3D digitisation and modelling of liturgical metal artefacts

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Abstract

The present work is aimed at showing the results obtained by testing different operational solutions for single-camera photogrammetric acquisitions of numerous complex metal liturgical artefact preserved in the Church of Santa Maria di Costantinopoli in Naples (Italy). The digitisation activity is aimed at supporting documentation, restoration, valorisation and dissemination of a rich liturgical collection that is not accessible to the public for security reasons. The number and diversity of the pieces required an expeditious surveying activity conducted in situ with low-cost instrumentation and image-based techniques adopted and compared with reference to the geometric-formal complexity and state of conservation of the objects. According to the level of difficulty acquisition, this work shows the results of the digitalisation of three different types identified among the many different liturgical objects of the collection about their different geometric, compositional and technological configuration in terms of topology, shape, composition, materials and manufacturing technique. The adopted workflow produced results that allow qualitatively assess the examined objects and their materials, supporting architects, experts in the restoration of metal artefacts and art historians: the produced digital documentation represents a 3D digital support for restoration activities and, above all, to plane activities aimed at conservation and preventive maintenance, as well as for valorisation and dissemination activities through digital information systems.

1. Introduction and main goals

Accessibility of fragile and complex metal artefacts lacks digital solutions for the conservation, handling and dissemination of the pieces due to the ignorance of this type of art and the difficulty of transporting these objects for temporary exhibitions (Hallot & Gil, 2019).

There are many metal artworks, especially liturgical objects, on the national and international territory. However, these are still unknown and, for that reason, their historical development and artistic production remain unknown to the researchers (Boykina, 2022). Scientific studies focused on complex metal objects are increasing: these studies unable to build a hypothetical notion of the influence of the silversmiths and their production on the economic, religious, and artistic life of the urban context (Paolicchi, 2024; Dautović et al. 2022; Fathi, 2021).

Many current research activities in the field of Cultural Heritage are aimed at multiscale digital documentation of complex objects.

The scientific literature suggests that for the digitisation of small artifacts, NeRF works in scenarios with homogeneous textures, variable lighting conditions, reflective surfaces and fine details, but they have higher noise and lower texture quality than other well-established image-based techniques such as digital photogrammetry (Croce et al. 2024).

Anyway, photorealistic, metric and geometric quality of digital photogrammetric documentation of cultural heritage objects is strongly influenced by the intrinsic complexity of the subject

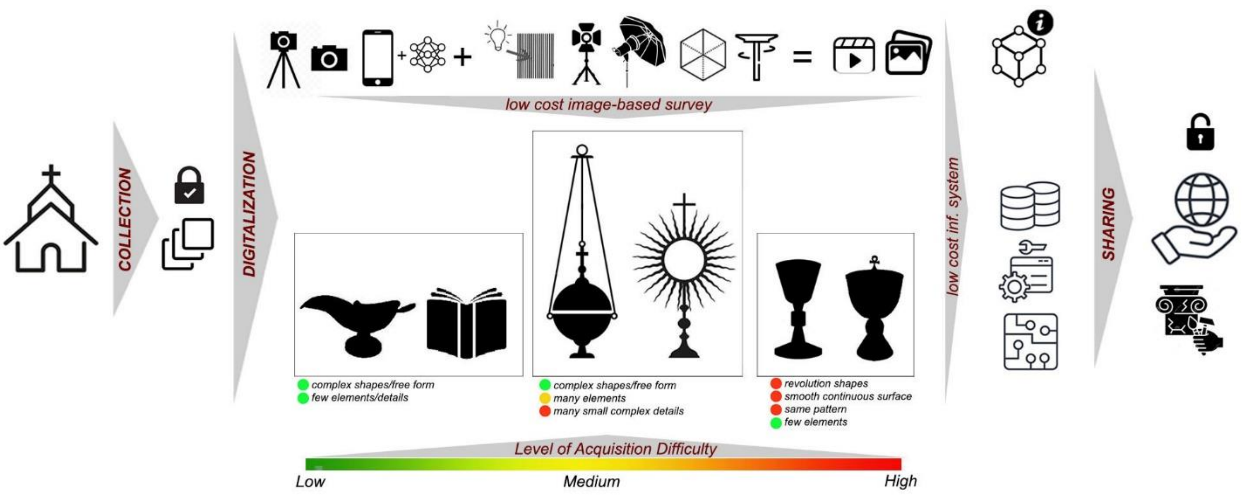

Figure 1. Methodological workflow: metal artefacts classification, digitalisation and valorisation.

(Nicolae, et al., 2014), the environmental conditions and the technical and methodological solutions adopted.
As known, transparent or highly reflective objects pose significant challenges to conventional workflows as they generate surface alterations that confound data processing algorithms. In fact, the digital photogrammetric process (SfM and MSV) is based on finding homologous points between multiple partially overlapping frames.
However, the movement of the reflective object with a fixed camera or the movement of a camera around the reflective object causes the reflections to move to different points on the surface, in relation to the surrounding light sources, complicating the search for corresponding points between the photos and, thus, the recognition of the position of the surfaces, leading to errors in the generation of the model and/or its measurements.
According to these premises, the main goal of this research work in progress is to digitalise the wide collection of detailed liturgical artifacts made from highly reflective materials preserved in the Church of Santa Maria di Costantinopoli in Naples using digital photogrammetry as low-cost image-based techniques.
Therefore the acquisition activity is aimed at demonstrating how digital photogrammetry, despite passive capture technique, is a fast low-cost technique to elaborate detailed models of metal artifacts for the purpose of restoration and dissemination.

2. Digitalisation of metal artefacts: theoretical background

Reflective materials limit the use of active acquisition devices such as high/medium cost lidar or structured light scanners. Moreover, these artefacts cannot be moved out of churches or museums, present a very high level of finesse, must be carefully handled to preserve their state of conservation and require good texture rendering in terms of visualization aimed at restoration and dissemination.
The scientific literature focused on the digitisation of complex reflective metal objects provides several examples of research that suggest different ways to fix digital photogrammetric issues (Sun et al. 2024; Kim, et al., 2024; Liang, et al, 2023; Hallot & Gil, 2019; Conen, et al., 2018; Wells, et al., 2005): diffusion-based Depth Inpainting framework, applications to deal with reflections by segmenting, skipping or interpolating images in post-production; installation of polarising filters on camera lenses and in the composition of the photographic set in order to eliminate reflections; application of sprays to temporarily colour and matt surfaces.
However, the elimination of reflections with such procedures does not always guarantee a good metric result and may result in the loss of relevant information on the qualitative characteristics of materials and the condition of the state of conservation, such as oxidation, colour alteration of metals or differences between matt and polished surfaces (MacDonald, et al., 2014).

3. Methodological Workflow

The adopted workflow produced results that made possible to qualitatively assess the examined objects and their materials, involving architects, experts in the restoration of metal artefacts and art historians.
The produced documentation represents a 3D digital support for restoration activities and, above all, to plane procedures aimed at conservation and preventive maintenance, as well as for valorization and dissemination activities through digital information systems (Scandurra et al. 2023; Lanzara, et al., 2022). From historical-artistic analysis to restoration and conservation of metal artefacts, the methodological workflow is composed by the steps listed below.

1.Multidisciplinary studies:
- historical and artistic investigation;
- evaluation of the conservation status of the artwork (materials, mechanical damage, chemical damage, connection systems);
- diagnostic investigations (*i.e.* biological, chemical, physical);

2. Digitalisation:
- photographic documentation (all stages of restoration work);
- digitalisation (terrestrial Digital Photogrammetry and videogrammetry) at the Church of S. Maria di Costantinopoli and UniSOB Restoration Lab of Metal and alloy materials and artefacts;
- 2D drawing-thematic mapping (*e.g.* condition report/state of conservation), manipulation, editing and implementation of *reality based* 3D models;
- definition of restoration project;

3. Conservation/Restoration:
- disassembly and cataloging of pieces (element, sub-element, parts and sub-parts);
- cleaning, revision of internal structures, deformations correction from volumes and plates, disinfestation and consolidation of internal timber structures, restoration and/or replacement of mechanical connections;
- assembly of clean and restored parts;

4. Data management and artefacts monitoring (*work in progress*):
- restoration/conservation datasheet;
- implementation of open web-based database/CDE;
- planning preventive monitoring and conservation;

5. Data sharing and artefacts valorisation (*work in progress*):
- implementation of open database for data collection and management of conservation and restoration activities;
- dissemination of open models.

Digitisation and accessibility of many sacred objects held in churches raise crucial questions about their possible digital use, both for consultation by a specialist audience and for a wider audience of visitors. In this context, the new modes of representation and the variety of digital media and formats offer different possibilities of access, both physical and cognitive, to these artefacts.
Careful acquisition and selection of the most appropriate technical solutions is essential to ensure a versatile use of digital models. In fact, an accurate digital 3D model meets several needs: for restoration it allows a thorough analysis of the state of conservation and material characteristics; instead, for valorization, it supports the digital musealization of these artefacts.
In popular and museum applications, the level of detail of models can be reduced compared to that required for restoration, using simplification processes that lighten the details without compromising visual rendering.
This process also allows the integration of key information on objects into digital models, offering interactive virtual user experiences accessible to a wide and diverse audience. Thus, even those who do not have specialized training can better appreciate and understand cultural assets.

4. Case Studies: classification and digitalisation

4.1 The metal artefacts collection of the Church of Santa Maria di Costantinopoli in Naples

This study aims to show the results obtained by testing different operational low-cost solutions for single-camera photogrammetric acquisitions of numerous and various complex metal liturgical objects preserved at the Church of Santa Maria di Costantinopoli in Naples (Italy), (Catello et al., 2000).

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The digitalisation activity was aimed at supporting the documentation, restoration, valorisation and dissemination of a rich artistic not accessible collection for security reasons.

Since March 2019, the students of the master's degree Course in Conservation and Restoration of Cultural Heritage of the University Suor Orsola Benincasa of Naples had the opportunity to work in the didactic worksite inside the Church of Santa Maria di Costantinopoli for the restoration of numerous and important works of goldsmithing of the '600, '700 and '800. For a better framing of the works, art historians and conservators have drawn up the historical path about the Noble Art of Neapolitan goldsmiths described in the available sources published over the centuries to reconstruct the evolution and define characteristics and types of pieces by analyzing the marks of the art, analysis of typological and stylistic, deciphering the allegorical figures, recognition of coats of arms and reading inscriptions, if present, in order to reconstruct the identity of the works and their authors. The collection is made up of more than ninety-five pieces that differ in function (pyxes, chalices, monstrances, navicula, thuribles e inserts on cloth cover), material (gold, silver, copper, copper-plated silver), shape (continuous and smooth revolution surfaces, *e.g.* chalice bowls, handles, stems and feet, or characterised by the repetition of the same decorative pattern, *e.g.* pyxes), technique (smooth curved slabs or surface finishes, *e.g.* embossing and chiselling), mechanical constraints and state of preservation.

These properties and conditions inevitably influence the survey activities due to the presence of very small elements (joints, details) alternating with smooth surfaces of high reflectivity (Zhu, et al., 2024). In addition, restored objects exhibit higher reflectivity than unrestored objects, generating problems during acquisition and requiring the testing and comparison of different acquisition techniques.

The number and diversity of the pieces and the need to digitise them for restoration and to plane activities for their valorisation and dissemination, based on digitisation and computerisation of the pieces, required an expeditious surveying activity conducted in situ with low-cost instrumentation and image-based techniques adopted and compared with reference to the geometric-formal complexity of the objects to be surveyed and their state of conservation.

More in detail, this work shows the results of the acquisition of three different types identified among the many different liturgical objects of the collection according to their different geometric, compositional and technological configuration in terms of topology, shape, composition, materials and manufacturing technique. According to the level of difficulty acquisition, the following pieces and related categories have been identified:

1. complex shapes with few elements and presence of engraved surfaces (level of difficulty acquisition: low; artefacts: restored silver navicula and restored silver inserts on fabric book cover);
2. complex shapes with many elements and small complex details (level of difficulty acquisition: medium; artefacts: restored silver thuribles and silver/golden silver mostrance with radiated disk and glass case)
3. revolution shapes, smooth continuous surface, with same pattern (level of difficulty acquisition: high; artefacts: silver chalice and pyxes).

The low-cost equipment consists of digital camera mounted on a tripod, polarising filters, a rotator for positioning and moving the object, diffuse light sources, curtains and opaque paneling to isolate the objects from the context and for further diffusion of ambient light.

In addition, for some of the objects, the use of colour calibration tools was tried to facilitate the post-production work of the acquired images regarding colour reproduction.

In photographic sets, targets and metric scales were added to ensure the dimensional accuracy of the reconstructed object.

To identify the most suitable workflow, three different types of cameras were used to compare the final yield and a smartphone with dedicated applications for reconstructing objects from photos.

4.1.1. Radial mostrance (Digital Photogrammetry)

The piece, dating to the late 18th and early 19th century, is particularly detailed: the receptacle consists of a circular glass case behind which is inserted a ray, formed by flaming or lanceolate rays in silver and golden silver, enriched with Eucharistic symbols such as grape clusters, wheat ears and angelic heads, with precious stones and painted enamels.

At the sides of the base are placed the figures of the theological virtues: the Faith, recognizable by the iconographic attributes of the cross and the chalice, and the Hope, represented with the anchor. The knot presents two angels on a golden copper globe, surrounded by three heads of cherubim among clouds, on which are finely engraved the sun, moon and stars. The pair of winged angels who rule the Heart have fluid and soft robes. All these pieces were disassembled for restoration. The monstrance was placed on a rotating plate and acquired by digital terrestrial photogrammetry and videogrammetry using a camera Canon EOS R, Canon EF 50 mm, f/1,2, flash-light 400W, reflective white umbrella 90 cm, without polarisers, ground sampling distance of 1m. (Fig. 2).

Flash illuminators have a very high quality of light and are suitable for the reproduction of artworks; they are characterized by constant brightness, contrast and colour. Each flash is characterized by a light source, which delivers a flash with a different power and a reflector for the direction of the light. Useful accessories for reproduction are diffusers (soft boxes) or umbrella reflectors that spread and concentrate the light.

The use of these accessories avoids direct lighting of the subject and excessive contrasts. Umbrella reflectors are excellent light sources, used both as a main light and as a fill light. The larger the reflectors, the more the light will be diffused and the shadows very soft. The photographs and frames extracted from the video were processed through a traditional photogrammetric pipeline. Anyway, the mesh model showed critical features such as holes and deformations in correspondence of the continuous curved surfaces of the globe and base (Fig. 3).

Therefore, after localized processing and filtering for retopology of irregular mesh portions and closing of holes, the reality-based model was manipulated by replacing the damaged portions with ideal Nurbs patches modelled and transformed into meshes in CAD environment (Rhinoceros), exported in .obj format, integrated into the original mesh model, structured and textured in photogrammetric environment (Fig. 4).

Figure 2. Photographic set for digitisation of the monstrance.

Figure 3. Comparison between photo and 3D photogrammetric model: despite the high level of detail, there are gaps on smooth surface of the golden globe.

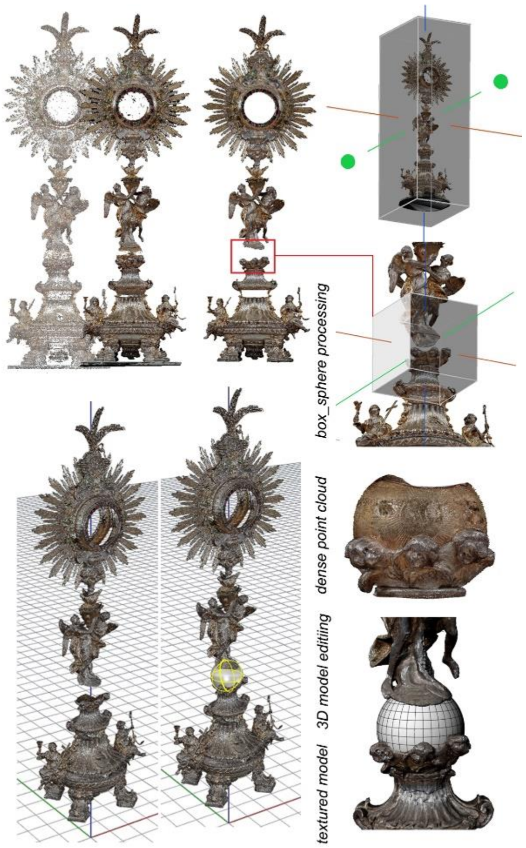

Figure 4. Photogrammetric and CAD editing of the reality-based model of the monstrance.

4.1.2. Navicula (Digital Photogrammetry)

For the silver navicula, meticulously restored and polished, several acquisition tests have generated a navigable model without reflections. In addition to the Nikon DSLR camera, two smartphones were used to compare the acquisitions (Figg. 5, 6).
The first capture was made with an iPhone 11, placing the navicula on a rotating plate inside a black-background photo tent, without direct light to avoid additional reflections.
However, the resulting model, after processing, had side-overlapping errors.
A second capture was made with a Nikon D3500, equipped with a 35 mm lens, F/3.5 and exposure time of 1/200 s to ensure sharp images. The navicula was again placed on a rotating plate inside a blue background photo tent. To solve the problems of image alignment, maximum size markers of 5 mm were applied to the surface. Although the model was complete, the surface was uneven due to the many reflections of the metal.
The latest acquisition, which produced the best model, was performed with a Samsung S22 Plus which produced images with a focal length of 5.4 mm and an exposure time of 1/100 s. In this configuration, a photo box with white background and two headlights composed of LED panels, placed externally to filter the incoming light and set at 4000K, to eliminate shadows and internal reflections.

Figure 5. Photogrammetric 3D model of the navicula: comparison between dense point-cloud and mesh.

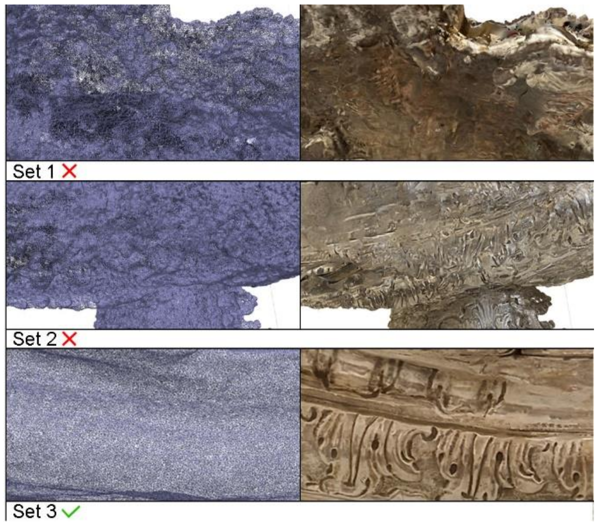

Figure 6. 3D Digital Photogrammetry of the navicula: comparison of processing from different photographic set.

To further reduce reflections, the photos were taken through a small opening in the box, also limiting reflections from outside.
The final dataset, consisting of 316 shots taken at a maximum distance of 10 cm from the object, produced a complete model with very few reflections from the first stages of processing.
The images were previously masked, isolating the object from the background and masking the markers placed on the surface. This step is essential for the subsequent texturization.
The point cloud, generated at the highest quality, was then filtered to remove any residual dark reflections.
Detailed mesh pattern highlighted silver surface finish and details were further enhanced by the final texturing.

4.1.3. Pyxes (Digital Photogrammetry and NeRF)

For the acquisition of the two silver pissides (revolution surfaces), characterized by the repetition of a pattern with presence of complex chisels and the brilliance of metals due to recent restorations, it was decided to make a double digital acquisition: a traditional photogrammetric process and an acquisition using an app based on NeRF (Neural Radiance Fields).
Artificial intelligence has been tested and applied to the photogrammetry process to fast elaborate 3D models for cultural heritage valorisation. Then, a smartphone was used to compare the acquisitions.
The smartphone captured images with a focal length of 3.5 mm and an exposure time of 1/50 s. During the acquisition phase, to minimize noise and environmental reflections, a blue background was adopted, in natural light conditions.
The 172-frames dataset was then processed via a traditional photogrammetric pipeline.
The dense point cloud, processed with the highest quality, was subsequently filtered to eliminate dark reflections.
The result is a high-resolution, textured 3D model that is morphologically accurate with chromatic details and bright variations of reflective surfaces.
The mobile platform *Luma AI* was used for the second acquisition. This app is commonly available on both the App Store and iOS devices. The scan was carried out with the same device and under the same lighting conditions.
Through the application a video of 2.30 minutes was captured. The scan data was uploaded in the cloud, where an AI based system reconstructs the final 3D model exportable in different formats (Fig. 7).

Figure 7. NeRF 3D reconstruction of the pyxes (left: *Luma AI* screen; right: PDF 3D viewer).

The comparison between models showed significant qualitative differences: the photogrammetric model presents details and accurate chromaticity.
The model created with NeRF technology, displayed in the application, thanks to real-time rendering, returns a realistic color reproduction and high interactivity, such as rotation and zoom. However, NeRF mesh, exported as .obj, has a lot of noise (due to the surrounding environment) and an insufficient photorealistic rendering compared to the photogrammetric mesh.
Therefore, AI approach is efficient and expeditious compared to the photogrammetric process because it quickly returns 3D models for interactive evaluation and sharing of the artefacts. However, the same models are not yet suitable for specialist activities.

Chalice (Digital Photogrammetry)

The restored silver chalice has a smooth and highly reflective revolution cup at the top, while the stem decorated with floral motifs and angel heads is slightly burnished and opaque, thus less reflective.
Then, to optimize the process of digitizing and aligning images, targets were applied on the object.
The operation was carried out using a rotating plate placed inside a white box to isolate the object. The 245 images were acquired with a smartphone and processed in *Agisoft Metashape*. Before texturization, the markers were masked to avoid gaps in the final model rendering. The 3D model consists of a detailed and complete polygonal mesh in the stem part and several gaps in the upper portion, characterized by a continuous and very reflective surface, typically more difficult to acquire.
To complete the model, the upper portion of the chalice was isolated from the stem.
Then the model was exported as textured mesh .obj and imported into *Rhinoceros* to reconstruct the sections of the upper part as NURBS surface using existing parts as reference.

Figure 8. 3D photogrammetric model of the chalice: data processing and integration of the smooth revolution area; final result and detail of surface treatment.

Figure 9. Digitalisation of chalice: photographic set.

Figure 10. 3D photogrammetric model of the bucket: general (CAD integration of smooth revolution area; PDF 3D viewer) and particular view (detailed elements and surface treatment).

The NURBS surface has been transformed into mesh and joined to the remaining part of the model. The complete model was then textured again in a photogrammetric environment (Fig. 8, 9).
The digitisation of the silver bucket has provided the same process, processing and editing, due to the same geometric characteristics and material of the chalice (Fig. 10).

4.1.4. Silver inserts on missals covers (Photogrammetry)

The methodology of acquisition of the two liturgical missals, characterized by red velvet covers with silver inserts, was the same for both copies. These volumes, with symmetrical decorations on both sides, presented similar problems in the acquisition phases.
The first approach involved a double photo capture, one for each side of the cover, placing the messengers on a lectern inside a blue-background photo curtain to reduce light interference and reflections. The shots were taken with a Nikon D3500 reflex camera, equipped with a 35 mm lens. To optimize focus and depth of field, an aperture of F/3.5 was initially used, which allows for good sharpness of surface details but with a low depth of field. The exposure time of 1/200 s helped to minimize the risk of motion blur, ensuring image stability. Two datasets of 80 images each were acquired at this initial stage, maintaining 10-15 cm from the cover to reduce reflections caused by the interaction between lighting and velvety surface. However, despite processing using the *Agisoft Metashape* software with color filtering, the resulting model appeared incomplete and affected by residual reflections, not meeting the quality criteria set.
The second acquisition phase was planned, placing the book vertically on a rotating plate with markers to facilitate scaling and alignment of the model in subsequent phases. The blue background has been retained also for this configuration to reduce light interference. Using the same camera and lens, we opted for an aperture of F/7.1, which increases the depth of field, improving sharpness over the entire image surface. The exposure time was set to 1/100 s, despite the use of a tripod, to ensure clear and stable details in the shot, but maintaining a distance from the cover of about 20 cm. To avoid overlaps between the two sides of the cover during processing, non-reflective markers were applied with dimensions ranging from 5 to 8 mm, placed at strategic points to facilitate alignment. The final dataset, consisting of 181 images, was processed in high quality, including a masking phase to isolate the subject and reduce reflections.
The resulting point cloud was chromatically filtered to eliminate additional residual reflections, then used to generate a high-resolution mesh suitable for texturing, accurately returning the details of the book's surface (Fig. 11).

5. Results and Comparison

The pieces were acquired in private rooms of the ecclesiastical complex because they cannot be moved outside: this is a frequent condition and complication for digitisation and investigation activities of precious and fragile artworks.
However, the various experiments and digitisation methods have produced good results, also thanks to a first round of scans tested in natural light conditions.
During this preliminary step, several problems have emerged, including difficulty in aligning images and excessive noise due to environmental reflections.
The use of polarized lights and specific color backgrounds allowed reduction of reflections and good control of each shot.
The comparison between models showed significant qualitative differences: the photogrammetric models present accurate detail, essential to support conservation, restoration and diagnostic documentation.
Anyway, models created with NeRF technology fast returns a realistic chromatic reproduction and high interactivity accessible via special apps aimed at evaluation and sharing of the artefacts.

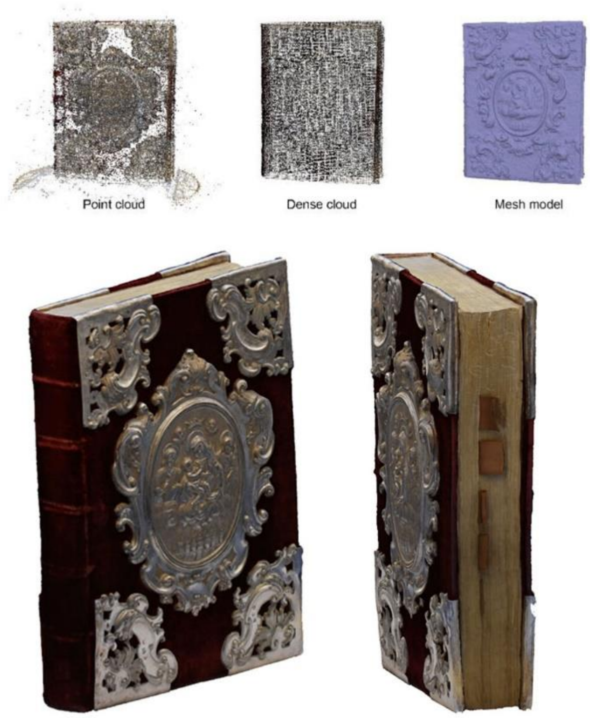

Figure 11. 3D photogrammetric models of silver inserts on missal cover: main photogrammetric steps and views.

6. Data sharing, management and valorisation of artefacts

The acquisition activity is aimed at the study and restoration of the pieces and provides useful models for different forms of dissemination and accessibility of sacred objects that are not usually displayed for security reasons.
This work is part of a larger project to digitize and musealize the church of Santa Maria in Constantinople, based on a multi-scale approach.
The multi-level digitisation allows not only to virtually recreate these objects, but also to place them in their physical and historical context within the church. The digitisation and creation of a virtual archive offers these objects in an informative, open and accessible way to a non-specialized public, thus enriching the collective awareness of the artistic ecclesiastical heritage.
Interactive tools, complemented by descriptions and explanations suitable for various levels of public, allow visitors to discover not only the artistic and technical value of these artefacts, but also their religious, historical and cultural significance. To optimize sharing and enjoyment of a wide audience, the capture was designed to process photorealistic digital models, with particular attention to the elimination of reflections, to create light and easily texturable meshes.
Digital models, enriched with information hotspots that provide specifications on the ornamental details, materials and liturgical and symbolic meaning of each element, will be made accessible in the church spaces through the installation of specific monitors and the website dedicated to the Church of Santa Maria di Costantinopoli (Fig. 12).
This approach allows for an interactive three-dimensional experience, allowing users to explore the object in every detail, rotating and zooming in on the parts that are most interesting.
Dissemination events have been planned to share with a wide and specialized public the multiscalar approach of this study, from container (church) to content (liturgical artworks).
This integration between digital technology and historical-artistic heritage offers a unique opportunity to access and understand the religious heritage even at a distance, enhancing the role of the church as guardian of culture and tradition.

Figure 12. Digital models of the liturgical collection implemented with hotspots to share historical-artistic and constructive/material detailed information of the pieces.

7. Conclusion and Future Works

The masterpieces of sacred metal collection and goldsmithery are generally not accessible for reasons of security and unknown for ignorance of these specific artworks. Today's digital technologies overcome these limitations through interactive dissemination experiences.
In this project, different fast and low-cost acquisition methodologies were tested and integrated to achieve optimal results, addressing the challenges of 3D modelling of numerous reflective and complex objects in a limited time: the output are morphologically and chromatically accurate.
Due to the reduced available time for completing and delivering digital models, further testing and comparisons between digitisation technologies are *in progress* to optimize the quality of output.
A low-cost expeditious digitisation of artworks is useful for restorers to plan and manage conservation and restoration work, by recording digital copies in the different stages of intervention, and as tools for cataloguing and communicating, disseminating and exploiting the little-known sacred collections through applications accessible to a wider public.

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