POLITECNICO DI TORINO
Repository ISTITUZIONALE

RECONSTRUCTIVE 3D MODELLING AND INTERACTIVE VISUALIZATION FOR ACCESSIBILITY OF PIFFETTI'S LIBRARY IN THE VILLA DELLA REGINA MUSEUM (TURIN)

(Article begins on next page)

01 September 2024

RECONSTRUCTIVE 3D MODELLING AND INTERACTIVE VISUALIZATION FOR ACCESSIBILITY OF PIFFETTI'S LIBRARY IN THE VILLA DELLA REGINA MUSEUM (TURIN)

R. Spallone [1]*, M. Russo [2], C. Teolato [3], M. Vitali [1], V. Palma[4], E. Pupi[1]

*[1] Dept. of Architecture and Design, Politecnico di Torino, Italy - (roberta.spallone, marco.vitali, enrico.pupi)@polito.it
[2] Dept. of History, Representation and Restoration of Architecture, Sapienza University of Rome, Italy - m.russo@uniroma1.it
[3] Direzione regionale Musei Piemonte – Via Accademia delle Scienze 5, Torino, Italy - chiara.teolato@beniculturali.it
4 Shazarch s.r.l., Radicondoli, Siena, Italy - valerio@shazarch.com

KEY WORDS: Reconstructive 3D Modelling, Augmented Reality, Virtual Reality, Virtual Portal, Museums Accessibility, Piffetti's Library, Villa della Regina, Quirinale.

ABSTRACT:

This research is realised in the framework of a project recently funded as part of the PNRR (National Recovery and Resilience Plan) in the Accessibility sector. The working team has been established in the framework of the scientific agreement between the Museum of Villa della Regina in Turin, the Department of Architecture and Design at Politecnico di Torino, and the Department of History, Drawing and Restoration of Architecture at Sapienza Università di Roma, and includes knowledge from art history, digital surveying, 3D modelling, and digital solutions for cultural heritage. The research involves the reconstructive 3D modelling of Piffetti's Library, once placed in the cabinet toward midnight and west inside the Villa della Regina and today in the Palazzo del Quirinale, and its interactive visualisation through augmented reality (AR) and virtual reality (VR) aimed at accessibility.

1. INTRODUCTION

This research is realised in the framework of the scientific agreement between the Direzione regionale Musei Piemonte, specifically the Museum of Villa della Regina in Turin, the Department of Architecture and Design at Politecnico di Torino, and the Department of History, Drawing and Restoration of Architecture at Sapienza Università di Roma. The research involves the reconstructive 3D modelling of Piffetti's Library, once placed in the cabinet toward midnight and west inside the Villa della Regina and today in the Palazzo del Quirinale, and its interactive visualisation through augmented reality (AR) and virtual reality (VR) aimed at accessibility. Following the National Recovery and Resilience Plan (PNRR)'s goal of reducing obstacles, inequalities and gaps that limit citizens' participation in cultural life and heritage, the project, recently funded as part of the PNRR in the Accessibility sector, intends the term in its broader meaning of accessibility to knowledge.

Figure 1. Piffetti's Library at Quirinale (Photo: M. Russo).

2. METHODOLOGICAL FRAMEWORK

The working group represented by the authors of this paper includes knowledge from art history, digital surveying, 3D modelling, and digital solutions for cultural heritage.

The subject of the research is a library made of wood with ivory and tortoiseshell inlays between 1734 and 1755. It is a craftwork realized by the famous cabinetmaker Pietro Piffetti to be placed in the library cabinet of Villa della Regina. The boiserie occupied the four sides of the small room. In 1868 it was moved to Moncalieri Castle and, in 1876, sent to the Palazzo del Quirinale in Rome, where it is currently located. Given the larger dimensions of the Quirinale cabinet where it was intended to be placed, it was shipped back to Turin in 1879. In a few months, cabinetmaker Giacomo Quarelli made the necessary additions and modifications to arrange the library on three walls (Morozzi, 2008).

The idea of visualizing the library asset in the now-empty room of the Villa della Regina, and allowing visitors to the Quirinale to virtually tour the villa's room furnished with the library now located there, involved the design of AR and VR experiences based on 3D reconstruction.

During the recent COVID pandemic, many museums had digital media for remote visits (Zhou et al, 2022). In contrast, AR technologies have suffered relative stagnation, despite the rapid development of technologies and devices (Amin et al, 2015, Bekele et al 2018). AR involves the creation of a continuum between real and virtual and aspires to bring users back to cultural sites by developing interactive content that can engage visitors in activities conceived from the design-for-all perspective. This project intends not only to re-establish the relationship between the community and museums as a physical place, increasing knowledge interactively, but also to allow the experience to be replicated in other spaces and times through VR, and to enjoy during the visit to Quirinale, the previous

---

* Corresponding author

The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium "Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future", 25–30 June 2023, Florence, Italy

Piffetti library in Quirinale and Piffetti room in Villa della Regina

Photogrammetric survey in Quirinale (2022) and Villa della Regina (2023)

Recognition of the elements and comparison between the current layout in Quirinale and the reconstructed layout in Villa della Regina

Main section and preliminary 3D modelling of Piffetti's library

3D modelling of the library at Quirinale

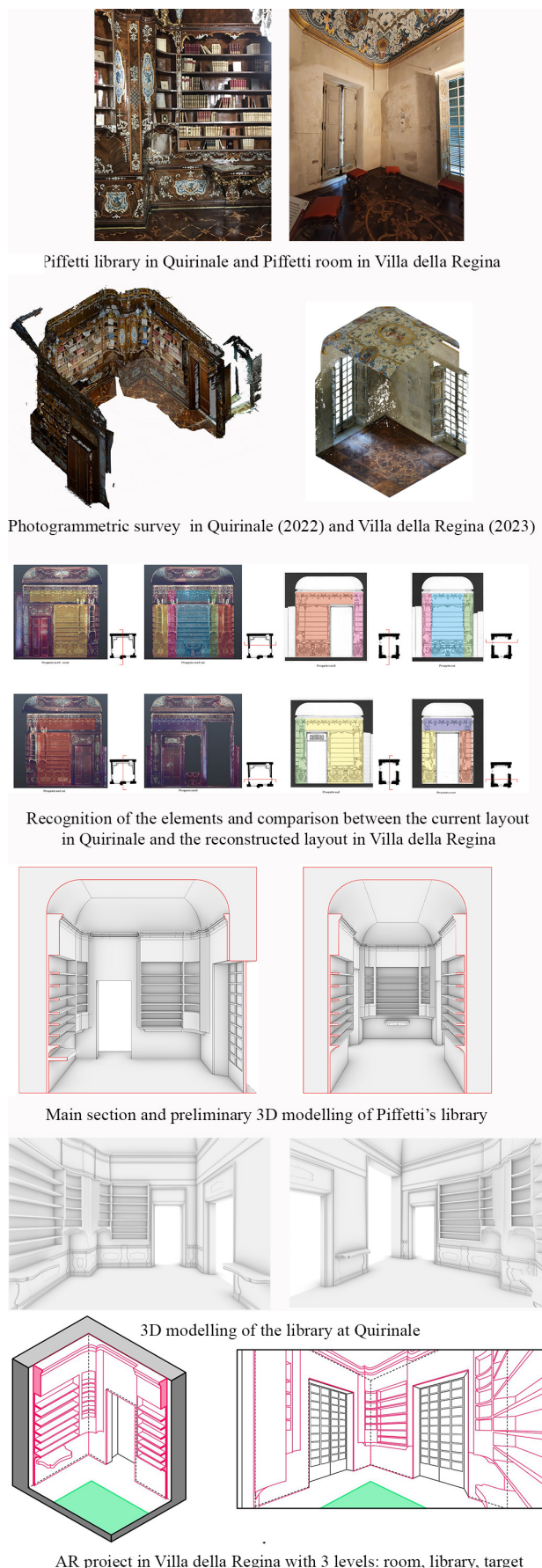AR proiect in Villa della Regina with 3 levels: room, library, target

Figure 2. Pipeline of the research (Editing: R. Spallone).

installation in Villa della Regina, comparing the layout of the library in its former location with the current one. In summary, it involves the communication of the virtual model in Villa della Regina, through AR, remotely and inside the Quirinale through VR, and the implementation of a "virtual portal" connecting the spaces of Villa della Regina and the Quirinale.

The first crucial stage of reconstructive modelling, aided by archival and bibliographic sources, involves a rigorous philological study to recognise the original parts of the eighteenth-century artefact within the present-day library and represent them complying with the principles of data transparency outlined in the London Charter (2009). Identifying the geometric adaptations necessary for placement in the Quirinale non-regular room is also a matter. They consist of small wood additions and fills to adhere the library to the walls. The modelling integrates the data from a laser-scanner survey by Studio Azimut in 2016 with the current photogrammetric survey by the scholars of Sapienza. The cabinet's photogrammetric survey in Villa della Regina complements the library's integrated metric survey.

Modelling is geared toward the project's goals of inclusive communication. To make the experience accessible to the broad public during the visit to the villa and to avoid the current sanitisation problems, it is intended to deploy an AR application that can be downloaded on visitors' smartphones using Android and iOS platforms (Othman et al, 2022). The realization of experiences in AR and VR involves the creation of two models. These two models must be realised with different levels of detail and dedicated texturing processes. The model aimed at VR applications needs more detail and realistic texturing. In contrast, the model devoted to AR applications must be structured by a simplified geometry (especially for objects of complex shapes, such as the decorative apparatus identifiable in the library cornice and the console shelves) and by texturing of less detail to make the model lighter and easier to explore through the app and devices with different performance level. However, the realistic rendering of the model is supported by the textures and commensurate with the detail appreciable from the stopping points provided for the villa visitors. The AR experience will be based on an image-based tracking solution (recognition of the cabinet floor as a 2D reference point has already been tested) and extended tracking features (the possibility of keeping the digital layers consistent with the real space even when the target is out of the visual field). At the same time, the VR visualisation on a web-based platform will be compatible with mobile devices and the Oculus Rift.

3. PIFFETTI'S LIBRARY YESTERDAY AND TODAY

In 1713, with the acquisition of the royal title by Vittorio Amedeo II, who had become King of Sicily, and the subsequent arrival of Filippo Juvarra in Turin, many building sites were started to modernize the city and the residences inhabited by the sovereigns. These included Villa della Regina, where the Sicilian architect was commissioned to rethink the architectural spaces and their decoration. In addition to the realization, in 1729-1730, of the great representative villa's main hall, built on two levels with tribunes on the second floor, a new phase of renovations started in 1733 with the redesigning of the villa's gardens and rooms with new decorative, pictorial and stucco decorations and furnishings for Queen Polissena d'Assia – Rheinfels, wife of Carlo Emanuele III, who had inherited the villa from Anna Maria d'Orelans in 1728. Among these interventions, Pietro Piffetti, one of the leading cabinetmakers of the time, active above all in the service of the Savoy court, was commissioned to make the bookcase to be placed in the Cabinet 'towards midnight and west' inside the King's

The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium "Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future", 25–30 June 2023, Florence, Italy

Apartment.Designated by the sovereign as furniture superintendent in 1731, the cabinetmaker created, between 1733 and 1739, the 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.

The decorations on the bookshelves were in perfect harmony with the wooden floor inlaid by the same cabinetmaker, with the 'Minerva che scaccia i giganti' (Minerva driving out the giants) painted by Giovanni Francesco Fariano with blue and gold figures on a white background, and with the festoons and garlands in the same colors on the baseboard and uprights of the library, constituting an appropriate counterpoint to the exotic taste choices adopted for the 'China-style' Cabinets in the Turin Villa, made in the same years.

With the handover of Villa della Regina to the Figlie dei Militari in 1865, the cladding of the small room was dismantled between 1867 and 1868 and taken to the Moncalieri Castle Wardrobe. It was not until 1876 that the furnishings were transferred to the Quirinale Palace, elected, following the capital's move to Rome, as the residence of the king. Here Princess Margherita, even before assuming the role of Queen of Italy, undertook the task of arranging the flats reserved for her by Umberto, the hereditary prince at the time, drawing on the most suitable pieces taken from the other Savoy residences that were more in keeping with a neo-Rococo style of furnishing not lacking in exotic influences.

At the time of unpacking, the state of conservation of the library did not appear satisfactory for a reuse project. However, in 1879 it was decided to allocate the furniture to the palace's new library to be placed in a room adjoining the bedroom of Queen Margherita, entrusting the restoration and adaptation of the precious woodwork to Giacomo Quarelli. In the same year, the cabinetmaker from Turin signed a contract in which he undertook to complete the work in his workshop in just three months and to make the inlaid wooden floor for the new Library at the Quirinale. For this reason, the furnishings returned to Turin for a short period, during which the necessary masonry work was carried out in Rome, under the guidance of the architect of the Royal House, for the room destined to house the valuable 18th-century bookshelves.

Figure 3. Villa della Regina library cabinet (Photo: C. Teolato).

Piffetti's boiserie was adapted to the larger dimensions of the new room, allocating the existing pieces to three walls and creating the cladding of the fourth wall with the window from scratch. The console table under the mirror, which was not mentioned in the Villa della Regina inventory of 1755, was inserted with the 19th-century installation, while the one on the opposite wall has representations of military exploits dating from 1733 and 1734, one of which bears Piffetti's signature. In addition to the cladding of the fourth wall, the decoration of the vault also dates back to the 19th century, entrusted to the painter Davide Natali, and the band and frieze added above the shelves to complement the greater height of the room, which have now become closely integrated parts of the precious carvings and inlays of the 18th-century woodwork (Morozzi, 2005; Morozzi, 2008).

The possibility of being able to restore, albeit in digital format, Piffetti's library at Villa della Regina, i.e. the original room for which it was conceived and built, will make it possible to give back to visitors use an important part of the residence's history, the one that led to its 18th-century facies and the only one visible today, thus helping to make accessible content that is currently no longer intelligible.

4. DIGITAL SURVEY AND DATA PROCESS

The survey planning considered the different case studies' scales, geometry, and material characteristics. The two architectural spaces at Villa della Regina and Quirinale were surveyed using well-known active and passive 3D acquisition techniques, extracting helpful geometric information for the analysis and virtual reconstruction of the spaces. The library survey design was challenging because it presented several bottlenecks in the 3D acquisition process. The first problem is represented by the low illumination level, supplied by a big window and a chandelier placed in the center of the room. This latter is an essential obstacle due to its position at 300 centimeters from the floor and its diameter of 150 centimeters. The second bottleneck is represented by the materials and surface finish of the artefact, which presents many optical non-cooperative materials and reflective surfaces. For all these reasons, the 3D acquisition of the library was based on integrating different active and passive techniques and planning several metrological checks during the survey pipeline to validate the 3D data accuracy and reliability.

From the architectonic point of view, two different campaigns were organized to acquire 3D space data. Studio Azimut surveyed the architectonic space in Quirinale in 2016 with a 3D laser scanner Focus 3D (Faro), generating a final 3D point cloud of 0.5 cm of resolution. The books have been temporarily removed, and different scan stations have been planned, reducing shadow effects and completing the acquisition of all the hidden surfaces of the library.

The Villa della Regina room survey was carried out in 2023 using a photogrammetric methodology with Alpha 7R IV (Sony) equipped with CMOS sensor (9504 x 6336 pixels), a focal length of 28 mm and an average working distance of 300 cm. The photogrammetric block composed by 208 images was acquired following a horizontal baseline of 75 cm and a vertical one of 90 cm, obtaining an average GSD of 0.4 mm), a better approach to register the geometrical and radiometric information for the following AR/VR experience. The accuracy of the 3D model obtained by the photogrammetric approach has been verified by comparing direct measures of the principal dimensions. The simple space did not require data integration or additional metrological comparison.

On the contrary, changing the scale of the library survey in Quirinale required more complex planning. We considered the
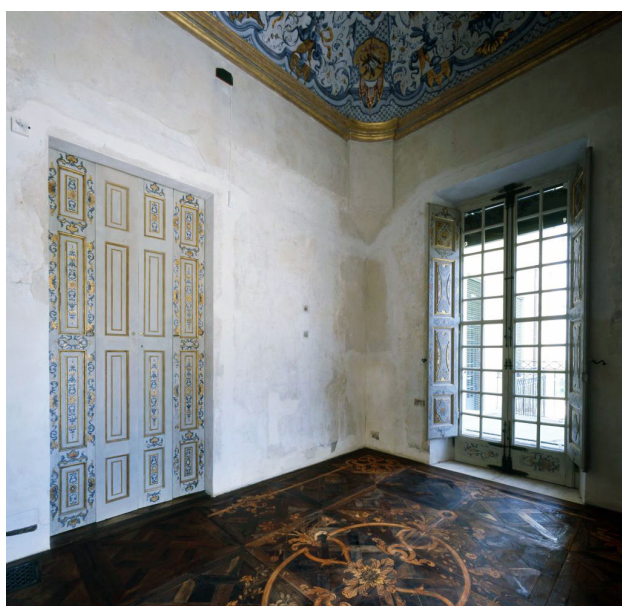
The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium "Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future", 25–30 June 2023, Florence, Italy

integration of the previous 3D active acquisition with a photogrammetric campaign in the summer of 2022. The complexity of the photogrammetric acquisition required several attempts to optimize lighting conditions and move different artificial spotlights. The final 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. The acquisition phase defined a photogrammetric block of 178 images at a working distance of 150 cm, a horizontal baseline of 70 cm, and a vertical baseline of 50 cm, achieving an average GSD of 0.4 mm on the library surface. Besides, 26 GCPs were extracted from the range-based cloud to frame the photogrammetric system within a grid of known coordinates, reducing possible orientation errors. In addition, integrating different active and passive sensors has been carried on also in the detail scale, comparing photogrammetry (using the same camera, parameters, and lighting condition) with an iReal 2S 3D Laser Scanner (Scantech) triangulation infrared instrument. The survey made it possible to highlight the geometric issues and scale variation in such a complex artifact, testing the instrumentation for this specific activity.

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 in real-time through the "feature detection" mode and translated into point clouds and mesh models. Finally, the images were all processed within the Metashape program (Agisoft), always keeping the GCPs extracted from the point cloud as a reference to reduce frame orientation errors. To compare them, all 3D data from Quirinale have been integrated into the same reference system. The values extracted from point clouds comparison at different scales validated the quality of the acquired library (see in the present volume: Russo et al., Integrated 3D Acquisition of Complex Wooden Artefacts: The Piffetti's Library in Quirinale Palace (Rome)). Besides, data acquired in Villa della Regina has been processed and managed separately from the Quirinale, considering the different scopes of modelling and visualization of the case study.

Figure 4. Point cloud from photogrammetric survey (Processing: M. Russo).

5. 3D MODELLING FROM DIGITAL SURVEY

The modeling operations of the Piffetti Library necessarily required some prior analyses and evaluations, relating on the one hand to the data obtained from the carried out survey campaigns, and on the other hand to the high degree of complexity characterizing the artifact: in such a view, modeling was oriented not only toward a faithful digital reproduction of the eighteenth-century woodwork in its current configuration at the Palazzo del Quirinale, but the part-by-part reconstructive

methodology involved made it possible to create a discretized digital model.

First, the analysis focused on comparing the data from the point cloud (Studio Azimuth, 2016) with the photogrammetric reconstruction (done by Michele Russo for the present
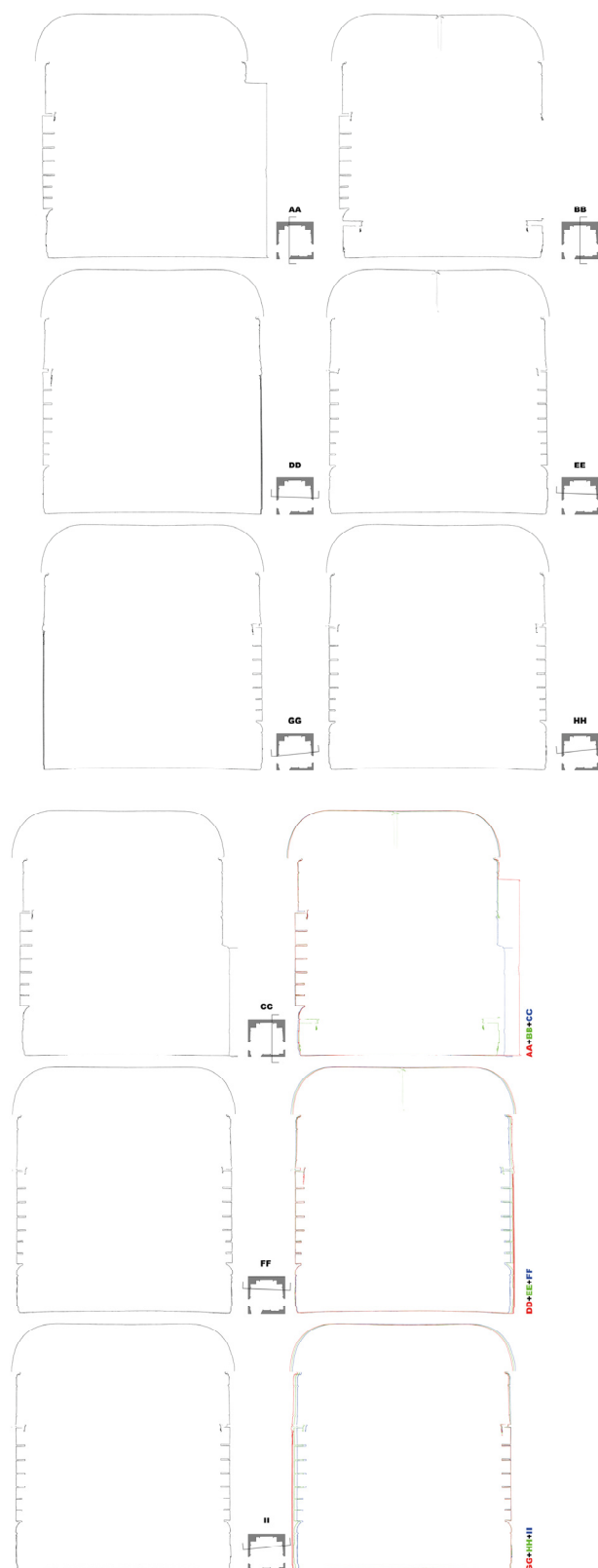

Figure 5. Shelves' significant sections and superimposition from photogrammetric survey (Drawing: E. Pupi).

The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium "Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future", 25–30 June 2023, Florence, Italy

research), during this operation both geometric models were exported from the corresponding softwares, Autodesk ReCap and Agisoft Metashape, respectively, and were imported into the McNeel Rhinoceros workspace. In the first case, the .e57 format was used, while in the second case since it was a mesh geometry, the .obj format was used and the .jpg format was employed for the texture map.

Overlapping data from the two captures made it possible to make organic assessments regarding several aspects central in the field of digital reconstruction: the divergence of the connecting surfaces due to the rearrangement of the artifact in the room at Palazzo del Quirinale, the thickness of the shelves of the scans where the books are stored, and the identification of a series of sculptural elements of notable morphological sophistication.

Next, again within the McNeel Rhinoceros workspace, digital modeling of the artifact was carried out through the use of NURBS geometry, this choice is connected to several factors, foremost among them being the possibility at a later time to be able to transform the model through a mesh triangulation, assigning to this process a level of accuracy and a corresponding number of polygons appropriate to the respective purposes of Virtual Reality and Augmented Reality.

The digital model during the process was kept in real dimensions, adopting meters as the unit of measurement; while regarding the organization of the level browser, an initial subdivision corresponding to the constituent macro-elements of the artifact was adopted: the cloister vault, the boiseries and the floor. As previously mentioned, digital reconstruction has also provided for further hierarchical grades, a discrete division between original and integrative elements, and the recognition of parts to be incorporated at a later stage because of their very high level of complexity.

Concerning the first task, the process largely made use of curves-based modeling, in other words, the identification and tracing of sharp edges and the subsequent creation of surfaces. This process required the temporary isolation of specific sections of the data from the surveys, in order to compensate for irregularities and the presence of several non-planar surfaces, in addition to the native woodwork shape of the Piffetti's Library. Rather, about the moldings present both above and below the boiseries, was decided to reconstruct the profiles, also making use of the photographic documentation as a descriptive support of the state of art, after which the profiles were developed according to the tracks identified as described above. In the case of the parts where manual modeling would have required the use of other types of software (sculpting), an integrative process was opted, in order to returning a fairly faithful topology of the sculptural elements, using the data from the surveys with great precision: this was accomplished by.
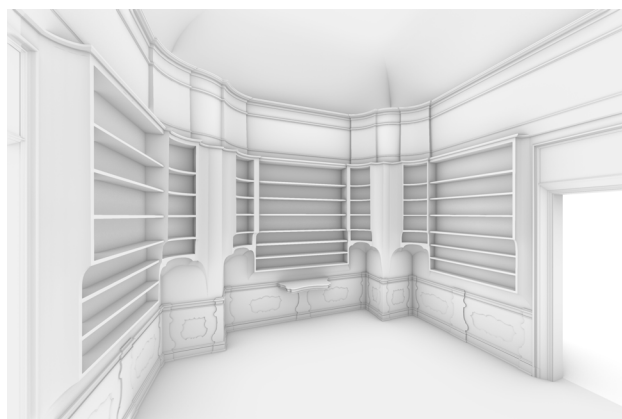

Figure 6. 3D model of Quirinale library (Modelling: E. Pupi).

isolating the necessary portions of the point cloud and then triangulating them through a mesh geometry. The last operation, although it generated a hybrid model in the McNeel Rhinoceros workspace, was found to be an excellent compromise solution in terms of quality/runtime ratio. The elements involved in this practice were almost all of the sculptural decorations, such as the parts below the consoles.

The described procedures involved in obtaining a digital copy of the library in the current arrangement at the Palazzo del Quirinale, while providing for its necessary interpretive readjustment in the native setup of the Villa della Regina. This process optimized modeling time.

Figure 7. Comparison between photogrammetric survey and 3D model of Quirinale library (Modelling and editing: E. Pupi).

6. 3D MODELLING INTERPRETATION FOR THE ASSET IN VILLA DELLA REGINA

Compared to the digital model that represents the current configuration of the artefact at the Quirinale, the virtual reconstruction of the library in its original location at the Villa della Regina required some fundamental steps, including:
• the analysis and photogrammetric survey of the room in which it was set up;
• the study of the literature describing its consistencies, its original layout, its transfer to Rome, and integration by Quarelli, together with the analysis of an important survey of 1876 (Antonetto, 2010) which confirms the reconstructive hypotheses presented in the bibliography;
• the development of a working methodology that would make it easy to dismantle and reconfigure the digital model taken from the survey to restore it to its original configuration and for subsequent optimization operations for AR and VR applications.

Concerning the analysis of the room and the photogrammetric survey, the work carried out made it possible to verify the presence, on the (original) plasterwork as reported in the bibliography (Perino, 2008), of a network of signs recognized as a geometric pattern related to the assembly of the furniture and of wooden dowels held by iron clasps used to fix the woodwork to the walls, according to a technique used in other rooms of the building.

The dimensional findings confirmed a full correspondence of the traces on the plasterwork with the size and partitioning of the individual modules of the bookcase which, as hypothesized in previous studies (Antonetto, 2010) and as confirmed by the 1876 survey, were positioned in the room to form a quadrilateral with the four corners shaped as double recesses: the central body of the bookcase at the Quirinale, now placed between two false pillars, was positioned on the short wall next
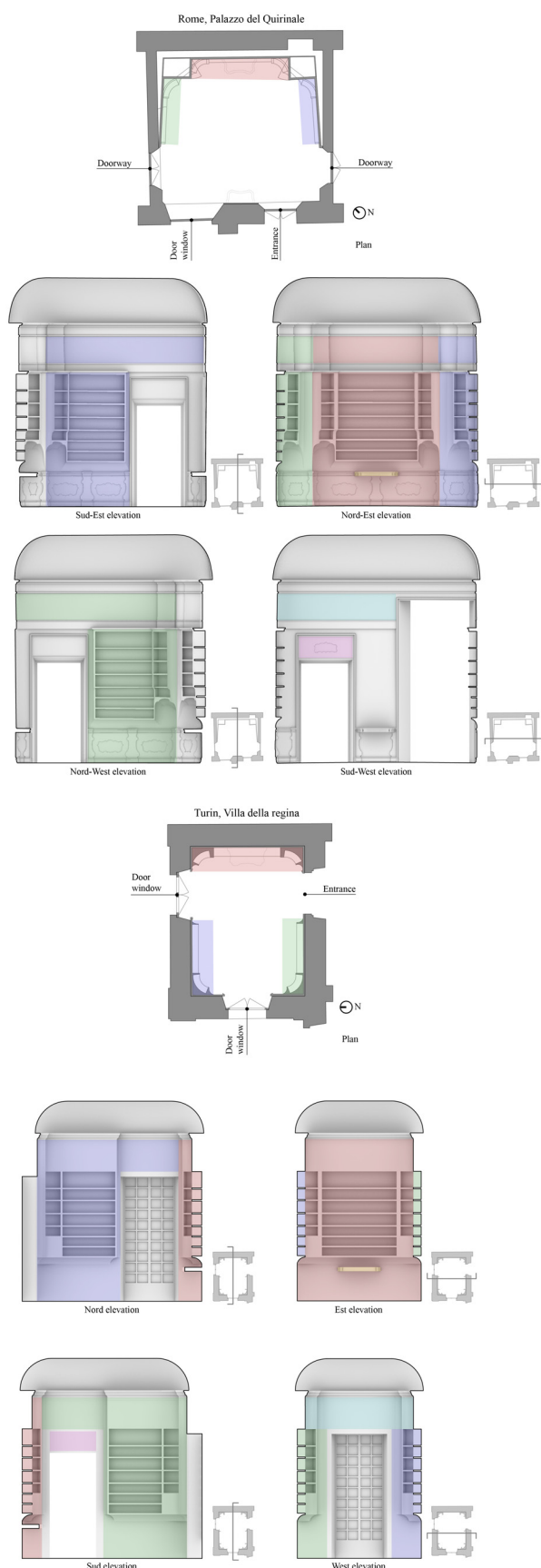
The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium "Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future", 25–30 June 2023, Florence, Italy

Figure 8. Identification of the elements in Palazzo del Quirinale and Villa della Regina (Drawing and editing: E. Pupi).

to the room entrance and the angled wings ended at the entrance door and the French window on its axis; the other two modules, arranged opposite each other on the long sides of the cabinet, ended with two wings that framed the French window on the west side and, symmetrically to the main body, with the other two openings. The height of the bookshelves is slightly higher than the windows and coincides with the beginning of the concave pilasters at the room's four corners. The frieze above the bookshelf is now tripartite due to the greater height of the room in which it is located: even from the drawings of the time (Sezione della Nuova Biblioteca di S.M, Section of the New Library of S.M., in Antonetto, 2010) it is evident that only the higher, central band was the original part of the frieze (called 'fregio esistente', 'existing frieze' in the drawing), while the other two (a 'giunta al fregio', 'added frieze' and a 'soprafregio', 'above frieze') were elements designed to adapt the furniture to the new room for which it was intended. The main sources, referring to the inventories of 1755 and 1811 (Antonetto, 2010) also make it possible to imagine that of the two consoles 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 (Palacios-Gonzàlez, 1996). Based on this reasoning, the modelling work conducted from the survey of the library in its current location was organized in such a way as to respect the modular logic by elements that governed the dismantling of the furniture and the reassembly of the individual parts at the Quirinale.

The construction methodology, which integrates the geometric modelling of surfaces and volumes from edges and profiles (for the portions of the artefact with a more regular course) and the modelling of mesh surfaces (for the portions with a sculptural character), has made it possible to obtain a relatively light model that integrates a reality-based approach and a geometric-interpretative reconstruction approach. This model is quite flexible and lends itself, with not too onerous steps and dedicated textures, to the different needs and purposes of VR and AR applications.

Figure 9. Identification of the geometric pattern for assembling the furniture and iron clasps in the cabinet of Villa della Regina (Photo: E. Pupi).

7. AR AND VR EXPERIENCES

The digital reconstruction of the Piffetti Library at Villa della Regina presents an opportunity to integrate AR and VR technologies, enhancing the visitor's experience and understanding of the historical site. The project aims to develop

The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium "Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future", 25–30 June 2023, Florence, Italy

an AR application that allows visitors to visualize the digital reconstruction of the wooden artifact within its original environment and a VR visualization for a broader online audience.

Over the past two decades, AR has been widely studied as an enabling technology for cultural heritage along with VR and other immersive technologies within the reality-virtuality continuum (Kounavis et al, 2012; Milgram and Kishino, 1994). These technologies can provide more intuitive access to spatial information compared to traditional on-screen displays of three-dimensional models by superimposing digital layers onto real world images (Amin and Govilkar, 2015). By tracking the user's position concerning the surrounding environment, AR systems can generate images of virtual objects as if they were in physical space. In the field of CH, these tools have proven beneficial for professionals in accessing, comparing, and understanding space-related information about artifacts, while facilitating the preservation, reconstruction, and analysis of historical sites and monuments (Bekele et al, 2018; Pierdicca et al, 2015). Moreover, AR and VR technologies have played a significant role in developing engaging forms of storytelling and immersive experiences aimed at visitors, enhancing learning and engagement (Luigini, 2019; Mortara et al, 2014).

The AR application for the visitors of the Piffetti Library will be developed using Unity for deployment on Android and iOS platforms and will be installed on the user's devices or devices provided at the site. The application will display the reconstructed model in the correct perspective, enabling visitors to understand the original integration of the wooden artifact within the Gabinetto della Libreria. The AR installation will rely on markerless solutions for image anchoring (Bekele et al, 2018) to avoid custom markers in the room (such as information panels or printed matrix codes).

A first feature-based solution has been tested to ensure a working baseline functionality. We adopted the image recognition and tracking technologies developed by PTC in the Vuforia AR library for Unity. The accurate overlay of the digital component has been ensured using the inlaid floor of the Gabinetto, which serves as a two-dimensional reference point that can be easily framed when observing the room through the mobile camera. To achieve this, an image of the floor was taken, and the central inlaid portion was straightened using photo editing software. Image target is examined as a two-dimensional reference object capable of being detected and tracked to activate the AR functions.
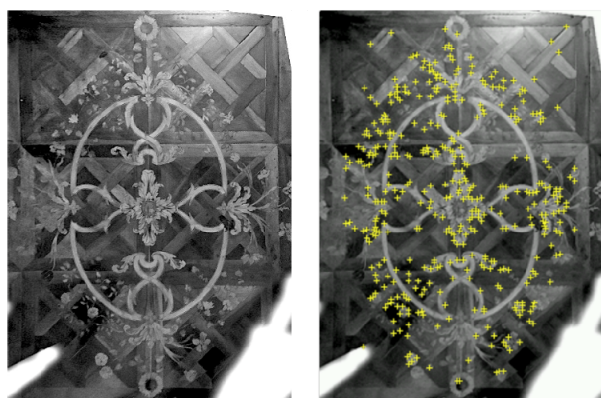

Figure 10. Left: the floor in the cabinet of Villa della Regina. Right: natural features calculated by the Vuforia service (Editing: V. Palma).
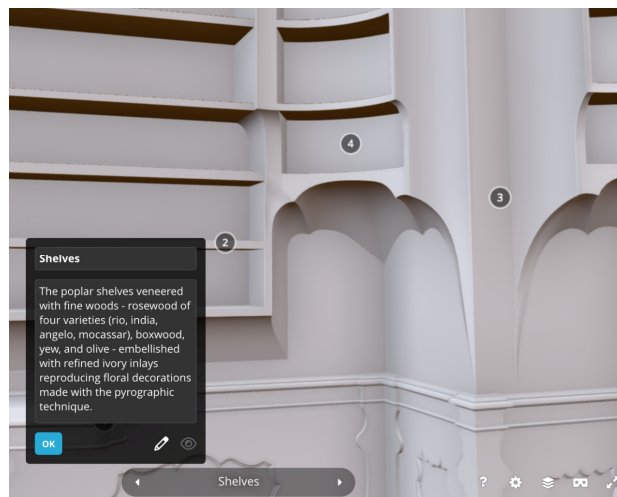

Figure 11. The Sketchfab interface allowing to add and edit annotations (Editing: V. Palma).

Natural features calculated by the Vuforia service are compared with features extracted from the camera for effective tracking.

Movable elements such as chairs were removed from the image to prevent potential confusion for the AR engine.

The project development also plans to evaluate tracking solutions using a model-based approach, specifically relying on pre-acquired three-dimensional models (Palma et al, 2022).

The AR application will feature a reduced geometric detail of the VR model, making it smaller in terms of disk space and computational power required.

This allows for a more reliable application and compatibility with a wider range of devices.

The visual quality of the model will be enhanced by applying textures that provide an optimal level of detail, tailored to the user's point of view, ensuring a visually appealing representation while avoiding unnecessary complexity.

The VR visualization of the digital model will be uploaded to the Sketchfab platform (sketchfab.com), an online service compatible with mobile devices and Oculus Rift. The VR model will benefit from a higher level of detail in both meshes and textures, as the interaction mode allows for greater focus on detail and less need for responsiveness compared to AR.

Both the AR and VR experiences will incorporate interactive elements within the models, allowing users to access additional information through spatial triggers.

In the VR visualization on the Sketchfab platform, the built-in annotation system will be used to create hotspots on the model, enabling users to access specific views and detailed information. With the support of the Markdown language, these small, clickable notes can be enhanced with links, images, and various formatting options, ensuring and engaging experience and sound information.

Similarly, the application developed in Unity will offer custom UI elements and functions to provide interaction with multimedia documentation within the AR model.

The project also envisions a virtual connection between Villa della Regina and Quirinale, showcasing the real and virtually relocated library.

The implementation of this connection, whether through totems, information panels, or QR code recognition systems, will depend on conditions of the surrounding environment still to be discussed with the site managers.

The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium "Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future", 25–30 June 2023, Florence, Italy

8. CONCLUSIONS

As seen above, the presented project is currently in progress. Educational, interactive, and narrative paths may enrich such experiences, currently being defined (e.g., related to the collection of books placed in the artefact, the decorative and iconographic apparatus instituted by Piffetti in the historiated portions of the library, the decomposition and recomposition of the two libraries, etc.).

This paper is the result of an ongoing research project carried out by the authors. R. Spallone wrote paragraphs 2; C. Teolato par. 3, M. Russo par. 4, E. Pupi par. 5, M. Vitali par. 6, V. Palma par. 7. The authors wrote together parr. 1 and 8.

REFERENCES

Amin, D., Govilkar, S., 2015. Comparative Study of Augmented Reality SDK's. *International Journal on Computational Science & Applications*, 5(1), 11–26. https://doi.org/10.5121/ijcsa.2015.5102

Antonetto R., 2010. Il mobile piemontese del Settecento, vol. 1, Le firme. Torino: Allemandi.

Bekele, M. K., Pierdicca, R., Frontoni, E., Malinverni, E. S., Gain, J., 2018. A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage. *Journal on Computing and Cultural Heritage*, 11(2).7:1-7:36. https://doi.org/10.1145/3145534

Gonzàlez-Palacios, A., 1996. Il patrimonio artistico del Quirinale. I Mobili Italini. Milano/Roma: BNL Edizioni/Eecta Kounavis, C. D., Kasimati, A. E., Zamani, E. D., 2012. Enhancing the Tourism Experience through Mobile Augmented Reality: Challenges and Prospects. *International Journal of Engineering Business Management*, 4, 10. https://doi.org/10.5772/51644

Luigini, A., 2018. Four dichotomies on digital environments between art, heritage and education: opening address. In Luigini A. (ed.), *International and Interdisciplinary Conference on Digital Environments for Education, Arts and Heritage*. Cham: Springer, 3–12. ISBN 978-3-030-12239-3

Milgram, P., Kishino, F., 1994. A Taxonomy of Mixed Reality Visual Displays. *IEICE TRANSACTIONS on Information and Systems*, 77(12), 1321–29.

Morozzi, L., 2005. Gusto eclettico e scelte esotiche alla corte sabauda nella seconda metà dell'Ottocento. Arredi delle residenze piemontesi nel Palazzo del Quirinale. In: Caterina, L., Mossetti, C., Villa della Regina. Il riflesso dell'Oriente nel Piemonte del Settecento. Umberto Allemandi & C., Turin, 102-113

Morozzi, L., 2008. Storie di quadri e altro: Giaquinto e gli arredi di Villa della Regina da Torino al Quirinale. In: Mossetti, C., Traversi, P. Juvarra a Villa della Regina. Le storie di Enea di Corrado Giaquinto. Editris, Turin, 83-95.

Mortara, M., Catalano, C. E., Bellotti, F., Fiucci, G., Houry-Panchetti, M., Petridis, P., 2014. Learning Cultural Heritage by Serious Games. *Journal of Cultural Heritage*, 15(3), 318–25. https://doi.org/10.1016/j.culher.2013.04.004

Othman, M. K., Nogoibaeva, · A., Leong, L. S., Barawi, M. H., 2022. Usability evaluation of a virtual reality smartphone app for a living museum. *Universal Access in the Information Society,* 21, 995–1012. doi.org/10.1007/s10209-021-00820-4

Palma, V., Spallone, R., Cicone, G., Lops, G., Rinauro, R., 2022. Scalable AR for BIM on Telecommunication Network Sites. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLVI-2/W1-2022, 409–14. https://doi.org/10.5194/isprs-archives-XLVI-2-W1-2022-409-2022.

Perino, Giorgio R., 2008. Le *boiseries* della Villa al Quirinale attraverso il rilievo. In: Mossetti, C., Traversi, P. Juvarra a Villa della Regina. Le storie di Enea di Corrado Giaquinto. Editris, Turin, 95-102.

Pierdicca, R., Frontoni, E., Zingaretti, P., Malinverni, E. S., Colosi, F., Orazi R., 2015. Making Visible the Invisible. Augmented Reality Visualization for 3D Reconstructions of Archaeological Sites. In De Paolis, L. T., Mongelli, A. (eds.) *Augmented and Virtual Reality*, edited by 9254:25–37. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-22888-4_3

The London Charter for the Computer-Based Visualisation of Cultural Heritage, Draft 2.1, 7 February 2009, http://www.londoncharter.org/

Zhou, Y., Chen, J., Wang, M. 2022. A meta-analytic review on incorporating virtual and augmented reality in museum learning. *Educational Research Review*, 36. doi.org/10.1016/j.edurev.2022.100454