Phygital sculptures for archaeological dissemination: The head of Sant'Elena

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Abstract

The construction physical copies of statues is not new, but it still contains several elements to investigate. On the one hand, the optimization of the digital models for their physical fruition while preserving the distinctive features, and on the other hand, the pipeline for constructing a reliable physical copy in terms of morphometrics and material. These two steps require experimentation and comparisons, allowing the processes to be validated to reach scientifically accurate results. The article, starting from the case study of the head of Sant'Elena preserved inside the homonym mausoleum, proposes the comparison of different processes of physical and digital 3D acquisition and reproduction of the work to expand its fruition for people with visual impairment.

1. INTRODUCTION

The present contribution is mainly framed in the digitization domain for the knowledge, conservation, and dissemination of Cultural Heritage. The research presented here concerns the study on the "Head of Sant'Elena," intending to propose the development of a 1:1 scale copy for its tactile use. The aim is to expand the artwork's fruition, improving communication via tactile path for visually impaired or blind people. The object, owned by the Pontifical Commission for Sacred Archaeology, comes from the Mausoleum of Sant'Elena, a site managed by the Special Superintendence of Rome and the Pontifical Commission. The application of the research process started with the 3D digitalization, based on a structured light 3D scanner, which allowed us to investigate the artwork in a new way, opening different scenarios. The digital twin allowed the creation of products helpful for various purposes related to specific characteristics. The main goal is to generate a 1:1 scale physical copy of the model. Every passage of the process of production and digital transformation will be tested from the metrological point of view, evaluating the level of the digital model accuracy and the production process reliability.

2. STATE OF THE ART

The 3D digital survey of statuary complexes is a field of research that dates back more than twenty years. Surveying experiments on statues have marked a fundamental step in developing active and passive non-contact surveying techniques for Cultural Heritage [2][16]. These experiments defined the 3D acquisition pipeline, preparing for their extensive application in the C.H. domain [2][11].

Why did the first experiments focus mainly, but not exclusively, on statuary complexes? Firstly, statues define a formal complexity in space that is difficult to survey. In the first 2000s, range-based tools were compared with some of the first applications to build 3D models by images [6]. In five years, the definitive development of Visual Structure from Motion techniques opened some early comparisons between active and passive systems for minor artifacts [20]. These experiments implemented and refined an acquisition process that is now well-established at different scales in multiple fields of C.H. applications.

A second reason should be found in the privileged survey condition given by the artifact size. Statues often present a reduced scale, preserving a considerable variation between overall size and individual details. This characteristic led to better exploitation of the high-resolution range maps of systems with a reduced work volume [7], opening up several developments in the multi-resolution domain, even at larger scales up to urban models [12].

Finally, statues suggest a dual issue: material and surface finish. These two elements only sometimes define an ideal acquisition condition for active and passive optical instruments. The former suffers from optically non-cooperative materials [17] or back-scattering problems [13]. Besides, the latter is strongly constrained by external light conditions, material conservation conditions, surface patinas, and the level of light reflection [18].

All these boundary conditions define a complex but comprehensive research framework, which motivates many experiments in sculpture. Over the last two decades, surveying techniques have changed thanks to developments in the instrumental field and implementations of digital data management [8], reducing hardware systems' size by optimizing optical and digital aspects [3]. The numerous experiments focused on low-cost techniques for the 3D acquisition of minor archaeological and statuary artifacts [5][15][19], highlighting considerable interest in the domain. In recent years, well-defined methodologies with increasingly accessible 3D systems have made it possible to plan massive 3D acquisition campaigns of entire museum collections, building accurate databases of digital twins [14]. These can be used for virtual analysis and conservation or visualization in Augmented, Mixed, and Virtual Reality. In parallel, prototyping techniques have also seen considerable development, making it possible to produce physical copies of 3D models with high reliability and low cost [1]. The physical reproduction of digital twins is a resource for the definition of material models [22] on which to perform formal analyses, introduce physical substitutions, or initiate those contact study operations not permitted in original works [21].

The article's research proposes a metrological comparison between a real artifact, its digital twin, the derived physical copy, and the optimized virtual model within this development framework. The aim here is to verify a data translation process from physical to digital and back, tracing the whole pipeline concerning the communicative scope of the outputs. The metrological validation validates the approach, measuring the level of the model reliability and the overall process, identifying a tested method of definition of the physical copies.

3. CASE STUDY

The Mausoleum of Sant'Elena constitutes one of the most important architectural complexes of early Christian Rome in the 4th century. Built between 315 A.D. and 326 A.D., originally intended to serve as a burial ground, it was later used as a tomb for Flavia Giulia Elena, the emperor's mother, who died in 329 A.D. The marble head that is the subject of the contribution (Inv. PCAS-82) is one of the most important finds preserved in the Antiquarium of the Mausoleum of Sant'Elena, a cultural site of the Soprintendenza Speciale Archeologia, Belle Arti e Paesaggio of Rome, reopened in 2019 after a long restoration, thanks to an agreement with the Pontifical Commission for Sacred Archaeology, which currently manages it as part of a tour that also includes the nearby catacombs of SS. Marcellino e Pietro [4][9].

The find is a female head-portrait in Pentelic marble, 21 cm high, consisting of two matching fragments and lacking the lower part of the face and a large part of the nose. The left profile is unfinished, probably because it was not visible in the original location. The hairstyle is 'turban-like,' with a large plait that wraps around the hair, divided by a central parting and folded in regular waves that descend to the nape, hiding the ears. The expression on the face is firm, severe, and slightly abstract, thanks to the fixity of the gaze. All the features seem to lead back to the Constantinian iconography of Elena, mother of the emperor Constantino, based on both stylistic comparisons and the provenance of the find, which can be linked to the 1976 excavation in the M5-M8 galleries of the catacombs of SS. Marcellino e Pietro. [10]
The studies on the artifact, which will be illustrated below, authorized by the Pontifical Commission, are part of some works promoted in 2021 by the Special Superintendence of Rome to complete the Antiquarium of the complex and facilitate its accessibility. (Fig.01)

Fig. 01. Head of Sant'Elena

The contribution analyses the result of an experiment aimed at creating a physical copy for its tactile enjoyment. The creation of the digital twin responds to the requirements of Italian regulations that prevent the creation of copies with contact methodologies; therefore, the use of metrological tools of surveying and 3D printing offers an exciting option for constructing artifacts for multisensory use.

4. METHODOLOGY AND RESULTS

The methodology has foreseen the application of digital photogrammetry and a hand-held 3D laser scanner with fringe projection and metrological capabilities suitable for acquiring small objects. The construction of the first accurate digital twin (Gold Standard) made with a structured light 3D laser scanner opened many comparisons between virtual models and physical ones obtained by various techniques. This activity has allowed us to evaluate the data accuracy and reliability for every passage, preserving the original data within specific tolerances defined by the superintendency. (Fig.02)
The results obtained from the experimentation concern the metrological verification of different copies of the artifact. Through the method of comparison with the original artwork, we have validated the following:

- The metrological correspondence of the copy made with a 3D printer and optimized by the *scialbatura* process will constitute the new original on which to make contact copies.
- The copy is made with a cement-based mixture of marble aggregated for tactile enjoyment.
- The verification of different non-contact acquisition techniques comparing the results of acquisition operations with photogrammetric methods (SfM) versus 3D laser scanner techniques with a critical evaluation of the quality of the surfaces obtained.

Fig. 02. Gold Standard model (textured); PLA model (textured); 1:1 scale resin cast model; SFM model (textured)

The metric comparison between the surveyed models reveals some specificities related to the manufacturing process and the models' definition. The variation between models is less than a millimetre overall. Specifically, the comparison between the Gold Standard (GS) model, given by the survey of the original with the 3D scanner, and the photogrammetric model of the original shows a good distribution of the detachment, with greater values in correspondence of the face, attributable to the more significant presence of edges and variations in depth in the model. The comparison between the GS and the 3D laser scanner scan of the PLA version (the template used for the subsequent construction of the cast model) shows a higher overall reliability than the other copies. The PLA model obtained using 3D printing and *scialbatura* (deblurring) to fill the stepping of the 3D printing process concerning its good reliability can be considered a new original subjected to the subsequent processing phases necessary to produce the cast material copy. Analyzing the data obtained by comparison with the GS, one notices a particular error concentration at the model's base. This error is generalized, although of a negligible magnitude. This error is attributable to the scanning process, particularly the digital reassembly of the various scans to complete the model, probably due to a drift in the scan orientations. The comparison between the GS and the 3D laser scanner model of the cast resin copy shows an excellent correspondence of the front part of the head, with more significant variations at the base to some parts of the hair. These differences can be attributed in part to the differences between the GS and the head made of PLA concerning the base, and in part to the manufacturing process of the silicone matrix used as the form of the new copy made in 3 separate sections for the *sformo* (Draft phase). Overall, the comparisons show good reliability of both the methodologies for acquiring the casts and the physical copies, confirming the validity of the production process capable of producing geometrically reliable copies through non-contact methods (Fig.03)

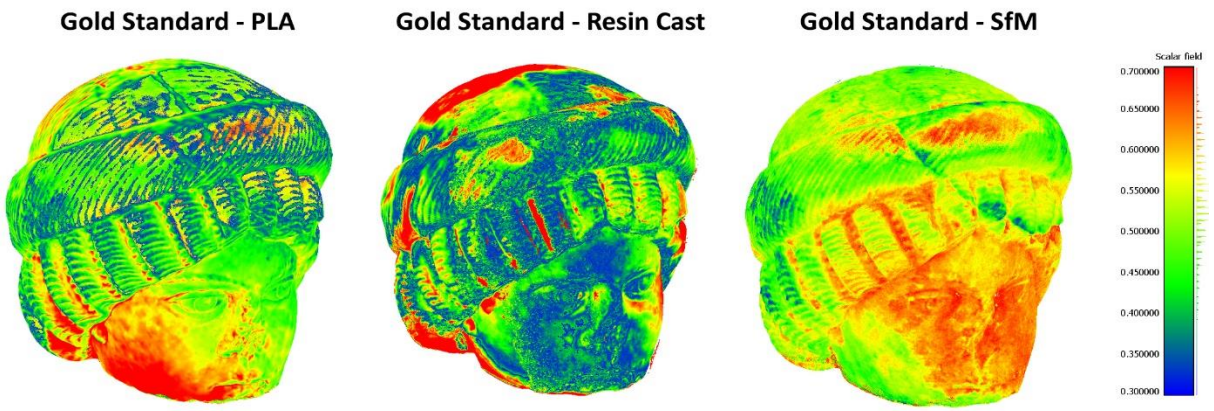

Fig. 03. Comparisons and deviation in mm: Gold Standard - PLA physical model; Gold Standard - Cast physical model; Gold Standard - SFM model.

The process of verifying the trustworthiness of the physical and digital copies shown is a prerequisite for using the phygital twins for communication purposes. This makes it possible to validate the geometric quality of the model in terms of its distance from the original, allowing, on the one hand, the production of reliable physical twins and the strict relation between virtual and real artifacts, also evaluating, if necessary, the optimization of the model topology for specific communication applications.

CONCLUSION

The paper has several objectives framed in the digitization processes of Cultural Heritage. Rapid prototyping techniques and the possibility of disseminating artifacts in a multisensory form are among the most significant challenges in preserving and communicating Cultural Heritage. Creating copies offers excellent options for expanding the user base by allowing a new museum to fruition. The contribution fits into this context, expanding the communication capacity of specific artworks with technologically advanced proposals whose quality is scientifically evaluated. Although the market already offers several solutions for the multisensory and web fruition of Cultural Heritage, only a scientific approach that considers the intrinsic quality of the copies will be able to guarantee proper realization and study of the asset, which operating in this way can also be appreciated and studied directly through its twins. The topic can also be expanded in the nearly future to the issue of texture optimization.

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