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Original article

A multidisciplinary approach for the study and the virtual reconstruction of the ancient polychromy of Roman sarcophagi

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ABSTRACT

In this paper, we report a multidisciplinary approach for the analytic study and the reconstruction of the ancient colour used for Roman sarcophagi. For this purpose, we adopted the three-dimensional (3D) digital technology and found it to be a valuable tool for the identification, documentation and reconstruction of the ancient colour. This technology proved to be an excellent link between archaeological knowledge and scientific analyses. Therefore, 3D digital technologies would effectively facilitate the exchange of information and collaboration between experts in various disciplines. This is extremely important in order to obtain demonstrable results in a new area of study, such as polychrome Roman sarcophagi (and the ancient polychromy and gilding on the marble). In this study, the digital 3D model of Ulpia Domnina's sarcophagus (National Roman Museum in Rome, inv. no. 125891) has been used to identify both the pigments and the techniques of application used, and to explore the potential of emerging technologies in the reconstruction and visualization of the ancient colour.

1. Research aims

The aim of this work is to show the results of a practical application of 3D digital technology as a linking bridge between archaeological and scientific data, in order to provide a better knowledge of the original polychromy via the production of virtual reconstructions. This use of computer-based technologies with consolidated scientific analyses could succeed in obtaining a common work platform for a better knowledge of ancient colour (and gilding), and the dissemination of the results.

2. Introduction

Roman sarcophagi have been systematically studied from a typological, stylistic and iconographic point of view since the late nineteenth century. This has given rise to a great *Corpus* and an extensive scientific production [1]. Conversely, the papers related to the polychromy field are less than ten in a century. Therefore, nowadays there is only little knowledge about pigments, dyes, and binders used by Roman artists, and about the pictorial style and the techniques used to apply both colour and gilding [2]. For this reason, the considerations by Pietrogrande [3], Gütschow [4] and Reuterswärd [5] from the first half of the last century are of fundamental importance, although they are unsupported by scientific analysis. However, in the past few years, there has been a renewed interest in ancient polychromy that has generated several research projects and also two analytical publications on Roman sarcophagi [6,7].

This new interest involved the use of computer-based technologies in the study of the ancient polychromy and gilding. However, the polychrome reconstruction is not a consolidated subject of research, since a lot of work has to be done still to improve our

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Fig. 1. Sarcophagus of Ulpia Domnina and some polychrome details, National Roman Museum in Rome (inv. no. 125891).

knowledge of the methods and techniques of colour application on Greek and Roman artwork [2,8]. Some polychrome reconstructions are often based on the commonly known colours for the antiquity (i.e. red and yellow ochre, lead white, cinnabar, carbon black, Egyptian blue, etc.) with artistic interpretations.

The technical focus of this work is to show the potential of digital technologies coupled with high-quality 3D models in the experimentation of several painting techniques and reproduction of the alternative reconstruction hypotheses based on scientific analysis data. Our reconstruction uses all the information collected by visual observation of the sarcophagus and its virtual photorealistic 3D model, the historical and stylistic knowledge derived from these observation and the results of scientific analyses. It is thanks to multidisciplinary research that it was possible to propose an accurate virtual reconstruction from an analytical as well as a historical point of view.

A long testing campaign was also undertaken to define the more proper tools and pipeline for an effective selection and application of materials to the digital 3D model and the implementation of more realistic renderings [9].

As a case study, the sarcophagus dedicated to Ulpia Domnina (National Roman Museum in Rome, inv. no. 125891) was chosen here, mainly because of the fair state of preservation of its original polychromy (Fig. 1) that could have potentially shed light on the colouring techniques used. This sarcophagus is made of Proconnesian marble [10] and was found in 1953 during the construction of a building in Rome [11,12]. From a typological point of view, it is part of the serial production of sarcophagi with Victories holding a shield and funerary Cupids [12,13].

3. Methodology

A laser triangulation scanner [14] was used to acquire geometric data and to create a 3D digital model of the artefact (see Subsection 3.1), whereas the colours of the remaining fragments of the original polychromies were measured by calculating the RGB (Red–Green–Blue) encoding of the selected painted traces (see Subsection 3.2 and Fig. 2). In addition to historical and iconographic researches, and a careful observation with binocular and portable stereoscopes, we also performed micro- and non-destructive investigations, namely Optical Petrographic Microscopy and Raman microscopy [15,16], in order to acquire information on the pigments and the techniques used to apply them on the marble surface (see Subsections 3.3 and 3.4). To this purpose, five small and representative samples, namely sample no. 5, 5A, 6, 6A and *interno* (Fig. 3), were chosen in collaboration with the Museum's restorers, respecting the criteria of minimum invasiveness.

3.1. Acquiring the 3D model

The digitization of the sarcophagus was performed first by producing a geometrical 3D model (acquired with a laser triangulation scanner) and then by acquiring the colour attribute [17] by means of high-resolution photographs (using a DSLR camera). The scanning system was chosen in laboratory considering the material and relief attributes; while the 3D scanning plan was decided on site, directly evaluating the spatial features of the sarcophagus [2]. Each scan provided data on a maximum area of nearly 50 × 30 cm; therefore, in order to obtain the complete relief of the sarcophagus, it was necessary to perform multiple scans from different angles. A total of 313 scans were acquired. The scanning resolution was kept at less than half a millimetre, thus allowing the generation of a highly-detailed digital model. A series of photographs was taken in order to enrich 3D models with high-resolution colour information, in parallel with 3D scanning [2]. All data were acquired in approximately eight hours by two expert operators.

The data collected were processed using MeshLab, an open source mesh processing system developed by Visual Computing Lab, ISTI-CNR [18,19]. The standard 3D scanning pipeline [14,17,20] was followed to produce a final 3D model of 19 million triangles; other lower-resolution meshes were created from this model, to support different phases of the virtual polychrome reconstruction process.

In addition to the characterization of the current colour traces [9,14], the 3D scanning can provide a very accurate digital model of the sarcophagus. The analysis of 3D geometry does not usually bring additional hints for the analysis of the ancient polychrome traces. Nevertheless, we shall see how the 3D model can be perfectly suited