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3D DIGITAL TOOLS FOR THE ARCHAEOLOGICAL MASSIVE ARTIFACTS DOCUMENTATION

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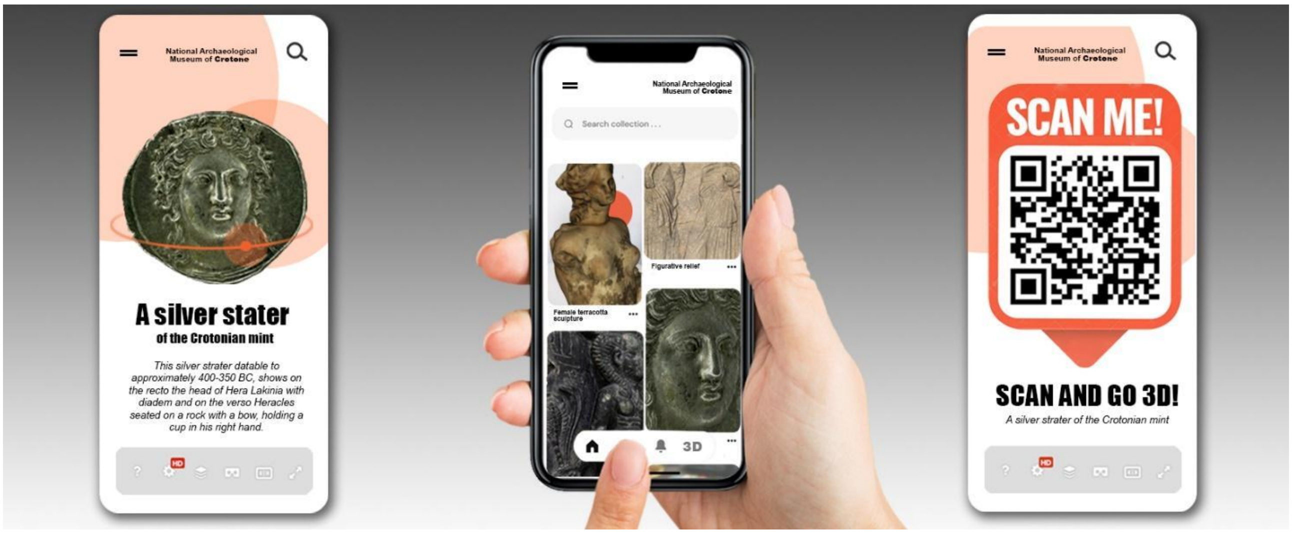


This silver strater datable to approximately 400-350 BC, shows on the recto the head of Hera Lakinia with diadem and on the verso Heracles seated on a rock with a bow, holding a cup in his right hand.

Data acquisition and optimization process results for the digitization of cultural assets and their sharing on digital platform (own infographic authors content, 2022).

Abstract

This study focuses on 3D acquisition and documentation procedures, innovating and implementing traditional survey methods to promote and increase the efficacy of the historical and archaeological heritage fruition. Especially within museum itineraries, modern digital technologies, if consistently applied, can promote a better interpretative reading, implementing the knowledge of scholars. Moreover, in coherence with the Horizon Europe “Cultural Heritage” area of intervention, for a new future inextricably linked to the history of Cultural Heritage, it is essential to experiment approaches that favor innovative mechanisms of fruition and promotion of works of art, based on the idea that the user is an active part of the experiential path. The study presents some acquisition experiences on different archaeological artifacts collected at the National Archaeological Museum of Crotone, applying integrated technologies and defining a rigorous methodological process of analysis and control.

Keywords: CH survey, Digital heritage, Semantic description, 3D modeling, Texture correction.

1. Introduction

In recent years, the Cultural Heritage (CH) field has experienced a rapid increase in the use of new technologies for more fluid and advanced knowledge, supporting, often, the creation of a heterogeneous integrated database, accessible to scholars and visitors, sharable and, implementable over time [Apollonio et al. 2018, p. 91]. In this process, non-invasive technologies for the generation of digital heritage models have produced an exponential quality growth of the acquired data [Inzerillo et al. 2019, p. 389]. However, there are still several issues in identifying a single approach that meets high levels of accuracy at the morphological, topological and texture mapping levels. This is even more relevant when interfacing with museum collections, for which an operational strategy has to be identified in order to optimize the process, often in a not ideal environment [Plisson and Zotkina 2015, p. 103].

Photogrammetry is one of the most portable, effective and flexible tool, guaranteeing efficient workflows also under difficult conditions [Nicolae et al. 2014, p. 451] or in presence of objects with special material characteristics.

Nevertheless, in relation to the object, the photogrammetric acquisition and processing times could be quite long and, in same case, as for small objects with complex surfaces and sub-millimeter morphological characteristics, a high level of expertise and experience is required [Apollonio et al. 2021, p. 486]. Indeed, the operational challenges are compounded by increasing difficulties as the scale of application is reduced [Antinozzi et al. 2020, p. 1538].

Another significant contribution to the generation of increasingly metrically correct models has come from the great development of handheld structured light scanners [Morena et al. 2019, p. 135]. These techniques provide rapid data acquisitions, a non-contact process, and ensure precise and accurate measurements, returning scaled digital 3D object copies. However, generally these scanners are specifically designed to capture a precise size range of the object and have a defined depth range in which to operate. In addition, as known, they are also quite influenced by the surface optical features of objects [Georgopoulus et al. 2010, p. 250] and often have cameras with limited resolution, influencing the result of the final texture.

As can be inferred, therefore, in case of reduced timeframes and high-performance demands, a fair compromise between different acquisition equipment should be found. Then, once the data has been obtained, it is necessary to work on the weak acquisition points, according to the mesh management and texture mapping process.

Fig. 1. Finds from the National Archeological Museum of Crotone: i) The strater; ii) The stele; iii) The sculpture; iv) The figurative relief (own infographic authors content, 2022).

The study presents an operational pipeline that outlines the relevance and challenges of the acquisition phase and discusses how to implement and optimize digital data for obtaining complex and semantic 3D models with high information density. The process has been tested on heterogeneous finds preserved in the National Archaeological Museum of Crotone (fig.1), each characterized by its own dimension, shape and material: i) the silver strater from the mint of Crotone (about 400-350 BC), showing on the recto the head of Hera Lakinia with diadem and on the verso Heracles seated on a rock with a bow, holding a cup in his right hand; ii) the stele known as the 'Cippus of Horo on the crocodiles', a charm made of engraved basalt from the Late Egyptian period (378 BC), which has engravings on the front, back and sides, although the façade is composed almost exclusively of bas-reliefs; iii) the female terracotta sculpture of a nude figure leaning on a column (first half of the 3rd century BC); iv) the figurative relief of a votive character of the end of the 5th century BC, depicting two female divinities in conversation.

Closely linked to the characteristic of the case studies is the choice to use several instruments that differ in type and specifications. The different parameters taken in consideration are: i) the size of the object and its surface details, which forces evaluations on the achievable resolution by the instrument; ii) the shape and the position of the artifact in the museum environment, which leads to specific projects for the acquisition set; iii) the material and consequently the texture, for which, besides understanding which is the most suitable technology, it is necessary to guarantee coherence and uniformity in lighting; iv) the available time, which forces to choose, besides the method that guarantees the best results, also the most efficient one in saving time and energy, bearing in mind first of all the final purpose of digitization. Based on these considerations, two parallel approaches were followed, illustrated below.

2. Materials and methods

Detailed, reflective and dark artifacts: photogrammetric approach

An efficient photogrammetric system for tiny object detection is based on the multi-viewpoint acquisition [Collins et al. 2019, p. 1443], in which the camera is fixed on a tripod and the object is rotated by a turntable. Starting from this configuration, different sensors were employed to survey two detailed findings (tab. 1): i) a Dino-Lite USB digital microscope for the silver Croton strater; ii) a full-frame Nikon camera, with a 105 mm macro lens, for the basalt Egyptian stele.

Digital USB microscopes are portable devices, configured as a webcam with a high-powered macro lens that connects to a computer, showing images directly on the display; they are the most user-friendly and the least expensive [Atsushi et al. 2011, p. 1045].

Widely implemented in several fields, these instruments can be used for micro-photogrammetric applications (fig. 2), reaching about 0.1 mm accuracy [Esmaeili and Ebadi 2017, p. 65]. Meanwhile, not very high resolution, lack of a wide dynamic range, narrow field of view, and poor depth of field are the weaknesses of this device. The AM7013MZT microscope, in our case, was implemented for the coin survey, working with a total magnification rate of 20x, the focus at distance of 48.7 mm and with a depth of field to 3.6 mm.

The difficulty of carrying out a complete survey with a USB microscope of an object that is small, but not negligible in thickness compared to the coin, led to the use of a more 'conventional' camera for the survey of the stele (fig. 3).

	SUPPLY	OPTICAL MAGNIFICATION	SENSOR	PIXEL SIZE	RESOLUTION
Dino-Lite AM7013MZT	battery powered	up to 200:1	CMOS 6.1 x 4.6 mm	$2.4 \cdot 10^{-3}$ mm	5 MP
Nikon D800E	power supply	up to 1:1	CMOS 35.9 x 24 mm	$4.9 \cdot 10^{-3}$ mm	36.3 MP

Tab. 1. Technical specifications of micro and macro photogrammetry instruments used for strater and stele survey (own infographic authors content, 2022).

Fig. 2. Zoom-in view and 3D model with texture mapping applied of the silver Croton strater acquired with Dino-Lite microscope (own infographic authors content, 2022).

In fact, full frame cameras combined with macro lenses are widely used for micro-photogrammetry [Verdiani et al. 2018, p. 235]. The Nikon D800E SRL camera, equipped with the AF-S VR Micro-Nikkor 105 mm f/2.8G IF-ED, was adopted to achieve high quality and close focusing with limited optical distortion. At a focusing distance of 700 mm, assuming a tabulated circle of confusion value of 0.29 mm, the depth of field is approximately 115 mm. However, each artifact was placed on a turning table, then camera inclination and rotational step angle were chosen in relation to the objects.

Fig. 3. Zoom-in view and 3D model with texture mapping applied of the basalt Egyptian stele acquired with Nikon camera (own infographic authors content, 2022).

	SUPPLY	LINEAR FIELD OF VIEW	3D RESOLUTION	ACQUISITION SPEED	TEXTURE RESOLUTION
Artec Eva	battery powered	from 214x148 mm to 536x371 mm	up to 0.2 mm	18 mln points/s	1.3 MP
Artec Leo	power supply	from 244×142 mm to 838×488 mm	up to 0.2 mm	35 mln points/s	2.3 MP

Tab. 2. Technical specifications of structured light system instruments used for sculpture and figurative relief survey (own infographic authors content, 2022).

The survey has been designed with calibrated plates built for both photogrammetric systems: calibration patterns which can be used as a constraint points (GCP) grid for the standard photogrammetric procedure needs. The lighting conditions, based on the polarized light of the microscopes and/or on the artificial lighting of the museum, have been improved with the adoption of a LED illumination ring.

As regards the silver Croton strater, two acquisition sets – for the recto and for the verso of the coin, averaging 80 captures each – were required, for a total of about 30 minutes of time. In the case of the stele, however, a single set of about 100 captures was sufficient, for about 20 minutes of work.

The datasets obtained were thus processed in a SfM software, Agisoft Metashape, according to the general photogrammetric workflow. The sparse point cloud was checked before proceeding with the reconstruction of the model, removing low-quality TPs via the Gradual Selection filter, a tool by Agisoft Metashape.

Opaque medium-size artifacts with simple textures: structured light scanner approach

Structured light techniques, in the last years, have benefited from recent advances in digital technology; the necessary hardware is increasingly available as well as better performance of data management software [Zhang 2018, p. 119]. Such progress, moreover, has made the instruments more practical, easily transportable and, therefore, implementable also in several fields as well as in the CH [Limongiello et al. 2022].

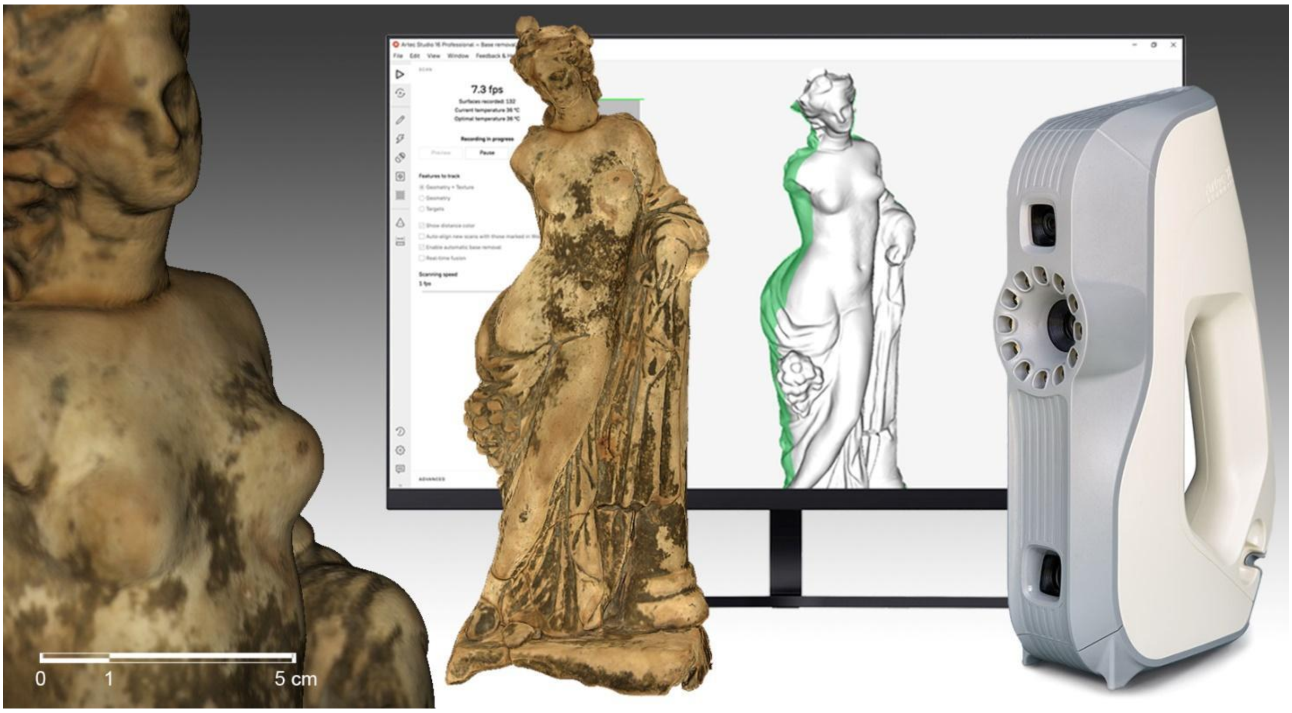


Fig. 4. Zoom-in view and 3D model with texture mapping applied of the female terracotta sculpture acquired with Artec Eva scanner (own infographic authors content, 2022).

Fig. 5. Zoom-in view and 3D model with texture mapping applied of the figurative relief acquired with Artec Leo scanner (own infographic authors content, 2022).

In case study, the museum finds were surveyed with the use of two different handheld scanners (tab. 2): i) Artec Leo for the figurative relief, ii) Artec Eva for the female terracotta sculpture.
The operating technology of structured light scanners is like stereoscopic vision systems in which depth information are based on the principle of triangulation; however, the instrument, in this case, projects on the surface of the object a particular pattern to ensure greater accuracy in the measurement as well as a higher acquisition speed [Bell et al. 2016, p. 2]. Artec Eva is a structured light scanner produced by the Artec 3D and ideal for prompt acquisition of medium-sized objects (fig. 4). Acquisitions were made rotating around the object by setting geometry and texture tracking modes and enabling HD data density with a value of 4x (time required: about 40 minutes).
However, with this instrument, the collected data must be monitored in real time on the notebook and visualized by the proprietary software with the aim to control any lost tracking. This drawback is overcome with Artec Leo (fig. 5), which is also a portable structured light scanner, but which allows the 3D replica of the object to be displayed directly in real time on its touch panel screen. Therefore, given the larger size and limited space around the figurative relief, this device was used for the survey of the second find. The hardware features, in fact, allow on-board real time processing without notebook support as well as a fast and intuitive workflow.
The acquisitions were carried out with the previous modes; but, due to the improved performance of the Artec Leo, data control and waiting time for registration of scans in HD mode was faster, about 30 minutes. The software used to manage the data is Artec Studio 15 Professional, a proprietary software, operating according to the typical steps foreseen by the program. Longer acquisition and post-processing times were found mainly with the surveys carried out with Artec Eva. The scans of the female terracotta sculpture, following the global registration, presented a max error of 0.3; the fusion of the scans was set with a resolution of 0.5 mm of and with the texturization in atlas mode (8192x8192 px). For the model of the figured relief, realized with the Artec Leo, being able to control the quality of the scans already during the acquisition phase, the max error reached was of 0.1, and the final model was obtained setting a resolution of 0.6 mm and an atlas texture of 8192x8192 px.

3. Data optimization

The set of collected data required a reasoned management process due to the heterogeneity of the information associated with them. Each case study acquired presents different parameters in relation to: density and structure of the processed mesh surfaces; quality of the applied textures; size and complexity of the resulting geometric model.

The methodology used defines a path aimed at the optimization of digital 3D mesh models that have a high quality of both the geometric surface and the applied texture. As known, in the texture mapping phase the most common problems, due to the often not ideal gripping conditions, are: low texture resolution; gaps and undercuts; photographic inconsistencies (variation of light and reflections) and topological errors due to the formal geometric complexity.

The mesh management and texture mapping process proposed consist of the following steps: mesh parameterization, mesh partitioning, mesh segmentation unwraps, UV map and island projection, UV layout optimization, mesh packing and baking. The quality of the result ensures effective consultation in the subsequent phases of investigation and an easy fruition to the public.

The procedure follows a reasoned path that elaborates the topological structure of the geometric model, analyzing and resolving computational and color errors, areas the under-squares and gaps, segmenting and reorganizing the collected data according to criteria defined in synergy with the Museum’s scholars and experts [Niang et al. 2017, p. 2].

4. Results and discussion

Before proceeding, therefore, to mesh segmentation, it was necessary to check the topological errors generated during post-processing. For each of the 3D models, the following steps were developed: removal of double vertices from the mesh and closure of the seam, and review of the edge connections. Particular attention was paid to the control of the polygonal loading of the surfaces with the aim of not losing the quality of the detail, but at the same time, to ensure easy management on a dedicated digital platform, to support the digitized version of the case studies, adding to the semantic models, through the creation of specific tags: notes, historical information, metric data or comments of scholars and experts.

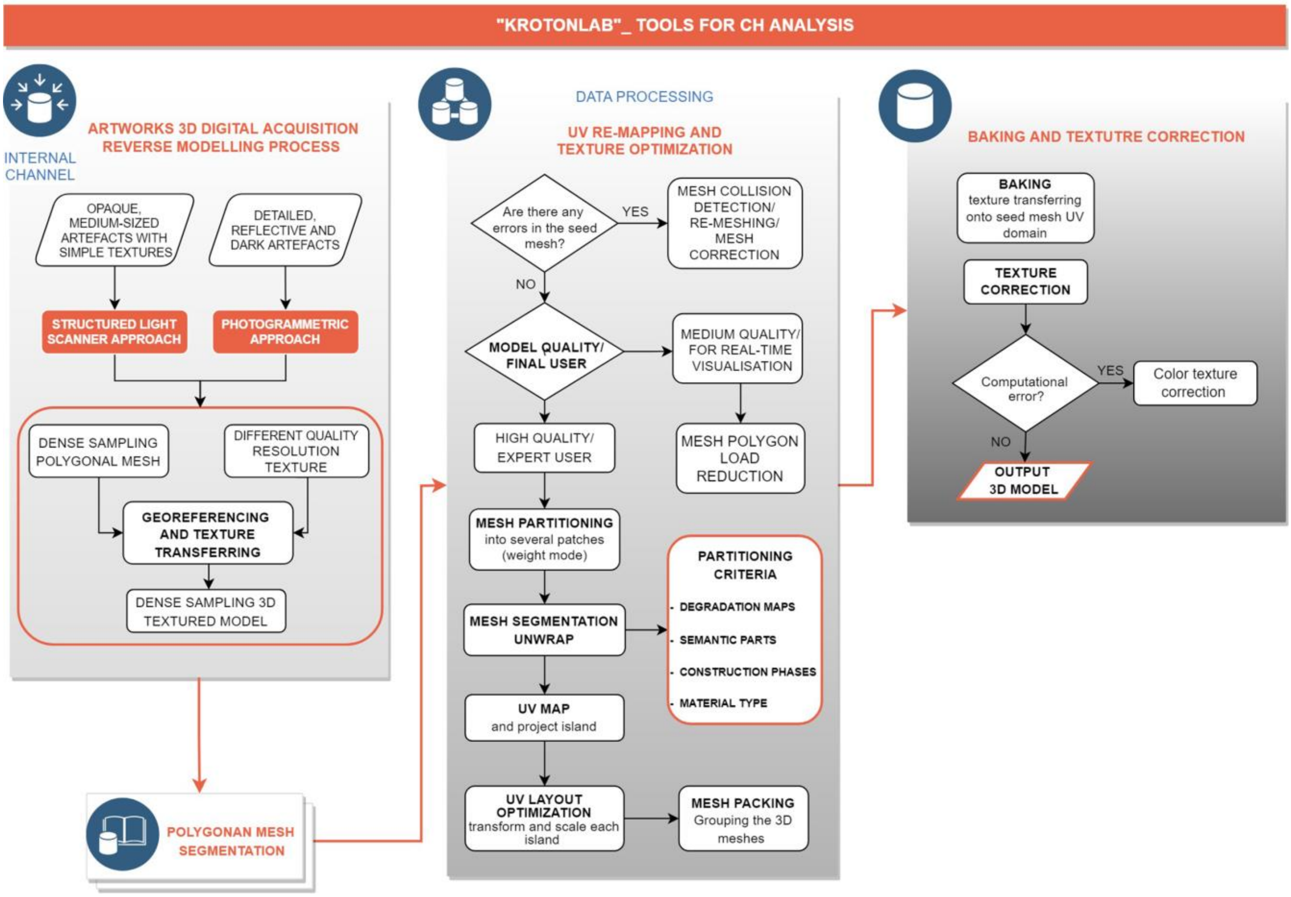
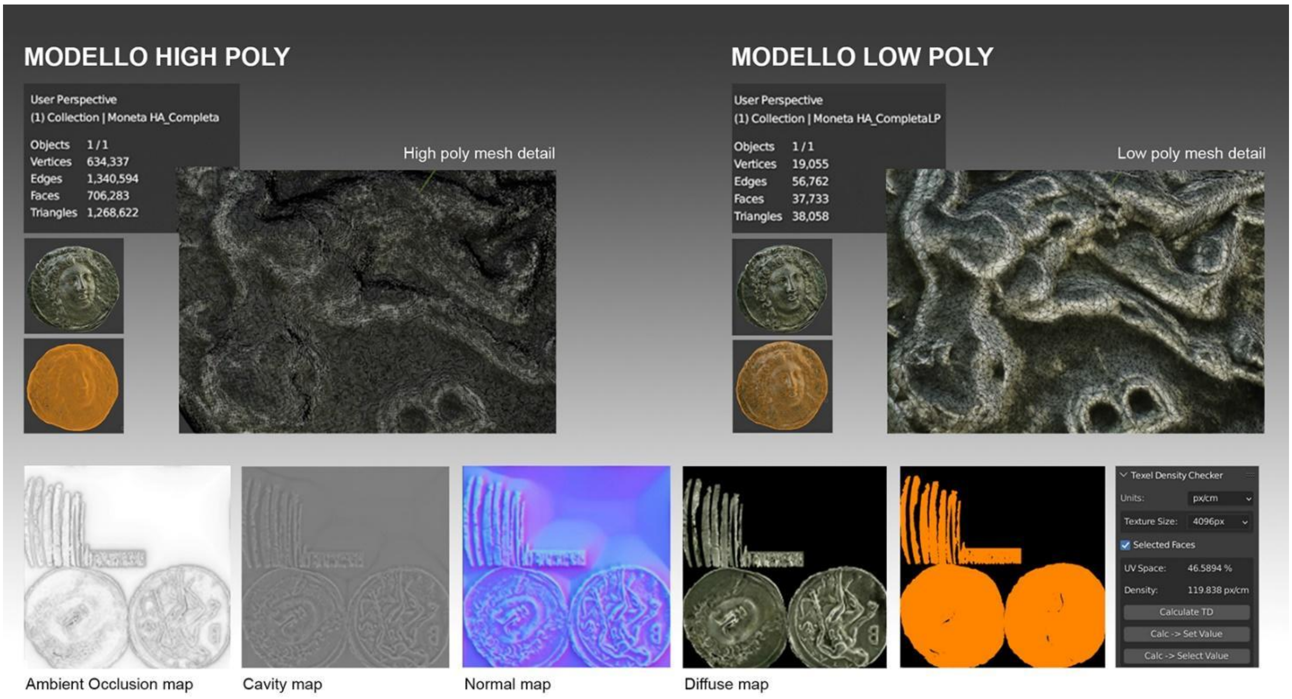


Fig. 6. The flowchart for developing high accuracy 3D shape measurement in relation to the object characteristics and to optimize the mesh and texture mapping process (own infographic authors content, 2022).



User Perspective
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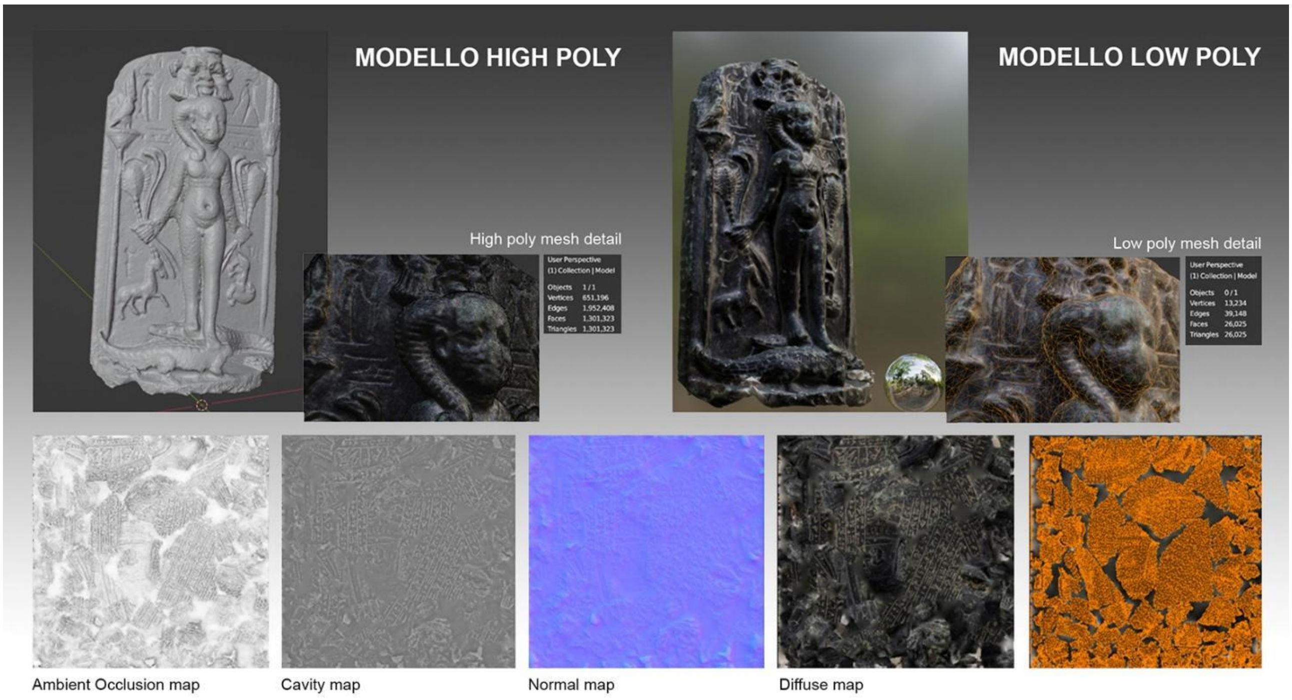
Objects 1 / 1
Vertices 634,337
Edges 1,340,594
Faces 706,283
Triangles 1,268,622

User Perspective
(1) Collection | Moneta HA_CompletaLP
Objects 1 / 1
Vertices 19,055
Edges 56,762
Faces 37,733
Triangles 38,058

Texel Density Checker
Units: px/cm
Texture Size: 4096px
☑ Selected Faces
UV Space: 46.5894 %
Density: 119.838 px/cm

Fig. 7. Optimization process of polygonal load and of the UV-Map of the silver Croton strater for online content dissemination (own infographic authors content, 2022).

Since the models will be displayed online on web dissemination platforms, re-meshing and re-topology processes were initiated on the polygonal models. The algorithm employed replaces the original mesh with a new one that preserves some formal characteristics (vertex position and edge geometry). The reconstructed mesh with a reduced number of polygonal faces (low poly) must maintain the geometric-formal structure of the original mesh (high poly).
The pipeline described below can be replicated on a variety of commercially available software.



User Perspective
(1) Collection | Model
Objects 1 / 1
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Faces 1,301,323
Triangles 1,301,323

User Perspective
(1) Collection | Model
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Vertices 13,234
Edges 39,148
Faces 26,025
Triangles 26,025

Fig. 8. Optimization process of polygonal load and of the UV-Map of the basalt Egyptian stele for online content dissemination (own infographic authors content, 2022).

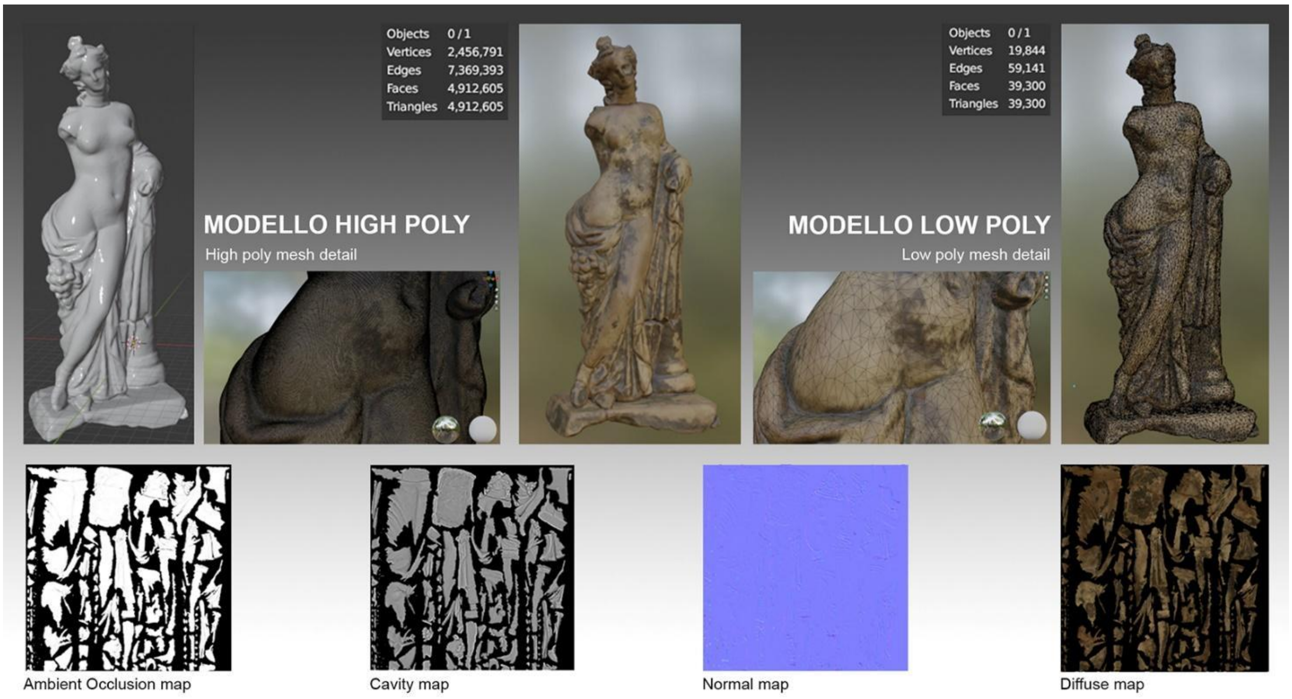

Fig. 9. Optimization process of polygonal load and of the UV-Map of the female terracotta sculpture for online content dissemination (own infographic authors content, 2022).

We preferred to develop the process (fig. 6) within the open-source working environment Blender (stable version 2.93 and beta version 3.0). For each artefact, the same methodological procedure was applied allowing, at the end of the process, to obtain 3D models with a good sampling in terms of geometric-formal definition and quality of the applied texture. The goal is to create digital products that meet the requirements of the CH dissemination standards.

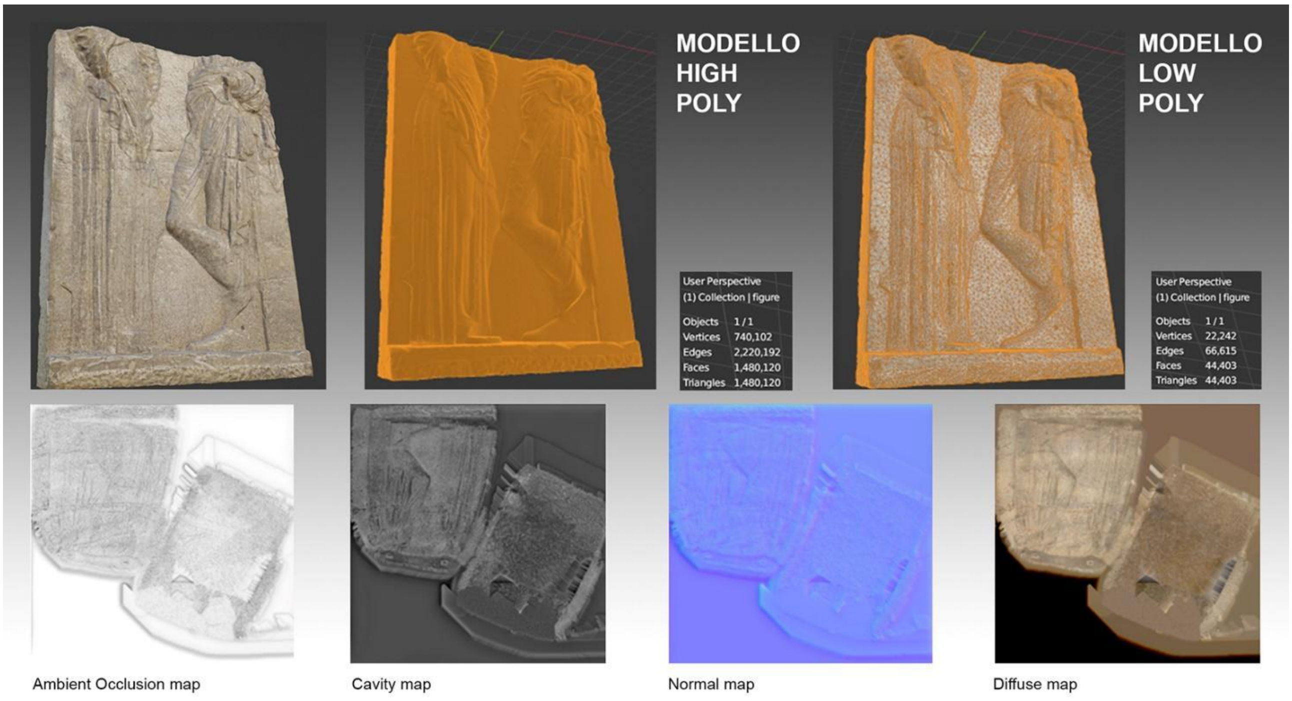

Fig. 10. Optimization process of polygonal load and of the UV-Map of the figurative relief for online content dissemination (own infographic authors content, 2022).

The phase involving texture mapping includes multiple preliminary processing, such as mesh partitioning, mesh parameterization, and texture transfer, which are interrelated and affect the result (Lai et al. 2018, p. 1).

Newer software technology uses dedicated UV vertex map generation tools to assign the texture to a numerical model with a complex geometric shape. Because the texture is a planar 2D figure, UV vertex maps establish a bidirectional correspondence between the vertices of the 3D polygon mesh and the pixels in the image. The libraries available within Blender software use an automated procedure to create UV maps. The tool is called the “Smart UV Project”.

Before assigning texture to the edited surface (Baking), a new material component was created through procedural techniques within Blender’s “Node Editor”. New information encoded in 2D maps, shaders (Displacement map, Lightmap, Cavity map, etc.) was associated with the component properties. In the final step, after Baking, some areas of interest have been selected with the Texture Painting mode tool and emphasized (by creating masks) editing some parameters such as: saturation, contrast and brightness (figg. 7-10).

The analysis and optimization process applied to the case studies generated digital models with a polygonal loading about 1/100 less than the original one (Blender modifier unsubdivision: collapse vertices). The polygonal mesh density computation was calculated having as target the preservation of the geometric peculiar features of the case studies. Regarding, instead, the surface texture mapping, the original texture was edited trying to maintain the highest possible resolution for the final baking phase. Strategically, the analysis workflow has been experimented on different case studies for geometric-formal typologies, for materials and for logistic difficulties of capture. The results confirm that the methodology can be applied to several heterogeneous contexts with digital results expendable and manageable for other disciplinary studies, without losing the necessary information that distinguishes the artworks analyzed.

5. Conclusions

The Horizon Europe “Cultural Heritage” area of intervention is one of the research policies recognized at European level, because it represents an opportunity for the entire multidisciplinary community to develop specific methods that keep in consideration the specificity and complexity of CH. In the field of “Digital Heritage”, technological innovation and specific training are able to return meaning and vitality to the CH, through renewed interpretations and according to functional criteria of conservation, diagnosis, restoration and fruition. The study describes the path of data acquisition and elaboration of different historical-archaeological artifacts. The use of appropriate devices in relation to the object and environmental characteristics and the data optimization will allow the creation of 3D models, digital twins, rich in information and useful for appropriate future restoration interventions. It is a priority to systematize the potentialities of the new digital procedures, to create platforms of open sharing that really bring to the future generations an added value in terms of knowledge, dissemination of the carried out research results.

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Appendix

Author Contributions: All authors conceived and designed the experimental survey; all authors wrote the Introduction, and the Conclusions. S.A. performed and wrote “Materials and methods_ Detailed, reflective and dark artifacts: photogrammetric approach”; S.M. performed and wrote “Materials and methods_ Opaque, medium-sized artifacts with simple textures: structured light scanner approach; F.D.P. performed and wrote the “Data optimization” and “Results and discussion”.

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