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Optical NDT supporting the restoration of a marble sculpture on the facade of the Gesù Nuovo church in Naples

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***Abstract* – The study focuses on an angel marble sculpture, placed on the central portal of the Gesu Nuovo church in Naples. The non-destructive and non-invasive optical techniques used were Active Thermography (AT) and 3D scanning. The measurements were carried out before and after the restoration of the marble sculpture, consisting in the consolidation of some disintegrated areas and in the removal of both black crusts and biodeteriogens, present in various areas of the sculpture.**

AT images provide a map of the structural homogeneity of the investigated areas, measuring the thermal response, which result altered where the degradation products are located (crusts and/or biological patinas). 3D scanning, on the other hand, allows obtaining a 3D model of the entire sculpture and measuring any structural variations due to the restoration on a millimeter scale.

I. INTRODUCTION

The use of non-invasive diagnostic techniques to analyze and monitor the state of health of a work of art is now a common practice applied to any work belonging to cultural heritage especially in a pre-restoration phase [1-4]. Among the different types of works of art, marble sculptures are one of the most complicated samples to analyze due to their three-dimensionality shape, highly reflective surface and their weight which make them difficult to manage. Often this analysis must be performed in situ, thus limiting the possible investigation techniques that can be performed. Non-destructive imaging techniques represent a possible solution for carrying out in situ analyzes and obtaining structural information on a work of art. Among numerous imaging tools, active thermography (AT) is a well-known non-invasive and contact-less technique representing a means of providing useful and efficient in situ analysis [5-8]. According to this technique, the sample analyzed is thermally stimulated using an external source and its response to the stimulus is recorded with a suitable infrared camera. It represents an effective analytical approach used in many fields and increasingly for the study of artworks and samples of interest for cultural heritage [9-12]. On the other hand 3D scanning technology allows the capture of 3D digital data and find valuable applications in different research field. Since it obtains 3D images and models of an individual body part or the entire human body without safety risk to people, it can be used as body scanners for orthopedics, prosthesis, post-trauma care, and plastic surgery [13,14]. Other applications concerns automotive (for gathering and storing 3D images of vehicles for reverse engineering or quality control)[15], fashion, criminology [16], digital museum [17] Recently, 3D scanning technologies have had a considerable impact on the field of protection, conservation and restoration of cultural heritage. 3D models obtained by the digital data processing of the scanned objects (i.e. sculptures) can archive the cultural relics data by storing them in the database, which is conducive to the subsequent repair and protection of the cultural heritage. For example, in ref.18 it is demonstrated the noncontact restoration of missing parts of stone Buddha statue based on 3D virtual modeling and assembly simulation, using the 3D printing technology to check the repair results.

In this work AT and 3D scanning techniques were used to analyze an angel marble sculpture, placed on the central portal of the Gesù Nuovo church in Naples both before and after a restoration work made on the statue. The analyzes conducted with the two techniques provided complementary information which allowed to identify various types of deterioration elements present on the surface of the investigated sculpture and at the same time to compare its state before and after the restoration work carried out.

II. MATERIALS AND METHODS

A. Scuplture investigated and restoration work

The used methodology aims at achieving a completely sustainable restoration, non-toxic for the operator, and with low environmental impact, of the sculpture of the angel on the right of the central portal of the Church of the Gesù Nuovo. The sculpture exhibited widespread surface erosion, with some areas experiencing disintegration, particularly on the right foot's big toe and the entire right hand. There was a pervasive biological attack caused by Hyphomycete fungi, specifically Aspergillus genus, as well as gram-positive heterotrophic bacteria, Clostridium sp., embedded on the stone surface due to the presence of guano. Various deposits remained on the surface, ranging from loose ones to typical black dendritic crusts that caused significant thermal stress on the surface. The restoration procedure employs various non-invasive and minimally invasive analysis techniques: preliminary operations of dusting and a first surface rinse were carried out; then, the pre-consolidation of the disintegrated areas was performed using a 30% aqueous-based nanosilica, which, in tests with nanocalce, yielded better penetration and consolidating action results; finally, the cleaning phase began in order to remove the carbonaceous deposits. Thicker black crusts were first thinned using a micro-drill, and then a gel of agar powder at 1-2% concentration mixed with water and various percentages of sodium bicarbonate (primarily 10-30-70%) was applied. The gel was applied in a fluid manner to create a thermal shock on the crust and facilitate subsequent removal, which was done mechanically with a scalpel. Finally, a natural antifungal, based on essential oils, was tested and yielded excellent results compared to traditional biocides. Once the cleaning was complete, consolidation operations were carried out, including some fillings to provide more coherence to the area. After all the fillings were completed, the entire surface was impregnated with lime water to restore compactness, and a thin layer of microcrystalline hot wax was applied as a protective coating.

B. AT analysis

AT measurements were made in situ before (PRE) and after (POST) the restoration work on the marble sculpture. The analysis was conducted separately on different areas of the statue. A portable hot air generator was used to thermally stimulate the various surface of the areas investigated. During the heating, the temperature increase was monitored in order to obtain a maximum $\Delta T = 7 \pm 1$ °C as uniform as possible on the surface analyzed. The thermal response achieved during and after heating was recorded with a frame rate of 10 Hz using the microbolometric LWIR camera AVIO TVS500 (spectral range 8–14 µm, FPA 320 × 240 pixels) mounting a 11 mm focal lens. The software IRT Analyzer (GRAYESS), with which the camera is supplied, was used for monitoring the temperature in real-time and for setting the parameters.
The measurements were carried out under environmental conditions with a temperature in the range 17 - 21 °C and humidity in the range 51-55 % for both PRE and POST restauration analysis.

C. 3D Scanning measurements

As previously mentioned, in order to obtain a precise assessment of the full 3D geometry of the sculpture, we use 3D scanning techniques, opting for structured-light scanning, a non-invasive contactless method that infers an unknown 3D geometry of a surface based on the distortion of known projected light patterns [19]. This technique is rapid and allows to assess sculpture 3D geometry in situ. For the 3D scanning phase, the Artec Eva handheld structured-light 3D scanner—which records both object geometry and texture—was chosen as recording tool. It uses white structured light and camera (1.3 MP), has an accuracy of 0.1 mm and a maximum point resolution of 0.2 mm. The scanning is followed by a post-processing of the gathered data, using a dedicated software (Artec Studio 17). During this process the separate scans are cleaned and aligned to obtain the full 3D geometry of the sculpture.
Scanning measurements were made in situ before (PRE) and after (POST) the restoration work on the marble sculpture.

III. RESULTS AND DISCUSSION

The AT analysis was performed on the marble sculpture investigated before and after the planned restoration work. The information obtained in PRE-phase allowed the detection of structural anomalies of various kinds and especially the areas of the surface most affected by crusts and patinas. This information allowed to carry out a more targeted and specific action in the restoration work and the results obtained were then examined by comparing the thermal data achieved both before and after restoration. As an example, Figure 1 shows visible and thermal images achieved before (PRE) and after (POST) restoration of two analyzed areas of the sculpture: face (1a) and body (1b). The thermal images showed refer to the induced thermal gap ΔT measured 50 seconds after the heating and achieved by subtracting the thermal frames $T(50)$-$T(0)$ extrapolated from the recorded sequences $T(t)$.
As clearly visible, in both cases the ΔT measured in different areas of the PRE thermal images are higher than those obtained in the POST.
In the graph in Figure 1c are reported the temporal thermal trend of the area P1 (indicated in the thermal images 1b),

extrapolated in the PRE and POST thermal sequences recorded. As can be seen, in the PRE-trend (black line), recovery is slower than in the POST-trend (red line) due to the presence of crusts which were eliminated during the restoration work.

The presence of crusts and patinas on the surface changes its reflectivity and roughness and probably increases the average local specific heat, this leads to greater overheating of these areas during the daily cycle and to a slowdown of the heat dissipation process, increasing their heat recovery times and reducing their capacity of acclimatization with the external environment. Basically, the presence of such crusts on the surface of the sculpture can lead over time to serious problems of degradation and deterioration due to the greater thermal stresses affecting these areas.

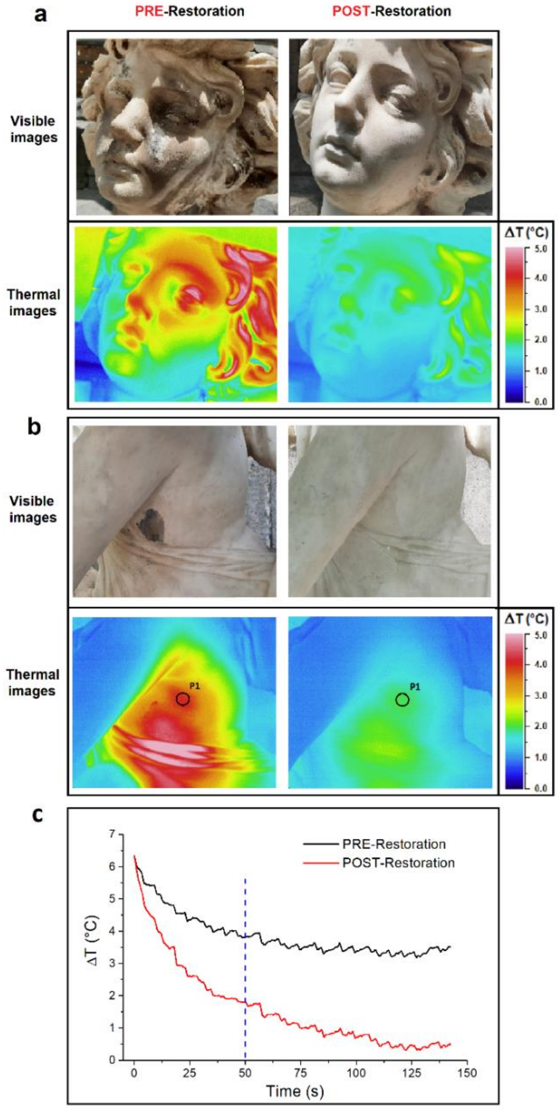

Fig. 1 Example of AT analysis performed on the marble sculpture investigated. Thermal and visible images acquired before (PRE) and after (POST) the restoration work of two areas of the sculpture: (a) face and (b) body. (c) PRE (black line) and POST (red line) temporal thermal trend of the area P1 indicated in the thermal images in (b). The dashed blue line refer to the time t=50 s in which the ΔT in the thermal images in (a) and in (b) were calculated.

Figure 2 shows the AT analysis performed on the hand of the sculpture. As can be seen, in the PRE thermal image, the fracture on the hand delimits two areas with very different thermal responses. This is presumably due to rainwater which, entering through the cracks, accumulates in the cavity under the hand, increasing its thermal inertia and slowing down the natural heat dissipation process. However, the comparison between the PRE and POST thermal images show how this discrepancy in the thermal behavior of the two parts of the hand was greatly attenuated after the local filling carried out during the restoration works.

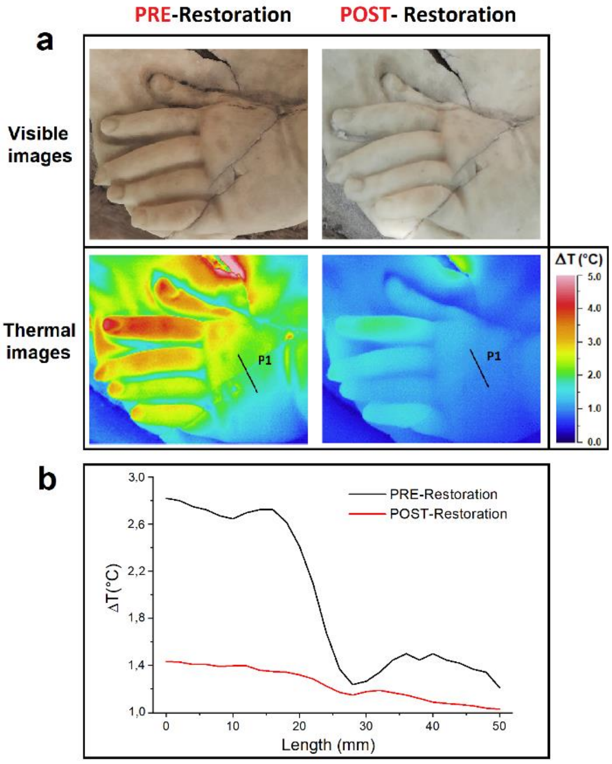

Fig. 2 AT analysis of the hand of the marble sculpture investigated: a) thermal and visible images acquired before (PRE) and after (POST) the restoration work, b) PRE (black line) and POST (red line) spatial trend of the temperature referred to the P1 lines indicated in the PRE and POST thermal images.

In Figure 2c are reported the spatial trend of the temperature referred to the P1 lines indicated in the thermal images. The spatial trends measured PRE (black line) and POST (red line) also confirm, from a quantitative point of view, how the two parts of the hand show a much more similar thermal response after the restoration works.

As to the 3D scanning measurements, figure 3 shows the 3D geometry of the sculpture before (PRE) (fig.3a) and after (POST) (fig. 3b) the restoration work.

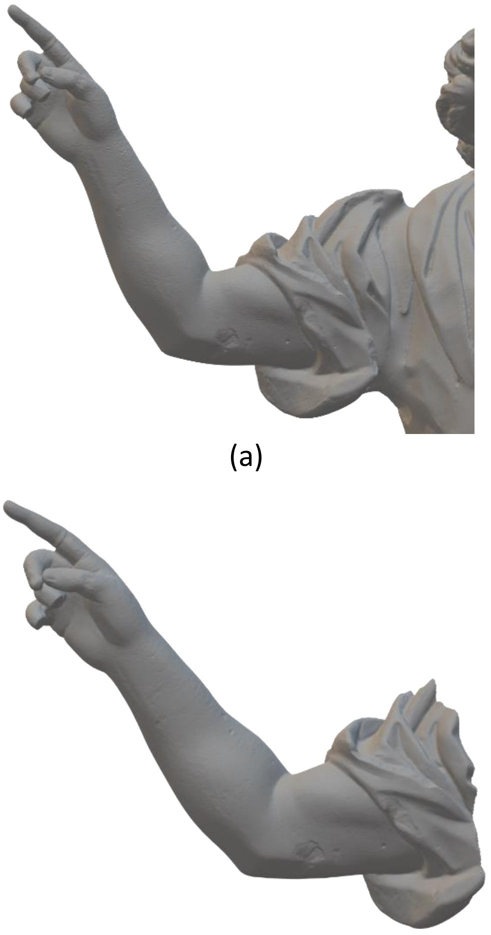

Fig. 3 3D scanning measurement of the arm of the marble sculpture investigated (a) before and (b) after the restoration work.

We focus our attention only on a part of the sculpture, i.e. the angel arm, because, due to the presence of the scaffolding, it was not possible to scan the entire statue. It is clear that the restoration work has not caused structural changes, but only a decrease in the surface roughness in some parts of the marble sculpture. In fact, as shown in Fig. 4, the marble surface after the restoration work appears more compact and smooth.

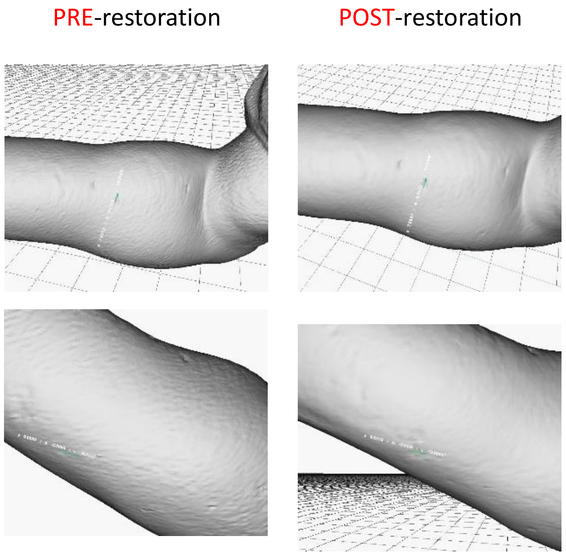

Fig. 4 Details of the 3D scanned sculpture arm, before (left) and after (right) the restoration work, showing surface roughness' change

IV. CONCLUSION

We exploited two non-destructive and non-invasive imaging techniques, i.e. Active Thermography (AT) and 3D scanning, to support the restoration work of an angel marble sculpture, placed on the central portal of the Gesu Nuovo church in Naples. The measurements were carried out before and after the restoration of the marble sculpture, consisting in the consolidation of some damaged areas and in the removal of both black crusts and biodeteriogens, present in various areas of the sculpture. Comparing the AT images and 3D models acquired PRE and POST the restoration of the sculpture, it results that the restoration work has reduced the structural in-homogeneities, making the marble surface more uniform and smooth, and therefore more resistant to external mechanical and thermal stress.

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