technologies used to construct physical models and digital tools such as AR applications to communicate content superimposed on physical models that can be easily implemented in relation to the advancement of research and enrichment of the user experience.

The construction of multimedia contents and their visualization using AR technologies through direct anchorage to the maquette, intended as a narrative artifact, is related to the possibility of making accessible information to generate different levels of interactivity and immersion [6].

The blending of physical and digital models now generates a powerful tool that can present and visualize in a tactile and three-dimensional way, as in the case of architectures that no longer exist, dynamic elements, textual objects, and much more [7].

Following the construction of the scale model, the AR fruition of the physical model focuses on the choice, organization, and construction of the multimedia contents to be anchored to the maquette. The objective is to make different languages interact within a single information context. In particular, the types of content to be built can be referred to the following categories:

- static contents in static vision, such as text documents, evocative images, videos, architectural drawings, and conceptual schemes
- static contents in dynamic vision, three-dimensional static contents providing additional information regarding transformations and changes over time, compositional, distributive, and environmental aspects
- dynamic contents in dynamic vision, thanks to specific animation software, to build and superimpose dynamic content such as videos and animations on the model.

The AR content designed for augmented fruition of the scale model of the Mirafiori Castle, for the most part, refers to the historical contextualization of the salient phases of the construction and transformation of the architectural complex, made explicit through labels that refer to textual information and images describing the protagonists involved in the construction, including those transformations made in the late 1700s in order to transform the castle into a tobacco factory. Some content will be displayed in overlays, such as the historical design drawings for the extension of the castle by Carlo di Castellamonte (1619-1620), only partially realized, associated with the digital creation of simplified volumes aimed at a better three-dimensional understanding of the hypothesized interventions. Again, other documents (such as Borgonio's famous engraving from 1655) will be displayed superimposed on the model to describe how it was built by showing the main references used for modeling the decorative apparatus of the facades and staircase, the gardens, etc. Contents of great interest, in order to understand the role of the castle in the construction of the image of the Savoy court on the European scene, will be the two views extracted from the Theatrum Sabaudiae (1682), from which architectural volumes were conceived as superimposed on the physical model, facilitating a comparative reading between celebratory images and built architecture.

The model may also be the physical medium for additional digital content dedicated to narrating scenes from life at the castle as witnessed by historical sources, such as amusements and games, sports activities, anecdotes, and events such as celebrations and weddings. Such a narrative system, in which the physical model is at the center of content that is diverse in both subject matter and mode of use, is constituted as an open system that can be easily implemented and can accommodate new content and links to different documentary sources over time.

5 WebAR applications: technical insights

Among the possible porting methodologies for a virtual environment on a mobile platform, the option of web augmented reality (WebAR) – accessed through a browser without installations, based on standardized technologies developed over decades such as JavaScript – maximizes compatibility [8]. Today, more than ever, in keeping with this goal, the preparation of materials to be integrated into a WebAR environment must consider limiting factors of different kinds.

The most obvious is the geometric (via CPU) and graphic (GPU) computational power of mobile devices, tied not only to lithographic technology and thus to classic transistor density calculations, but also to the less steep increase in battery efficiency [9].

The second, software-based factor arises from the use of a web environment. The trade-off here is between removing access barriers for any operating system and accessing the most modern and optimized APIs, particularly those related to real-time graphical processing established on the desktop and under constant development for mobile (real-time raytracing, AI-based upsampling).

A third factor is the natural delay in technology adoption by a broad audience, estimated roughly as a three-year span to reduce the adoption of devices from a given generation below 10% [10].

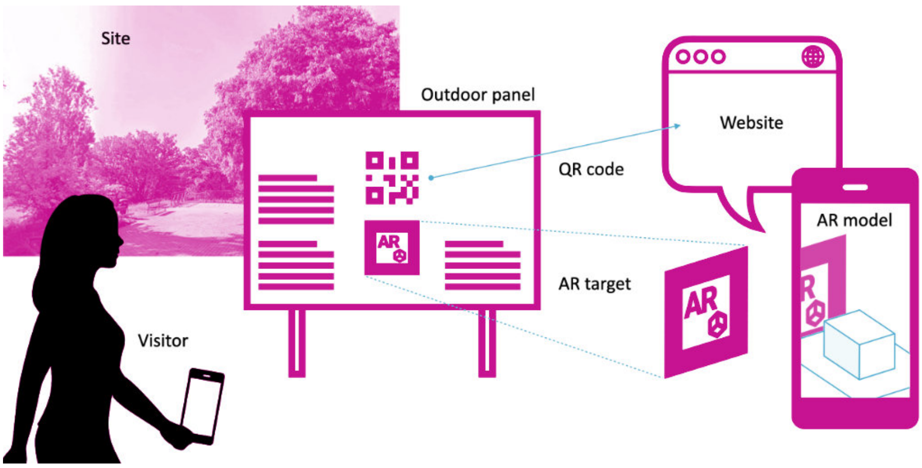

Fig. 6. Scheme of functioning and fruition of AR content associated with the panel related to Mirafiori Castle (graphic elaboration: G. Palma, V. Palma)

Within the set requirements, the AR.js platform was chosen to implement WebAR applications for showcasing the early stages of research documentation (Fig. 6), and it is expected to be utilized for upcoming applications based on the physical model [11].

AR.js allows tracking via image markers, has shown to be low in computational impact, and made the initial experiments largely interoperable with its family of free and open-source software (AFRAME, Threejs). This makes a potential migration to platforms with different or more advanced features easier, should they be implemented in the web environment. This flexibility offsets the risk that the choice of WebAR may be too conservative, cushioning the aforementioned software and adoption delay limitations.

The remaining optimization margin will relate to the processing of 3D models. From a geometrical standpoint, detailed models might allow lossless visualization up to "life-size", for example in virtual reality applications, where small portions of the model are accessed. Such detail, however, becomes an unused weight for scaled-down models.

In light of the limitations inherited from our past application, opting for a simplified model approach aligns with the current boundaries imposed by the technology. Specifically, the upcoming project will lean on pre-defined image targets situated on or around the 3D model, creating anchoring points for the AR overlay. Without extended tracking capabilities – a notable shortcoming of current WebAR technologies – the user is required to keep the target within sight for the entirety of the AR session.

In the case of the full display of the 3D model of the Castello di Mirafiori, it was possible to drastically reduce the number of polygons in the model by acting on small, repeated details, simplifying line subdivisions, and flattening 3D sections visible only from the front. This reduced the overall weight by 83% (from 200MB to about 26MB) without significantly altering the on-screen rendering at the desired resolutions, limiting computational requirements, energy impact, and loading times – another critical factor for slow connections (Fig. 7).

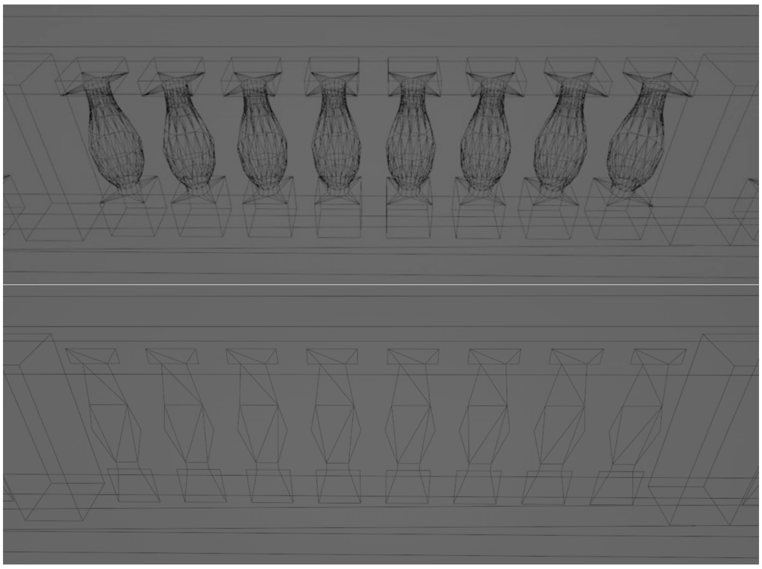

Fig. 7. Screenshots of the Blender modeling software interface showing a detail of the model before and after mesh reduction operations aimed at optimizing the AR web app (graphic elaboration: G. Palma, V. Palma).

These technological parameters align with our communication and dissemination objectives. Streamlined models allow for the effective conveyance of volumetric, typological, and hypothetical reconstructions that are informed by documentary research while providing a computationally efficient and smooth AR experience.

However, the real-time graphic processing of surfaces by the GPU may risk being another bottleneck for frame output. Rather than having the mobile device calculate approximate dynamic lighting for each frame, it is preferable to bake a static texture that applies fixed lights and shadows to the model's material. Processing on a desktop without time constraints, one can improve the lighting quality and subsequently compress the image into low-loss formats to reduce loading times, producing textures in this case that increase the total weight by less than 30%.

Decisions shaping the interface will be directed by a user-centric approach, emphasizing ease of access and directness rather than pushing the boundaries of WebAR's capabilities. By limiting touch interaction, the design can prompt users to rely on the intuitive camera tool for navigation, thus capitalizing on a key feature of AR. Still, interactive buttons or clickable element can be introduced for the sake of flexibility, enabling users to toggle through information layers or adjust the visual presentation, whether it's a close-up view of a 3D fragment or an in-depth look at an archival document. The web environment enables the integration of custom HTML+CSS multimedia content and supports a layered and dynamic presentation of the documentary research, seamlessly blending various content formats like textual information and historical iconography.

Camera movement freedom may be expanded in the future, potentially supporting full virtual/mixed reality experiences through extended tracking, which allows for persistent tracking even when the marker is no longer in the frame. This has recently been supported on native applications for recent generation devices and will likely be available on WebAR in the coming years.

6 Opportunities for project sharing and scalability

Mirafiori Castle, more than its intrinsic historical and architectural value, constitutes a strongly identifying element for the district that takes its name. Before the digital reconstructive work on Mirafiori Castle, nature-based solutions (NBS) were tested within the framework of proGIreg, including a hedgerow system to recall the castle gardens qualitatively.

The wish of the local community, which is very involved in promoting and protecting the site, to discover more about the history of the building resulted in meetings and discussions, culminating in the public presentation (December 2021) of the bibliographical and documentary analysis and the first outcomes of the digital reconstruction, which was followed by the collection of public memoirs about the artifact. The workflow also included the production of a video on the development process of the AR application and its functioning.

Many communication and dissemination events followed, such as ‘A Scuola di Orto’ (May 2022), where teachers and pupils of the Primo Levi Institute lead citizens on a virtual tour of Mirafiori Castle, ‘Open House’ (June 2022), or the ‘European Network of Living Labs’ (ENoLL) (Turin, September 2022) proposed to the European experts in attendance. From these came the idea to include such a visit and similar ones conceived from this on artifacts of cultural value, in the city’s official tourist itineraries, given the high environmental, social, and cultural content.

Finally, the city presented the outcomes of this project at the ‘Major Cities of Europe’ conference (Larissa, November 2022), as an example of how nature and technology can create useful synergies to meet citizens' needs and stimulate their involvement, trigger urban regeneration and generate new ideas and possibilities for transformation and development for the area.

Fondazione Mirafiori, thanks to the experience gained from the projects implemented in recent years, including proGIreg, has embarked on a path of co-design in the area that will see it engaged from 2023 to 2025. The foundation wants to work in an increasingly synergistic and innovative way on the attractiveness of the neighborhood, also through the introduction of new artistic elements that support the enhancement of the area, make the redeveloped areas more visible, and attract new visitors.

Also recalling the principles of the European Community's New European Bauhaus (NEB) initiative, on which the city has published a *manifesto*, it is intended to work on the paradigm of art, closely connected to the themes of sustainability and inclusion. Creativity and art, therefore, are intended as channels for rediscovering places, enhancing and developing their potential, and telling the story of territories and communities.

By focusing on the historical and, in some cases, artistic interest, several areas will be identified for enhancement through public art that can also refer to the natural and historical heritage, as well as its important migratory, industrial, and post-industrial memory.

In parallel, the city and the Foundation have begun a dialogue with Turismo Torino e Provincia s.c.r.l. to understand how to make the most of what has already been achieved in the area and to think of new tourism products to offer to its citizens and tourists passing through.

7 Conclusion

Currently, the authors are proceeding to assemble the scale model and to build the specific models and content inherent in the associated AR experiences, which at present concern two previously illustrated categories, static contents in static vision and static contents in dynamic vision.

The physical model, which is being finalized, will be placed in October 2023 at the Parish of St. Barnabas, which wants to mend its ties with the area also thanks to the renovation of the convent’s historic rooms, which can be used as guest quarters.

An event open to the public will be organized at the end of October 2023, with the presentation of the scale model and some of the AR contents associated with it.

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