Visualising Piffetti’s Library in Villa Della Regina Museum: an Interdisciplinary Digital Project for Knowledge Accessibility

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ABSTRACT: This paper presents interdisciplinary research to enhance knowledge accessibility in museums. The scientific project is finalized to return to the public the imagery of the library crafted by Pietro Piffetti, a recognized masterpiece of 18th-century cabinetmaking, within its original location in the Villa della Regina. In the past, the library was moved to the Quirinale, where it is located today. The work pipeline includes the archival research and bibliographical studies in the art-historical field; the 3D digital survey of the library at the Quirinale and the room, now empty, in Villa della Regina; the recognition of the original parts by Piffetti; the reconstructive digital modeling and texturing of the library; the creation of the app and services for augmented and virtual reality experience aimed to interactive enjoyment of the reconstructed model.

1. INTRODUCTION

This proposal arises as part of interdisciplinary research developed within a PNRR (National Recovery and Resilience Plan) project in the Accessibility sector that funded the Villa della Regina Museum (one of the Savoy royal residences managed by Direzione regionale Musei Piemonte) in Turin, Italy. The research concerns the digital reconstruction of a precious library made in the 18th century by the cabinetmaker Pietro Piffetti to furnish a small room in the Villa della Regina, later adapted with modifications and additions to a larger room in the Palazzo del Quirinale.

The work pipeline includes the archival research and bibliographical studies in the art-historical field; the 3D digital survey of the library at the Quirinale and the room, now empty, in Villa della Regina; the recognition of the original parts by Piffetti; the reconstructive digital modeling and texturing of the library; the creation of the app and services for augmented reality (AR) and virtual reality (VR) experience aimed to interactive enjoyment of the reconstructed model.

2. RESEARCH FRAMEWORK

The PNRR's goal of reducing obstacles, inequalities, and gaps that limit citizens' participation in cultural life and heritage has been interpreted in this project as a stimulus to increase the accessibility to knowledge.

The multidisciplinary team that developed the project includes scholars and professionals in art history, digital acquisition, 3D modeling methodologies, and the design of digital solutions for heritage presentation. The goal of the work is to return to the public the imagery of the library crafted by Piffetti, a recognized masterpiece of 18th-century cabinetmaking, within its original location in the Villa della Regina, inside the small study room of the Duke Carlo Emanuele III of Savoy.

The phases of the research include:

- The bibliographical and archival research about the artifact and the related studies in the art-historical field;
- The survey of the library by digital photogrammetry and Structure from Motion (SfM) technique and the comparison and

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integration with a laser-scanner survey by Studio Azimut in 2016;

- The SfM photogrammetric survey of the room in Villa della Regina;
- The recognition of the original and added parts, and the changes that occurred in the transfer from Turin to Rome;
- The reconstructive digital modeling and texturing of the library in the original layout and the room in Villa della Regina, carried out using geometric modeling techniques;
- The creation of an app and services for handheld devices (iOS and Android smartphones and tablets) and desktop devices (personal computers) for content fruition;
- The development of the augmented reality (AR) experience for mobile devices for interactive enjoyment of the reconstructive model within the Villa;
- The development of the virtual reality (VR) experience for immersive remote enjoyment through a web platform.

In two previous papers presented at the 29th CIPA Symposium [1], [2], the project's concept and the integrated survey of the cabinet, related to the first and second phases listed above, were described. In the present contribution, we report the entire project's development. We intend to explain how the digital processes characterizing the workflow are integrated, the potential, limits, and foreseeable development of the work done, and the scalability to museums and other cultural entities.

3. PIFFETTI'S LIBRARY FROM TURIN TO ROME

The bookcase made by Piffetti, one of the leading cabinetmakers of the 18th century, active mainly in the service of the Savoy court, is one of the most significant interventions related to the interior spaces of the Villa della Regina in Turin.

Since the end of the previous century, the building had been the favorite residence of Anna Maria d'Orleans, wife of Vittorio Amedeo II, King of Sicily, since 1713. The subsequent arrival of Filippo Juvarra in Turin involved, among other interventions, the rethinking of the architectural spaces of the Villa and their decoration. Further renovations, relating mainly to the gardens and decorative cycles, began in 1733.

The bookshelves were crafted between 1733 and 1739 and located in the *Gabinetto verso mezzanotte e ponente* (Cabinet toward midnight and west) inside the King's Apartment.

Figure 1: *Villa della Regina library cabinet (Photo: C. Teolato).*

Precious wall covering with poplar shelves veneered with fine woods—rosewood of four varieties (rio, india, angelo, mocassar), boxwood, yew, and olive—embellished with refined ivory inlays reproducing floral decorations made with the pyrographic technique, featured the library.

With the handover of the Villa della Regina to the Istituto delle Figlie dei Militari between 1867 and 1868, the library was disassembled and taken to the Guardaroba in the Castello di Moncalieri. Only in 1876 was the furniture transferred to the Palazzo del Quirinale, which was elected as the King's residence after the transfer of the capital to Rome. The furniture was destined, in 1879, for the cabinet next to Princess Margherita's bedroom. The new location required adaptations and additions for the room, which was larger, higher, and of different proportions. The adaptations and restoration were entrusted to Giacomo Quarelli, who brought the library back to Turin to carry out the work completed in three months in his workshop. At the same time, some masonry work affected the cabinet at the Quirinale.

Piffetti's woodwork was placed on three walls of the new room, while the fourth wall with the window was covered with a new set of shelves. The console under the mirror, not mentioned in the 1755 inventory of Villa della Regina, was also included with the 19th-century arrangement, while the one on the opposite wall features representations of military exploits from 1733 and 1734, one of them signed by Piffetti. The fascia and frieze were also added to adapt the furniture to the greater height of the cabinet [3], [4]. The possibility of restoring, albeit in digital format, Piffetti's library at Villa della Regina, inside the original room for which it was designed and built, today deprived of this heritage (Fig. 1), will allow an essential part of the Villa's history to be returned to visitors' enjoyment, thus helping to make accessible content that is currently no longer intelligible.

4. 3D DIGITAL SURVEY

The library survey considered the case studies' scales, geometry, and material characteristics.
Two acquisition campaigns were organized at the architectural scale (Fig. 2). Studio Azimut surveyed the Quirinale library's room in 2016 with a 3D laser scanner Focus 3D (Faro), generating a final 3D point cloud with a resolution of 0.5 cm. The Villa della Regina room survey was carried out in 2023 using a photogrammetric methodology with Alpha 7R IV (Sony) equipped with a CMOS sensor (9504 X 6336 pixels), a focal length of 28 mm, and an average working distance of 300 cm, obtaining an average GSD of 0.4 mm.
Besides, the library survey in Quirinale required more complex planning to overcome some bottlenecks. The first was the low illumination level provided by a big window and a central chandelier. The latter was also an obstacle due to its position 300 centimeters from the floor and its diameter of 150 centimeters. The second bottleneck was given by the materials and surface finish of the artifact, which presented optical non-cooperative materials and reflective surfaces. For all these reasons, the library's 3D acquisition was based on integrating different active and passive 3D techniques, validating the 3D data accuracy and reliability.
First, we considered integrating the previous 3D active acquisition with a photogrammetric campaign in the summer of 2022. The photogrammetric campaign used a 6D Mark II (Canon) equipped with a 36 X 24 cm CMOS sensor (6240 X 4160 pixels) with a fixed 24 mm lens at a working distance of 150 cm, achieving an average GSD of 0.4 mm on the library surface. Besides, 26 GCPs (Ground Control Points) were extracted from the range-based cloud, reducing possible orientation errors. In addition, different active and passive sensors have also been integrated in the detail scale, comparing photogrammetry in the same external conditions with an iReal 2S 3D Laser Scanner (Scantech) triangulation infrared instrument. The survey highlighted the geometric issues and scale variation in such a complex artifact, testing the instrumentation for this specific activity.

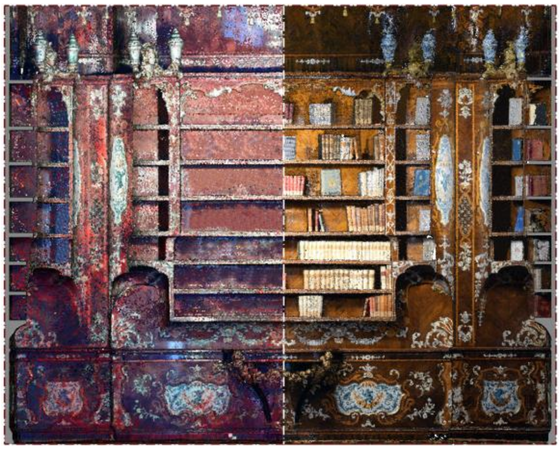

Figure 2: *The front side of the library. On the left is the range-based data, and on the right is the point cloud from photogrammetry. (Editing: M. Russo)*

The acquired 3D data were processed separately. The range maps from TLS have been aligned and optimized in the JRC Reconstructor program (Gexcel), to be managed within the ReCap PRO program (Autodesk) for visualizing and extracting the GCPs. The data from the triangulation system were oriented thanks to the feature detection, translating it into point clouds and mesh models. Finally, the images were all processed within the Metashape program (Agisoft), keeping the GCPs as a reference to reduce frame orientation errors. All 3D data from Quirinale have been integrated into the same reference system, comparing data at different scales and analyzing the reliability of the acquired library [2]. Besides, the survey in Villa della Regina has been processed and managed separately from the Quirinale, considering the different scopes of modeling and visualization of the case study.

5. ISSUES OF DATA TRANSPARENCY IN HERITAGE DIGITAL RECONSTRUCTION

Since the digital transition began, technological advances have made digital tools more accessible and affordable, revolutionizing how cultural institutions study, communicate, and represent cultural heritage. These technologies enable better information connections and scientific hypothesis representation, advancing heritage research and dissemination [5]. People increasingly recognize cultural heritage as a shared asset that must be preserved for future generations while maintaining its authentic traditions and memories. Digital visualizations are crucial here—they preserve cultural heritage and form an essential part of our reality and communal culture.

To maintain their value, reliability, and transparency in digital heritage communication must be ensured [6].

Transparency in digital heritage reconstruction presents two key challenges: mediating information for scholars and the public. For researchers, transparency maintains scientific rigor by allowing them to retrace steps and validate results. It enables scholars to evaluate their methods critically and ensures their interpretative choices in reconstructions remain clear and replicable. Transparency enhances understanding through accurate, coherent knowledge presentation for the public, supporting cultural institutions' educational goals.

Virtual reconstruction—a cornerstone of digital heritage—demonstrates why transparent methodologies matter. The Seville Principles (2012) define it as digitally reorganizing material remains to suggest past states. It helps plan physical restoration, rebuild lost artifacts digitally, and preserve intangible heritage. Through transparent communication, virtual reconstructions are understood as possible interpretations rather than definitive truths. This clarity enriches both academic discourse and public engagement with heritage.

Furthermore, transparent visualizations serve dual roles: as communication tools and research frameworks that deepen knowledge. By clearly conveying historical authenticity and interpretative decisions in digital reconstructions, they enable critical public engagement with cultural heritage, fostering new ways of interaction and thinking. This approach supports cultural democratization by promoting accessibility and deeper heritage connections. As Cesare Brandi notes, cultural heritage finds meaning not just in its creation but in its recognition by contemporary consciousness. Digital tools, used with transparent methods, bridge historical authenticity and modern understanding [7].

In conclusion, data transparency forms a fundamental principle of digital heritage reconstruction—not just a technical requirement. It strengthens scholarly work, builds public trust, and ensures digital visualizations meaningfully contribute to heritage preservation and sharing, translating verbal hypotheses into visual forms [8]. By making transparency central to their process, digital heritage projects achieve scientific excellence and cultural impact, securing their value for current and future generations.

6. PRELIMINARY RECOGNITION OF THE ORIGINAL PARTS

As seen when moving the library from Turin to Rome, Quarelli needed to adapt the artifact.

Concerning the point cloud and the digital model representing the current configuration of the artifact at the Quirinale, the digital reconstruction of the library in its original location required the analysis and photogrammetric survey of the room in which it was built, the study of the scientific literature concerning its construction, disassembly, and reassembly phases with additions, together with the analysis of an essential survey of the time (1876), which confirms the reconstructive hypotheses. The analysis of the cabinet at the Villa della Regina allowed us to verify the presence on the (original) plaster of a geometric grid used to assembly the furniture and wooden dowels held by iron hooks necessary to fasten the woodwork to the walls, according to a technique used in other rooms of the building [9]. Dimensional surveys have confirmed the complete correspondence of the traces on the plaster with the dimensions and subdivision of the individual modules of the bookcase, which, as hypothesized in previous studies [10] and confirmed by more recent investigations, were positioned in the room to form a quadrilateral with the four corners in the shape of a double recess: the central body of the bookcase at the Quirinale, now placed between two false pillars, was positioned on the short side of the Cabinet next to the entrance of the room; the other two modules of the bookcase, placed on the opposite long sides of the room, ended framing the French window on the west side and, symmetrically to the main body, with the other two openings. The frieze above the bookshelf is now tripartite due to the greater height of the room at the Quirinale: even from the drawings of the time (Sezione della Nuova Biblioteca di S.M.), it is evident that only its central band was the original part of the frieze (called ‘fregio esistente’, existing frieze, in the drawing). In contrast, the other two (a ‘giunta al fregio’, added to the frieze, and a ‘soprafregio’, above frieze) were designed to adapt the furniture to the new room. As seen above, the primary sources, referring to the inventories of 1755 and 1811 [10], also make it possible to imagine that of the two *consolles* currently present in the library, only one found its place in the original configuration, the one belonging to the central body: the other, reasonably added at the time of the new installation at the Quirinale, could be a readaptation of a game table mentioned in the 1811 inventory [11].

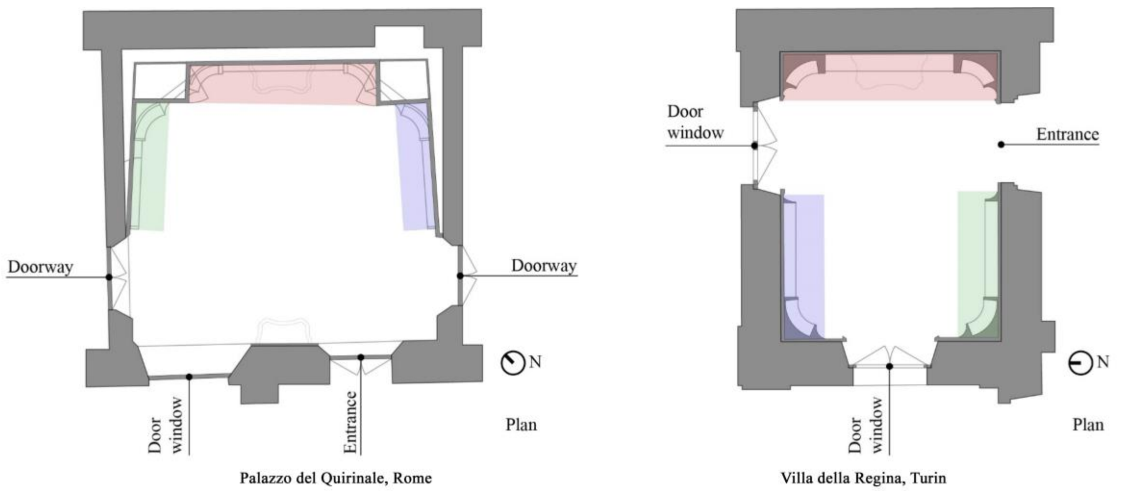

Figure 3: *The library assets in Palazzo del Quirinale and Villa della Regina. (Editing: M. Vitali).*

7. DEFINITIVE RECOGNITION, 3D RECONSTRUCTIVE MODELING AND TEXTURING

Piffetti's library digital modeling followed a philological approach that reversed the transformations undergone by the artifact over time. From its current location at the Palazzo del Quirinale, digital reconstruction sought to restore its original configuration at Villa della Regina in Turin. As shown in the process diagram (Fig. 4), this task utilized widely adopted digital tools in the cultural heritage domain [12] and required a rigorous methodological framework for selecting modeling techniques [13].

Geometric components (e.g., planar surfaces, single- and double-curvature surfaces) were modeled using NURBS geometry, while sculptural elements of high morphological complexity were retained as meshes derived from digital surveys. This approach optimized the balance between representational accuracy and computational manageability of the model, tailored to the specific requirements of AR and VR applications while maintaining high fidelity to the original artifact.

The digital reconstruction adhered to principles of visual abstraction, maintaining a balance between scientific accuracy and historical interpretation [14].

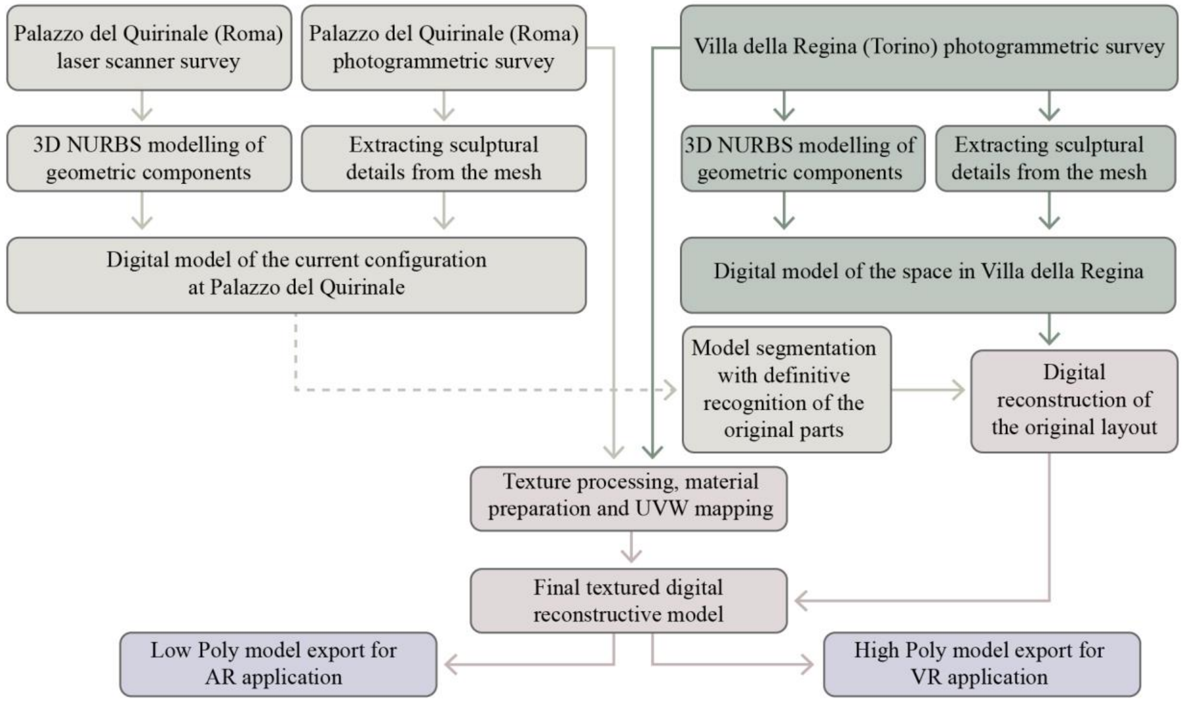

Figure 4: *Process diagram illustrating the digital modeling workflow of the Piffetti's Library, from source data to the generation of optimized models for AR and VR, encompassing NURBS modeling, sculptural detail extraction, and texturing. (Editing: E. Pupi).*

The methodology adopted furthermore aligns with the latest research on visualization in digital cultural heritage modeling, where representation simultaneously serves communicative and scientific research purposes, effectively addressing the complexity of the studied object [15].

Digital modeling was conducted using McNeel Rhinoceros 8, while Agisoft Metashape 2.1.3 was employed for processing digital photogrammetric surveys. Initially, the digital model of the current state was developed based on a point cloud generated by Studio Azimuth in 2016 [1]. For the restitution of sculptural decorative elements, data from photogrammetric surveys and high-resolution scans using a portable triangulation-based infrared system were integrated [2].

Most of the artifacts were modeled in Rhinoceros with NURBS geometry.

At the same time, sculptural decorations were processed in Metashape: high-density meshes were isolated, decimated for polygonal optimization, and retextured to restore UVW mapping lost during decimation, producing computationally sustainable meshes for AR and VR. These elements were imported into Rhinoceros, forming a hybrid NURBS-mesh model for further elaboration. The Villa della Regina environment was reconstructed from the photogrammetric survey, using NURBS modeling for walls, fixtures, shutters, the entrance door, and the floor. At the same time, the vault, including its impost molding, was imported as a decimated and textured mesh.

This methodological choice was particularly significant for AR applications, where precise dimensional correspondence between virtual and real elements is essential. Prior interpretative studies enabled the reconstruction of the original arrangement according to Piffetti's design at the Villa della Regina. The current state digital model was carefully segmented to extract the parts identified as original, which were reassembled within the Villa della Regina digital environment. The reverse process validated the interpretative transformation of the *boiseries*, demonstrating a tolerance of 10 millimeters, likely attributable to cumulative errors between digital surveys and corresponding 3D modeling (Fig. 5).

Given the high complexity of the inlays and wooden decorations, to obtain a digital model that could offer the most photorealistic fruition, texturing required meticulous processing of 2D orthophotos derived from photogrammetric

***Figure 5:** Digital reconstruction of the original configuration of Piffetti's Library at Villa della Regina. (Modeling: E. Pupi).*

surveys. Planar surfaces were textured using three orthophotos from the survey at the Palazzo del Quirinale. Single- and double-curvature surfaces necessitated specific 2D developments. For the Villa della Regina environment, orthophotos were prepared explicitly for shutters, fixtures, the entrance door, and the floor. Firstly, all 2D orthophotos underwent thorough retouching to compensate for minor gaps. Then, the elements of the composition were carefully contoured and saved separately in PNG format for use as diffuse channels in material creation.

Preliminary analysis demonstrated that achieving a sufficiently photorealistic result did not require additional mapping channels, such as displacement, normals, or specular layers. The materials application was performed within the Rhinoceros workspace, targeting the original Villa della Regina configuration's NURBS surfaces since meshes retained their original textures from the photogrammetric survey processing. Texturing the NURBS surfaces allowed subsequent management of various polygon resolutions for AR and VR applications. This process employed manual UVW mapping to ensure precise texture alignment with individual surfaces, with particular attention to curved areas (Fig. 6).

Differentiated model management for AR and VR represents an established strategy in cultural heritage valorization, where varying modes of interaction require specific geometric and texture optimization. This approach enhances user experience based on the unique characteristics of each technology [16]. Consequently, the final phase involved developing two distinct models for AR and VR (Fig. 7), and the geometric transformation process for NURBS followed different criteria:

Figure 6: *The Piffetti's Library's Rendering shows the complex texturing process applied to the NURBS surfaces, demonstrating the high-fidelity material application achieved through UVW mapping. (Modeling and rendering: E. Pupi).*

- For AR, only the *boiseries* components dismantled during the library's relocation were exported, excluding the vault, fixtures, shutters, entrance door, and floor. The conversion from NURBS to polygonal mesh was optimized with a maximum deviation of 1 millimeter from the surface, prioritizing model lightness for smooth visualization (total weight 386 MB, including 358 MB of the textures and 28 MB of the 3D model, consisting of about 737,000 polygons).
- For the VR, the entire model was exported to enable comprehensive visualization of the digitized environment and a higher polygon density with a maximum deviation of 0.1 millimeters was employed (total weight 643 MB including 577 MB of the textures and 66 MB of the 3D model, consisting of about 2,600,000 polygons).

In both cases, mesh elements remained unchanged, as previously optimized. After iterative testing, the FBX export format was selected for its ability to optimize model file size. Textures were preserved at maximum quality and resolution, with potential optimizations deferred to the AR and VR application preparation phase, ensuring maximum flexibility during final processing.

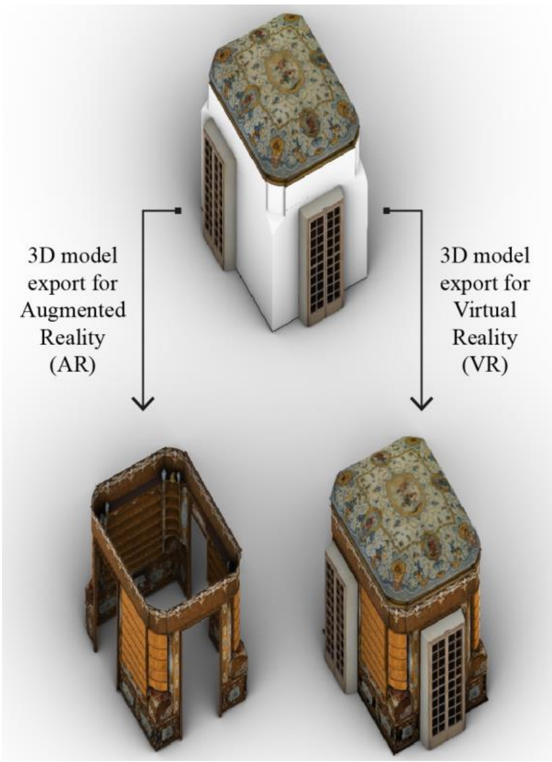

Figure 7: *The two optimized versions of Piffetti's Library model derived from the overall digital reconstructive model: the Low Poly model for AR applications, showing only the boiseries, and the High Poly model for VR applications, showing the complete digitized environment. (Editing: E. Pupi).*

8. COMMUNICATION THROUGH AR

AR has emerged as a pivotal tool in cultural heritage, offering solutions for a better understanding of reconstructed artifacts [17]. AR improves access to cultural resources by superimposing digital reconstructions onto physical environments, fostering an intuitive visualization of digital models based on interactive functions [18]. This technology has proven particularly effective in museum contexts, where it stimulates and addresses visitors' curiosity while supporting venues in promoting and strengthening audience engagement [19].

We developed an AR application using the Unity cross-platform game engine and its AR Foundation framework, a suite of tools enabling AR functionalities via platform-specific technologies like ARCore for Android and ARKit for iOS. To anchor the single 3D model produced, an image target (or "tracked image" in AR Foundation terminology) was employed, specifically a visual reference of the wooden floor (Fig. 8).

Figure 8: *Detail of the inlaid wooden floor extracted from the VR model to create the anchoring target for the AR model. (Editing: V. Palma).*

This approach leverages the natural features of the environment without requiring custom markers. AR Foundation provides extended tracking functions that record spatial data around the target and use the device's sensors to maintain the model's alignment with its initial position relative to the physical space, even when the target moves out of view.

During development, critical challenges for aligning virtual elements with the camera imagery included:

- Lighting consistency: ensuring seamless integration between virtual components and camera-captured imagery by balancing brightness levels.
- Model anchoring accuracy: maintaining precise placement of the 3D model.
- Occlusion of physical objects: addressing potential conflicts with movable room furnishings.

The lighting was configured with diffuse, fixed ambient light without cast shadows or light probes. This approach avoids lighting effects that might obscure texture details and reduces application resource demands. The room's natural light is provided by two full-height windows and supplemented by a single mobile floor lamp on one side of the space. The window orientation (northeast and northwest, shielded by another building volume) prevents direct sunlight. The natural light did not appear too intense during evaluation periods, avoiding stark contrasts between the room's interior and the digitally lightened library (Fig. 9). Artificial lighting creates noticeable shadows only on the vaulted ceiling above the thick cornice without disrupting the integration of the digital model.

The target area is large (1.54 × 2.31 meters) and effectively trackable despite the symmetry of the design, thanks to the contrasting inlays and the natural irregularity of the material (Fig. 8). This ensures precise and stable model placement. The relative position of the target and model was defined accurately during modeling, as the target image was extracted from the photogrammetric model itself. However, some inaccuracies were observed during tests, especially when using extended tracking. These deviations, typically within a few centimeters, do not compromise the application's effectiveness and can be corrected by realigning the target area within the field of view (Fig. 9). Critical alignment challenges were noted near the transition between the modeled boiserie above the shelving and the ceiling cornice, as well as around the window recesses.

The room's furniture, which will remain in place during the AR installation, can be easily repositioned to avoid obstructing the digital elements. Even if the taller floor lamp poses a minor visual challenge, its design minimally interferes with the AR experience's perspective illusion (Fig. 9).

The user experience was designed in collaboration with the museum's management, considering preservation requirements, particularly for the flooring. Visitors can step approximately one meter past the entrance before encountering mobile barriers (Fig. 10).

The model's "concave" design — intended to be viewed exclusively from within — aligns well

Figure 9: *Screenshot of the app in use. The top image displays the northwest window, allowing natural light into the room. The alignment of the model with the floor edges is shown just before restoring the ideal anchoring. The bottom image highlights the mobile floor lamp obscured by the digital model. (Editing: V. Palma).*

with the limited range of movement permitted. User interaction is primarily rotational, with restricted positional adjustments that prevent mesh "clipping" caused by close proximity to the model. However, scenarios where users step outside the room and redirect the device toward the cabinet need to be addressed. If the app remains in use, extended tracking features can maintain the model's position even when the device is moved several meters away from its anchoring location. This prompted us to design a digital 'panel' to cover the rear of the library model. This addition prevents visual inconsistencies, such as the model appearing to penetrate the room's wall when viewed from adjacent spaces.

Texture sizes were limited to reduce the overall application size and runtime resource demands, and compression was applied using Unity's build setup options. Starting from a total export size of 375 MB for the model, the memory footprint was reduced to approximately 260 MB. Texture reduction parameters were optimized empirically by evaluating the model's performance on the app running on target devices. The process of defining an acceptable level of detail was simplified by the usage constraints of the room, which prevent users from getting too close to the model's surfaces. Further reductions can be considered for the application rollout to maximize user accessibility to the service.

Figure 10: *AR application installed on the device. The image shows the user positioned near the area designated by the museum management for observing the room. The artificial lighting and the shadow cast on the ceiling by the cornice are visible, but these effects do not interfere with the integration of the digital component. (Editing: V. Palma).*

9. CONCLUSION

This experience represented an essential moment of welding between academic research and museum institutions, developing synergies between scholars belonging to the two realities that made it possible to offer the outcomes of a complex project to the community through simple and interactive modes of use. The deprivation from which the Villa suffered and the original look of one of its most valuable rooms come to light through the overlap between real and virtual.

The use of low-cost technologies and devices, ease of use, and adaptability to the museum context without the need for fixed or mobile installations offer excellent potential for the scalability of the product to other museum settings.

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