SCAN to HBIM FOR COMPLEX REFLECTIVE METAL ARTEFACTS. 3D DIGITISATION AND RESTORATION

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ABSTRACT:

3D digitisation of metal artefacts, regardless of the use of passive and active sensors and low or high costs technologies (digital photogrammetry, laser scanning, structured light 3D scanning) represents a challenge above all due to the high reflectivity, absorptivity and scattering of the materials, as documented by the specialistic literature (Frost et al., 2020, Hallot et al., 2019, Nicolae et al., 2014). Regardless of the size and material, mobility and immobility of the elements, artworks preservation and restoration involve intervention and collaboration between different specialists, such as restorers, conservators, diagnosts, architects, surveyors, modelers, archaeologists and art historians. This multidisciplinary process requires a virtual container aimed at systematisation and sharing of digital products and data deriving from heterogeneous diagnostic and applicative activities (Farella et al. 2022, Ferretti et al. 2022, Fiamma 2019). According to these premises, this paper shows a low-cost Scan to HBIM process aimed at digitisation of a complex reflective metal artefact, an altar frontal composed of several pieces characterized by different metal materials, functions, sizes and topological complexity (level of decorative detail). Therefore, this system is approached considering its individual components and its morphological-compositional complexity as a unique piece. The entire process has been tested both in research and didactic field, using low-cost tools for acquisition (cameras, smartphones, computers) and software open source for processing, filtering, editing and sculpting digital photogrammetric copies of highly reflective artefacts.

1. INTRODUCTION AND THEORETICAL BACKGROUND

1.1 HBIM between MICRO and MACRO

Digitisation of artworks is aimed at data systematisation, virtual conservation, enhancement, communication, and restoration. Recent technologies simplify systematisation and data sharing between specialists involved in the process.
Conservation and restoration of metal artefacts contribute to feeding experimentation both in research and teaching field, due to the complexity of materials and composition of the artifacts. According to SfM_*Structure from Motion* technique, high reflectivity of the material requires a specific photographic set, often medium or high cost. However, metal masterpieces generally lack accessibility (Hallot et al., 2018).
Moreover, different goals need high or low mesh manipulation (remeshing and texturing): mapping of state of preservation and storage of digital copies need high correspondence between real and digital element. According to these premises, CH *reality-based* models are indispensable support to digitize qualitative and quantitative characteristics, *e.g.* shareable thematic mapping in interdisciplinary and integrable containers.
Increasing interoperability between VPL flexibility and CAD or BIM systems allows to test semi-automatic processes aimed at optimizing the digitisation of complex artworks. Proliferation of digital twin and high-quality reality-based 3D models, automatically generated by image-based or range-based technologies, promotes building information systems based on semantic decomposition of models (geometric, structural, material, functional, historical-artistic systems) translated into structuring of a correspondent CDE_Common Data Environment, aimed at interoperability, information sharing and multidisciplinary collaboration.
Different performance of a digital twin requires a conscious, versatile and interoperable modelling activity between active modelling (CAD, VPL, BIM) and passive modelling (SfM, 3D Scanning). CH is a highly interdisciplinary application field and it requires data sharing among numerous professional figures, such as restorer, chemist, physicist, biologist, art historian, architect, engineer.
The relation between artwork restorer and the growing digitisation process generates current debate on the birth of new professions, evolving and integrating consolidated skills. These conditions inspire reinterpretation of the restorer figure and support the development of new digital professions for CH field. Furthermore, peculiarities in CH conservation and restoration promotes research and development of preventive, predictive systems and of innovative tools for systematization and data sharing.
ISO 29481-1:2016 (Part 1, Methodology and format), states *a digital twin represents a faithful and reliable support for decision-making processes, applications*, *e.g.* restoration and enhancement. Artefacts represent highly multidisciplinary information systems.
In recent years, an increasing number of Building Information Modeling declinations, first HeritageBIM, MuseumBIM (Ferretti et al, 2022, Lo Turco et al, 2022), ArchaeoBIM (Gaiani et al, 2021), integrated with VPL_Visual Programming Language, have been developed in engineering, architecture and design fields, promoting new applied research activities aimed at digitizing contents (artworks) and containers (architectures) in order to preserve, enhance and disseminate CH.
According to HBIM approach, one of the recent goals is to structure workflow aimed at sustainable and performing information models, adopting the most suitable digital methodology for each specific case study: global *vs* local model, parametric *vs* non-parametric approach, geometric modeling *vs* information modeling (LoTurco et al. 2022), according to the difference and complementarity between automatic (passive) modelling and aided (active) modelling.

According to a LOIN oriented approach, the solution is to integrate object-oriented modelling and photogrammetric models, to ensure maximum fidelity in sharing activities and authenticity preservation. Photogrammetric mesh of a decorative element/system can be directly manipulated and decomposed into parts and then inserted in HBIM environment.
Therefore, the hierarchical - compositional relationship of a complex system is explained by the relationship between portions of photogrammetric mesh semantically recognizable and distinguishable according to their meaning, function or material, preserving the same 3D model category (photogrammetric mesh discretisation). HBIM technology allows the integration of *reality-based* accurate digital models in the object - oriented environment and their up-load and sharing in CDE. The main goal in CH field is to systematize information in relation to individual components of integrated, web shared and upgradeable model, a data storage managed by specialists involved in the process or real – time automatic data storage from monitoring systems. Furthermore, these activities allow to test preventive approaches aimed at the conservation of the artworks in relation to environmental conditions, especially in the post-restoration - phase.

1.2 Introduction to metal artefacts acquisition and restoration.

Regarding artefacts acquisition and manipulation, the main goal of this study is to identify low-cost tools and methodology to optimize the digitisation of metal pieces and to facilitate the restoration activities between involved professionals, aimed at enhancement and fruition of the piece. However, digital photogrammetric survey of reflective objects requires to design a suitable photographic set, especially in post-restoration step, due to the high reflectivity of the piece after surfaces cleaning and restoration techniques. Precious materials, complexity and irregularity of shapes, size, conservation status of the pieces, *in-situ* acquisition, characterised by constraints limiting positioning and moving of the pieces, natural and artificial lighting conditions, require a specific workflow to facilitate the acquisition process.
The case study analysed in this paper is a system of elements made with different metals, characterised by a variable, complex geometry: topological or irregular complexity is inversely proportional to reflectivity. 3D acquisition methodology of objects with high levels of detail and reflective properties must be further developed and defined to provide controlled datasets. Lighting conditions can generate irregular models of metal artefacts. Reflection points cause errors in the reconstruction and design of the final models. Digital photogrammetry represents the low cost chosen approach to generate the 3D models of these kind of objects (Hallot et al., 2019).

2. CASE STUDY. THE METAL ALTAR FRONTAL OF SANTA MARIA LA NOVA CHURCH IN NAPLES

The case study, a metal frontal of an altar dating to the end of the seventeenth century, is placed in the Church of Santa Maria la Nova, in the historic center of Naples (Italy), (Fig. 1). It decorates the altar of the canopy of the Chapel of Maria SS. Delle Grazie, placed on the left side of the transept of the church. The canopy hosts the painting and the frontal dedicated to the Virgin of Grace (Fig. 2). The frontal, built in Baroque style, between 1687 and 1689 by the famous sculptor of silversmith Domenico Marinelli, is in the middle of the canopy. The pillars, the capitals and the great pavilion of the canopy are in wood entirely covered in chiselled silver and gilded copper.

Figure 1. The Church of Santa Maria la Nova in Naples, Italy. In red, the Chapel of SS. Maria delle Grazie.

Figure 2. The canopy, decorated by the altar silver frontal, of the SS. Maria delle Grazie Chapel in the Church of Santa Maria la Nova in Naples, Italy.

It is divided into three panels decorated with the *Stories of the Virgin* (from left, to right: *Nascita della Vergine*, *Assunzione della Vergine* and *Presentazione al Tempio*), and four caryatids in silver-plated brass in correspondence of the four pilasters making up the structure of the frontal and dividing the three scenes, completed by entablature and base. The caryatids are copies made in the 20th century, because the originals pieces were stolen during the second post-war period (Catello et al., 2000). Hence, the frontal is composed by three main parts: the structure (pilasters, basis and trabeation), the four caryatids and the three scenes of the Virgin's Histories. It is placed on a wooden base covered by sheets of lead and copper alloy. The caryatids and part of the decorations and elements that define the background and the characters of the scenes are assembled to the rest of the system by nails and bolts.

The wooden support, placed on the back of the frontal, is a grid composed of four vertical axes with shaped terminals embedded in three horizontal axes. Six rectangular panels fill in the gaps created by the wooden planks. The structure has architectural decorative elements, such as heads of cherubs that enrich the frames of the three panels.
The seventeenth-century artistic technique of realization of the scenes consists in perform backdrops and figures as partially protruding slabs. The most protruding decorative elements were cast and welded with iron nails (Catello, 2000).
The frontal is 258 cm wide, 104 cm high, and 22 cm deep. The realization of the artifact required about 135 kg of melted silver. Starting from the left, the first and third caryatids measure 56 cm high and 18 cm wide and weighing more than 5 kg, they carry the right arm up, while the left arm support the dress. In both the dress, with floral decoration, leaves uncovered left shoulder and right leg. The second and fourth sculptures, on the other hand, are 56 cm high and 16 cm wide, weigh 4 kg and stand symmetrically opposite to the couple previously described: both raise left arm, resting the weight on the right leg. In both figures, the drape of the dress is supported by the right arm and it leaves uncovered the shoulder, the right breast and the left leg. The caryatids are not symmetrical and they have different decorative details, such as the dress, the tilt of the head and the position of the arm holding the dress. The stems of the pilasters behind the caryatids are 56 cm high and 23 cm wide, covered with metal sheets decorated with a chisel finish: the front panels have a box bordered by flat and smooth frames with chisel decorations. The system is completely removable and decomposable.
This composition allows punctual restoration of different parts. The semantic decomposition of the piece allows distribution of documentation about restoration, analysis, monitoring and historical-artistic documentation of each part identified by meaning, function, material and execution techniques.
Historical building, especially the church, is a highly complex system. It can be discretized into macro-elements, then into elements and micro-elements, and their parts and sub-parts, both architectural and structural elements, mobile and immovable contained artworks (Lanzara et al., 2021).
However, a small-scale element is a complex system composed of structural and functional elements, parts and sub-parts. With reference to the case study, the frontal is anchored to a canopy inserted in an architectural shell, the chapel. At the same time, it is a mobile piece, divisible into further parts. However, it is not structurally independent. This study aims to extend this approach to small-scale elements, embedded in larger-scale architectural containers.
The explicitation of the hierarchical system and link of specific documentation can be managed in web-sharing CDE. This system supports data storage and query system.
However, considering an artefact as a complex microsystem focuses attention on the collaboration between figures involved in the process of restoration, conservation and enhancement of a cultural work, mobile or immobile.

3. METHODOLOGICAL WORKFLOW AND TOOLKIT

The general workflow (fig. 3), composed by data acquisition, digitisation, models optimization, data systematization and environmental monitoring to support the restoration activity of each component, consists of the following steps or activities:

- handling and disassembly of the altar frontal from the canopy of the chapel;
- disassembly of the altar frontal (structure, scenes and caryatids);
- photographic setting (instruments and parameters, GSD_Ground Sampling Distance control) for the photogrammetric acquisition (SfM_Structure from Motion) of the structure and of the caryatids (lights, filters and objects positioning, background);
- digital terrestrial photogrammetry of the original state of preservation;
- VPL for SfM_Structure from Motion, digital terrestrial photogrammetry;
- CAD/VPL filtering/manipulation of the mesh (remeshing, retopology, sculpting, if necessary, and texturing);
- orthophotos elaboration;
- documented diagnostic activity;
- thematic mappings extracted from orthophotos (decay mapping, technical intervention mapping);
- digital terrestrial photogrammetry of the pieces, after restoration;
- CAD/VPL filtering/manipulation of the mesh (remeshing, retopology, texturing and sculpting);
- assembly of the model (container) using authoring HBIM software (open source for didactic activities);
- CAD/VPL/HBIM hybrid modeling (photogrammetric models, CAD/VPL and object-oriented modeling) to digitalise pieces (content) and architectural system (container);
- systematization and integration of diagnostic, graphic, photographic, historical-artistic and monitoring documentation in CDE_Common Data Environment, on web-sharing platform through tag, link and markers tools (model/database querying), according to semantic decomposition (*tag*, *link* and *markers* tools).

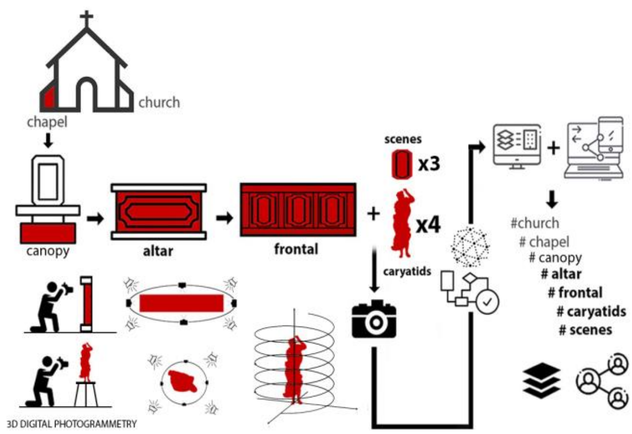


Figure 3. Scan to HBIM: from macro to micro.

The frontal has been positioned to allow a single and continuous photogrammetric acquisition.
The acquisition and restoration of each element are affected by weight, artwork placement and lighting conditions resulting from the relationship between content, movable and immovable works and container.
Therefore, the system has been disassembled and the main pieces, the structure, scenes and four caryatids (Fig. 4), have been acquired and restored for educational and research purposes and in collaboration with local authorities, according to the acquisition process based on the comparison between textured models and orthophotos, both processed by photographic acquisition with different cameras and lighting photographic sets (listed below according to different decreasing costs):

Figure 4. Frontal semantic decomposition: structure, scenes and caryatids.

- Camera Fujifilm GFX 100 S, 100 MP, 45/100 lens, Flash 400 W, equipped with 14cm diameter reflector, reflective and translucent diffusers and umbrellas (high cost), frontal post – restoration acquisition;
- Camera Canon EOS 250D, 18/55 mm lens, 24.1 MP, equipped with 14cm diameter reflector, reflective and translucent diffusers and umbrellas (high cost), frontal post – restoration acquisition;
- Camera Canon EOS 250D, 18/55 mm lens, 24.1 MP, LED spotlights (cold light) from restoration site (low cost), frontal post – restoration acquisition;
- smartphone and NIKON D5100, natural lighting and LED spotlights (cold light) from restoration site (low cost) frontal pre – restoration acquisition.

Cross-polarization images improve photogrammetric reconstruction and measurement on reflective surfaces (Wells et al., 2005, Conen et al., 2018). However, no errors occurred during photo alignment, regardless of the photographic set.
The floor modules (size and position) were used to scale and orient the model. About point cloud/mesh elaboration and mesh editing, CAD/VPL open-source software, compared with correspondent closed-source software listed above, are used for manipulation and texturing (*e.g. Meshroom vs 3D Zephyr*, *Meshmixer vs ZBrush* and *Instantmesh* or *Blender vs Cinema 4D* or *3ds Max*).
The results show that the approaches have produced good quality models using different terrestrial digital photogrammetric software (high cost – closed source and free – open-source software) to elaborate the point clouds and the texturized mesh of the pieces. Finally, the photogrammetric mesh was integrated with HBIM objects and the final model was uploaded in the CDE_*Common Data Environment* (educational version of BIM authoring software *Edificius* and collaborative web shared *usBIM platform*, both by ACCA software).

4. PRE AND POST RESTORATION DIGITISATION: VPL FOR SFM AND REMESHING

Diagnostics, 3D acquisition, documentation and restoration were addressed by various professionals.
Therefore, these activities were addressed by dismantling the frontal and separately treating the different parts (structure with scenes and caryatids). The elements features define diagnostic and acquisition methodology. Digital acquisition and graphic reconstruction of metal artefacts, both with passive and active sensors, presents numerous problems due to the high reflectivity of the material. Regarding metal objects, the damage is proportional to the degree of continuity and smoothness of the surfaces.
According to photogrammetric acquisition technique, the photographs were taken with axis shooting system along helicoidal path, from bottom to top for the caryatids, and along vertical bands (serpentine path), moving from left to right, front (silver) and back (wooden) for the structure and scenes (fig. 3).

4.1 Frontal digital photogrammetry

In pre - restoration phase only front with caryatids and partial lateral of the frontal were digitized by the students involved in the activity, without the wooden structure (the frontal was still inserted into the altar). A number of 127 photos were acquired with NIKON D5100 at a distance of 1 m, focal length 18 mm, f/3.5, exposure time 1/30 sec., ISO 1100. The state of preservation influences gloss of material and alters original color of metals. These alterations simplify photogrammetric capture of the model because they dampen the reflectivity of the material. Orthophotos were used to map the state of preservation, plan diagnostic activities and design intervention techniques (Fig. 5).
For post – restoration acquisition of the frontal structure (front, side, including scenes, and wooden back), 1039 photos were acquired with a camera Canon EOS 250D, focal distance 55 mm, f/5.6, exposure time 1/30 sec., ISO 400, at a distance of 50 cm from the piece. An initial test involved the use of four cold LED headlights (low cost), a second test included the use of projector, diffusers, reflective and translucent umbrellas. Both the groups of photos have been processed and the comparison shows mesh without gaps or irregularities both with low-cost camera and professional lights and using only four cold headlights. The reflectivity of the silver, with and without professional photographic set (reflector, diffuser and traslucent umbrellas), did not generate important differences in the color quality of the texture.

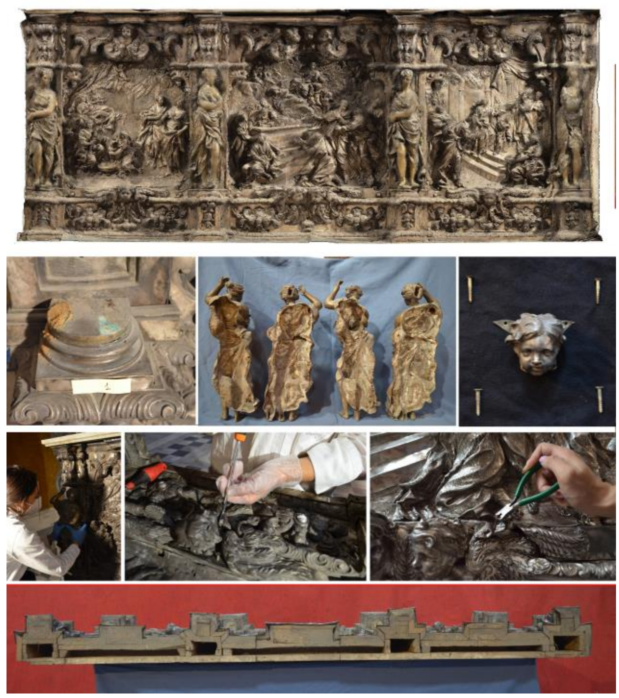


Figure 5. On the top: pre - restoration photogrammetric textured mesh of the frontal; on the bottom: disassembly of frontal details.

The texture elaborated by LED lights has been subjected to colour correction, editing the mosaic of the unique texture produced by .obj files export.
The three scenes of the altar frontal present a high formal complexity and variety of details. Therefore, despite the high reflectivity of the post-restoration material, the textured photogrammetric mesh has no holes or irregularities.
Finally, the altar frontal, reintegrated into the canopy, was photographed with the Fujifilm Camera GFX 100 S, focal length 62 mm, f/11, 1/125 sec., ISO 200, equipped with 14cm diameter reflector, reflective and translucent diffusers and umbrellas.
The comparison between details extrapolated from the models acquired with tested low-cost and high-cost photographic set demonstrates the regularity and the high level of detail of both products, due to the complexity of the piece. However, the photogrammetric mesh of smooth lesenes (without caryatids) that define the structure of the frontal and separate scenes present a limited number of holes, manually editable in CAD environment.
Therefore, post-restoration textured photogrammetric mesh of the frontal does not present problems, despite the high reflectivity of the material and regardless of specific digital photogrammetry software, thanks to the high complexity of the scenes (Fig. 6). In general, according to specialist literature (Hallot et al., 2019), many close-up photos allow textured models of metal works with a high level of detail characterized by a limited number of holes and irregularities that can be manually solved or with specific remeshing filters and automatic closing of holes.

4.2 Caryatids VPL photogrammetry

On the contrary, texturized models of post restoration caryatids require deep editing, due to the highly reflective smooth surfaces. The four caryatids were photographed with Camera Canon EOS 250D, 18/55 mm lens, 24.1 MP, illuminated with two LED cold headlights, placed on both sides of the statues to reduce shadow areas, without reflector, diffusers and reflective umbrellas.

Figure 6. Post - restoration photogrammetric acquisition of the frontal (structure and scenes, without caryatids): from point clouds to textured mesh and details.

Given highly economical toolset, meshes were characterized by many gaps and topological problems. Photogrammetric process produced a high poly mesh hardly importable in BIM environment.
Hence, the main goal is mesh postproduction processed by photogrammetry performed with essential tools and setting, filtering (decimation) and sculpting. Processing and post-production process has been managed only by applying open-source software: VPL approach for processing digital photogrammetric mesh (*Autodesk Meshroom*) and remeshing/sculpting tools to correct holes and deformations (*Meshmixer*).
The caryatid number one (in altar frontal, the first one, on the left) was chosen to test both the VPL SfM and traditional processes described above to make a comparison between open source (free) and closed source (high cost) software.
As described in previous chapter, the compared SfM_Structure from Motion Photogrammetry software are *3D Zephyr* (high cost - closed source, educational version) and *Meshroom* (low cost - open source VPL approach).
Step by step, VPL processing and remeshing algorithms enable custom filtering and editing operations (decimation, topological optimization, Laplacian filtering algorithms), aimed at processing an optimized structured mesh.
However, from the operational point of view, the main difference between these software is about point clouds and meshes processing time, higher using open source VPL software, and about the final number of mesh vertices and polygons.
Generic settings generate a higher resolution mesh and more points and polygons (high poly mesh), regardless of software (test 1). The comparison shows that the decimated VPL photogrammetric mesh (test 2) has fewer points and polygons and less noise (low poly mesh). However, both models have holes or deformations in the most reflective smooth areas (face or arms). Similar problems have emerged for other caryatids.

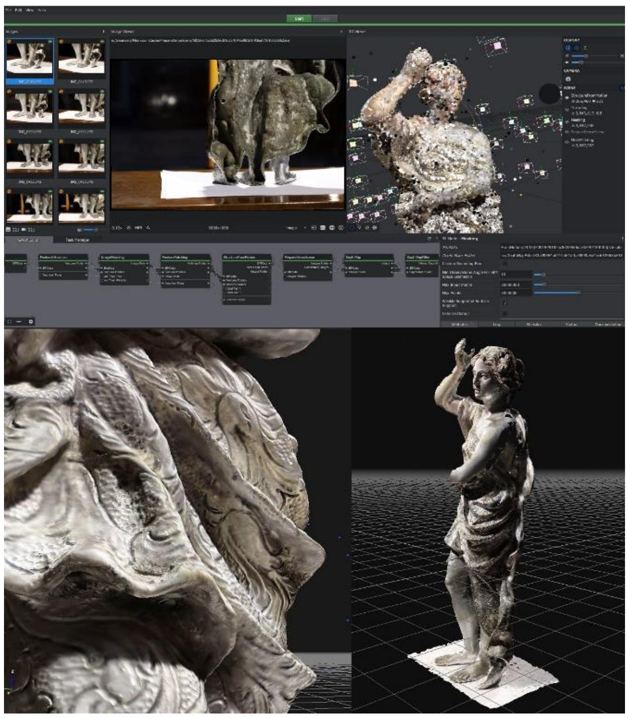


Figure 7. VPL for SfM: caryatid acquisition.

4.3 Caryatids mesh editing: remeshing and sculpting

To solve mesh issues, the first test was to eliminate dense cloud noise in correspondence of the face and the arm. The high reflectivity of the material at these smooth areas hindered SfM algorithms. However, elimination of internal points causes wide gap in correspondence of these two areas.
Therefore, remeshing algorithm (decimation and ritopologization) allows reduction of polygon number (*Meshroom*) and sculpting tools fixed irregularities and holes maintaining a high level of photorealism (*Meshmixer*).
The following modules of sculpting (*adaptive density*, *drag*, *smooth*, *flatten*, *inflate*, *refine*) allow to fix irregularities and issues of the textured mesh (imported as .obj file with unique texture), such as holes and noise. The *Adaptive density* module allows detail retention despite reduced polygon count (Fig. 8). However, this still increases the risk of artifact production. In this case, advanced sculpting does not generate problems because these areas did not present decay conditions.
These operations are essential to allow interoperability between modeling software. Then, textured meshes of the structure, scenes and decimated models of caryatids were imported in BIM authoring software (*Edificius*, ACCA software) and integrated into a CAD/HBIM hybrid model of the decorative canopy placed in the chapel. Finally, the hybrid model was imported on the collaborative web-sharing platform (*usBim Platform*,_ACCA software), (Figg. 9, 10).

5. SEMANTIC DECOMPOSITION FOR RESTORATION AND DOCUMENTATION

In the early stages of the research particular attention is paid to historical and archival research and to CAD drawings produced from traditional survey of the chapel and canopy.
Restoration work, made by students of Professional Training Course in Conservation and restoration of ceramic and glass products, metal and alloys (PFP4) foresees visual and diagnostic analysis.
Graphic and photographic documentation, datasheets and reports are loaded, collected and systematized in special folders structuring the ACDat on the platform. Graphic mappings report physical, chemical and mechanical damage, restoration techniques and distribution of connection types (Fig. 11).
The analyses were performed for each documented and restored element of the altar frontal.
Below, the list of non-destructive diagnostic investigations performed on the altar frontal:

- X-ray fluorescence (XRF), qualitative and semi-quantitative analysis of the nature of the chemical elements present on the tested surfaces (Fig. 12);
- Scanning Electron Microscopy and X-ray microanalysis (SEM-EDX), qualitative and quantitative analysis of the chemical composition of metal surface coatings;
- Ion chromatography, qualitative and quantitative analysis by assay of soluble salts in patinas of metal surfaces.

A SfM to HBIM workflow was adopted to build a digital twin as a web shared documented detailed system of parts and sub-parts accessible to specialist and even to non-specialist users. The frontal is simultaneously contained and container, and it is divisible into decorative elements (scenes assembled and decorative details), compositional and structural elements (caryatids bolted to the structure, base, entablature and pilasters) and functional elements, such as silver nails, iron, silver-plated brass, threaded pins, screws and seams, for figurative details anchoring.

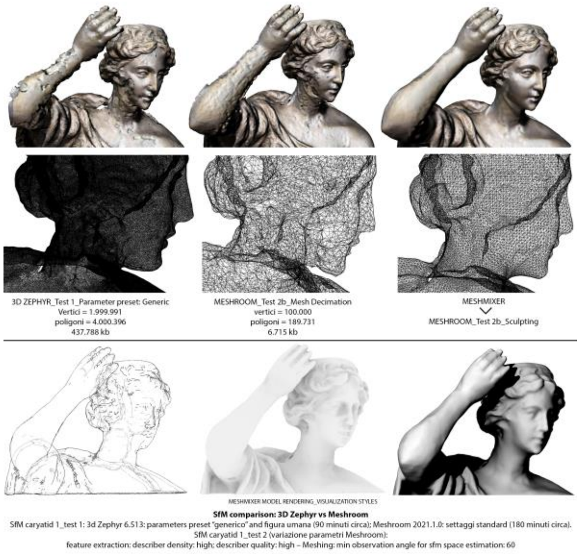


Figure 8. SfM comparison: high-cost *vs* open-source tools

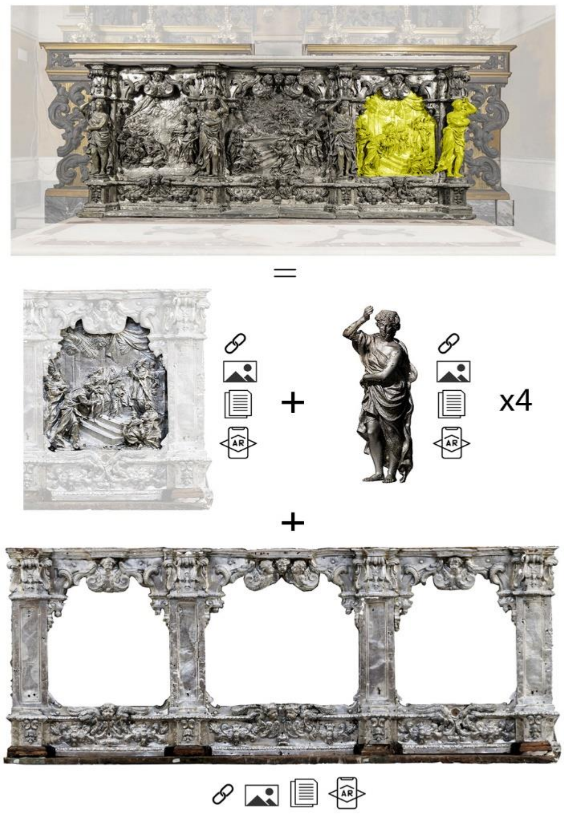


Figure 9. Frontal semantic decomposition for data storage

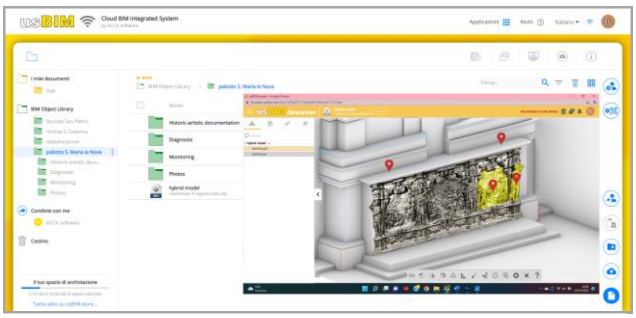


Figure10. CDE on web sharing collaboration platform. Work in progress: hybrid model and data storage and systematization

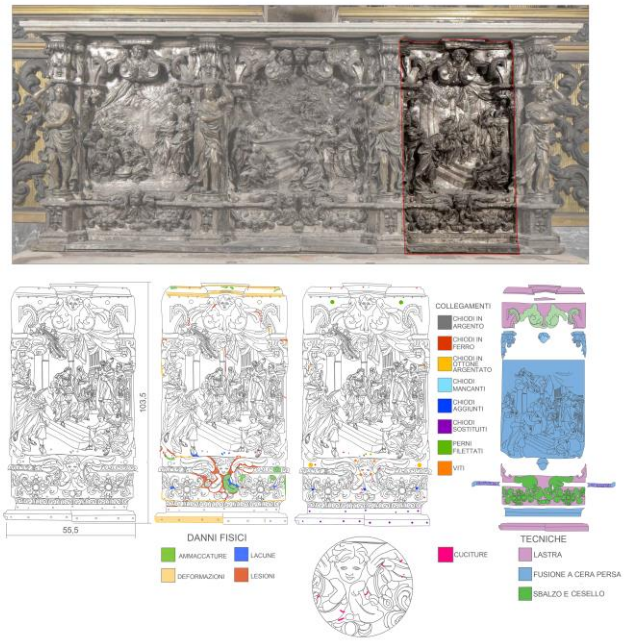
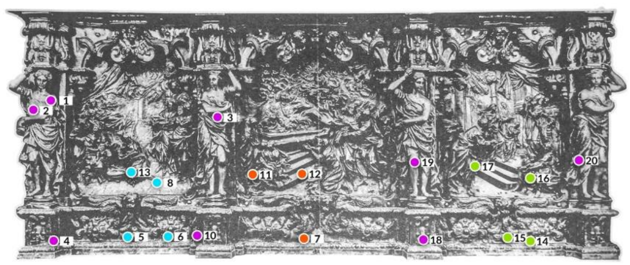


Figure 10. Thematic mapping of the altar frontal: decay mapping, intervention techniques and connection systems



Cariatidi

Tesista: Nunzia Saviano

1		Cariatide n.1	Cu, Zn.
2		Cariatide n.1	Cu, Zn. Ag (picco basso).
3		Cariatide n.2	Cu, Zn. Ag (picco molto basso).
4		Piedistallo n.1	Ag (picco molto alto), Cu. Zn (picco basso). Fe (impurezze).

10		Piedistallo n.2	Ag, Cu. Fe (impurezze).
18		Piedistallo n.3	Ag, Cu. Fe (impurezze, picco alto).
19		Cariatide n.3	Cu, Zn.
20		Cariatide n.4	Cu, Zn. Ag (picco basso).

Scena dx (Presentazione al Tempio)

Tesista: Melany Aisha Minichino

14		Ag, Cu. Fe (impurezze, picco basso).
15		Ag (picco alto), Cu*. Fe (impurezze)*. • Più *Cu* rispetto al punto 14. • Picco *Fe* leggermente più alto del punto 14.
16		Ag (picco alto), Cu (picco basso). Fe (impurezze, picco basso).
17		Cu (picco molto alto), Ag (picco alto) *. Fe (impurezze, picco basso). * Cu e Ag sono presenti in quantità simili.

Scena sx (Nascita della Vergine)

Tesista: Claudia Trancone

5		Ag, Cu. Impurezze: Ni, Fe.
6		Ag, Cu*
8		Ag (picco alto), Cu.
13		Ag (picco alto), Cu. Fe (impurezze, picco basso).

Scena centrale (Assunzione della Vergine)

Tesista: Roberta Franchitto

7		Ag, Cu.
11		Ag, Cu. Fe (impurezze, picco basso).
12		Ag, Cu (picchi alti).

Figure 11. X-ray fluorescence (XRF): detected points mapping.

All the textured photogrammetric mesh of the frontal elements were reassembled/contextualized in HBIM authoring software.
The chapel was modeled as one of the macro-elements of the Church according to object-oriented modeling technique, as well as the canopy, considered as a temporary digital container for the frontal. Finally, the digital twin of the decorative system is composed of pieces of photogrammetric textured mesh and HBIM objects.
Next acquisition of the other metal parts will allow the assembly of the entire system as a composition of photogrammetric textured mesh.

It allows to achieve a faithful digital twin of the metal canopy, according to a LOIN approach, working on the semantic composition of elements, sub-elements, parts and sub - parts of the artwork, and a detailed interactive and updatable storage and documentation of the parts in the web-sharing common data environment.
The platform tools allow to decompose and interrogate the uploaded hybrid model, to link documents, information, photos, diagnostic data and historical-artistic documentation.
From macro to micro, *Marker* tool allows the elements localization; *#Tag* tool allows the decomposition and querying of the system, according to the hierarchical relationship between elements; *Link* tool allows multidisciplinary documents and datasheet attachment to the different elements.
More specifically, the tested platform allows to organize a semantic sequence of several groups or systems: each system contains the following system, from macro to micro. The #chapel (container) represents a structural macro-element of the #church and it hosts the #canopy (element, content - container).
A first group (element) is represented by the canopy (content - container): the altar, the altarpiece, the pillars, the capitals, the pavilion are the content (microelements).
Then, a second group (sub-element) is represented by the #altar frontal as a whole piece (content – container), composed by the classic structure of decorated pilasters, entablature and bases (#structure), the #scenes, composed by different metal layers of decorative figures of the Virgin's histories and the #caryatids as contents (parts). Each piece is a data container.

6. MONITORING ACTIVITY

Preventive conservation is an open research topic: multiple risk factors need to find strategies, tools and methods of conservation and protection for CH. One of the main goals is to achieve infographic information systems aimed at documentation and asset CH management, including continuous monitoring of the real artifact to update digital twin in real time. According to Preventive Conservation (PC), the approach is aimed at identifying the relationship between microenvironmental variations and decay phenomena through non-invasive and non-destructive acquisition tools and techniques (NDT).
The goal is to define interconnected tools for the management and enhancement of heritage enriched by multidisciplinary information and interoperable processes of environmental data conversion and acquisition (container) aimed at predicting consequences and strategies in terms of conservation of the pieces (contents). Monitoring allows the adoption of preventive measures for the correct conservation of the piece, avoiding further restoration work too close in time. The model is a support to develop preventive conservation programs. According to these premises, this work is approaching a monitoring activity aimed at semantic-informative enrichment of digital model, including microclimatic data.
The hybrid CAD/VPL/HBIM model of the altar frontal was imported in web sharing platform for 3D graphic localization (marker) of the thermo-hygrometric sensors, located in the chapel, and the respective reports (link). The sensors, placed on the altar, to the right and to the left of the tabernacle, detected temperature and humidity data, monitoring the environmental conditions to prevent the interaction between their variations and the state of conservation of the restored artworks (Fig. 13).
Monitoring system was tested from June 2021 to May 2022, and the report uploading on the web-sharing platform is in progress.
Monitoring systems could be added among HBIM objects, implementing new, specific object-oriented tools for CH management, *e.g.* more detailed layering and mapping systems.

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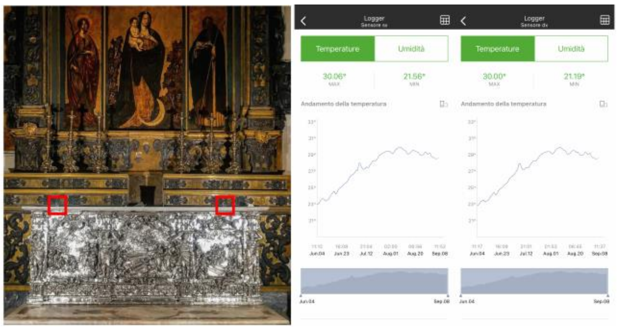

Figure 12. Thermo-hygrometric monitoring system.

7. CONCLUSIONS AND FUTURE WORKS

In conclusion, according to specialist literature, about acquisition step, a large number of photos at close range and greater focal distance, without high-cost cameras, photo light sets and software, allow to elaborate texturized photogrammetric models of highly detailed metal works (*i.e.* frontal scenes and caryatids dress), with limited number of holes and irregularities, manageable manually or with limited application of special remeshing and sculpting filters. On the contrary, elements characterized by continuous and smooth areas, (*i.e.* face and arms caryatids), need to deepen photogrammetric processing about mesh filtering, editing and sculpting. In the educational and research field, further tests in progress are aimed at enhancing the acquisition of highly reflective pieces, including collections of numerous and detailed metal artefacts. One positive aspect is that mesh topology of continuous surfaces is often associated with geometrically defined shapes, characterized by a recognizable geometric genesis, therefore more easily editable by traditional modeling tools. About HBIM approach, shared project in platform, construction ACDat and digital twin photogrammetric of the entire canopy and chapel are under construction. In conclusion, the semantic decomposition of the piece and the management of separate models allow experimentation of applications aimed at enhancing the artefact and simplify systematization shared heterogeneous data.

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