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High performance laser survey and 3D stress analysis for maintenance and preservation of artistic assets

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***Abstract* – The research described in this paper shows the results of preliminary analyses carried out on an artwork housed in a museum complex. A three-dimensional model of the sculpture, resulting from a laser scanner survey, has been analysed to understand its current state and seismic response, from a quantitative and qualitative point of view. The results highlight the great advantages resulting from integration of traditional and novel procedures in the field of conservation of artistic assets.**

Keywords— documentation of cultural heritage; laser scanning; conservation; seismic risk; 3D analysis.

I. INTRODUCTION

Italy is a Country rich in cultural assets that must be safeguarded and enhanced for their cultural value. These assets include both great architectural works and valuable assets, such as stuccoes, frescoes, sculptures, etc., that are an evidence of our past and culture. The safeguard and enhancement of these assets from natural disaster is a main task, particularly in the case of seismic risk. At the same time, these tasks are complex due to the interaction between the structural (building) and non-structural (artistic assets, movable and immovable) components.

As a consequence, novel multidisciplinary approaches have been proposed, and validated at National and International level, for the analysis of cultural heritage and for the identification of activities to be carried out for conservation and mitigation of seismic risk [1] [2] [3]. At the same time, novel analysis procedures have been proposed to mitigate the risk of loss of such evidence [4] [5] [6]. However, a systematic approach to the knowledge and analysis of movable assets in relation to natural risk mitigation is not adequately shared. It is therefore clear that there is the need of simple and expeditious tools, based on the integration of traditional and novel technologies, able to support the knowledge process and to facilitate the analysis of artistic assets.

The present study reports the preliminary results of a research carried out on an artwork housed in the Archaeological Museum of Ancient Capua, located in the municipality of Santa Maria Capua Vetere near Caserta. Starting from the three-dimensional model of the sculpture, qualitative and quantitative analyses have been implemented for the knowledge of its state of conservation and seismic response. The preliminary results highlight the advantage of using digital technologies in the process of knowledge and conservation of artistic assets.

II. THE STUDY-CASE: THE RESTING SATYR

The "resting Satyr" is a marble sculpture housed in the Archaeological Museum of Ancient Capua in the city of Santa Maria Capua Vetere, a town near Caserta. The artwork (Fig. 1) was discovered in the autumn of 2002 during the excavation activities of an ancient roman villa, a *domus* of imperial age [7].

Fig. 1. The resting Satyr, Archaeological Museum of Ancient Capua (photo by authors).

The Satyr is one of the many replicas created in Adrian-Antonine age and some technical peculiarities allow the artwork to be dated to the first half of the II century A.D, a period of great artistic and building production for the ancient city of Capua. The Satyr is in a frontal position, standing on an oval base and resting against a tree trunk on the right. Such as for the other replicas, the Satyr has his head raised – slightly rotate to the right –, the right shoulder higher than the left and the right leg flexed, rotated outward and moved back to the left heel [7].

When the sculpture was discovered, it was fragmented and showed several ancient damages that were repaired. In particular, interventions were carried out "*to connect the based cracked in two parts, the tree trunk to the body of the Satyr, the right leg with the left heel and, finally, the pine twig on the right side of the forehead*" [7].

The connection between the several parts was made with iron bars, fixed with lead. These elements caused further damage to the artwork and in the recent restoration works, steel bars, insured with epoxy resin, were put in place to connect the many parts in which the sculpture was found, while the lacks were filled with plasterworks aesthetically balanced [7].

III. TOOLS FOR THE KNOWLEDGE OF ARTISTIC ASSETS

The aim of the research is to acquire a thorough knowledge of artistic asset and to analyse its current state to support safety and safeguard processes taking the advantage of digital technologies. In order to achieve these goals, a first phase of analysis of the artwork and knowledge survey were implemented using traditional analysis and documentation tools.

In this phase, information deduced from bibliographic sources and concerning the history of asset, historical transformations and materials have been collected.

At the same time, a metric survey has been implemented. The Satyr survey was carried out by HandyScan 700 laser scanner by Creaform [8]. It is a handy device that allows to acquire high quality data even in the presence of environmental variations. After the warm up operations, consisting in the scanner calibration and optimization of shutter and resolution values, about 353 circle markers were put on the statue in order to acquire a network of reference points selected depending on the global and local configuration of the surface (Fig.2).

Fig. 2. Preliminary phase of scanning process (photo by authors).

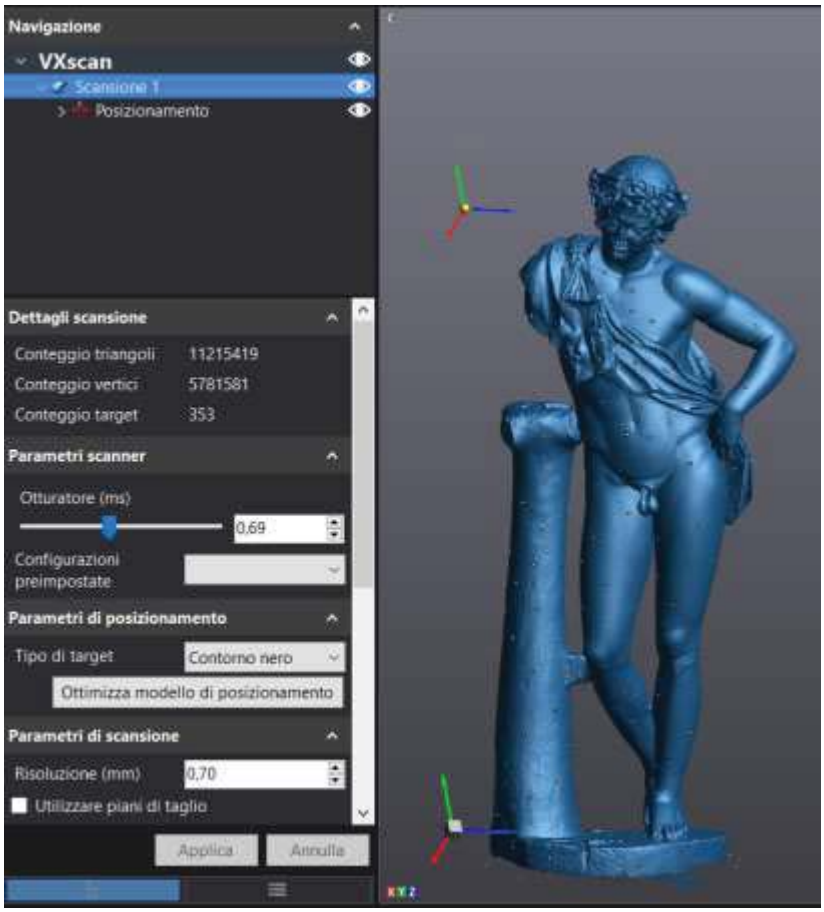

Fig. 3. Result of scanning process (photo by authors).

The scanning process required about three hours, due to the presence of several details, i.e. the cape and the wreath around the head, which required more than one scan. At the end of the scanning process, about 5,8M points and 11,2M triangular meshes have been acquired (Fig.3). In the post-processing phase, an optimized mesh model of the Satyr has been obtained with about 400.000 triangular elements, and then analysed in detail with the aim to assess the current state of the artwork and its safety.

All the information acquired from bibliographic sources and form dimensional survey have been digitalized in the form of SeVAMH protocol (Seismic Vulnerability Assessment of Movable Heritage protocol), which allows to store, process and evaluate from a qualitative point of view the state of conservation of artistic assets housed in museum or in valuable buildings [9].

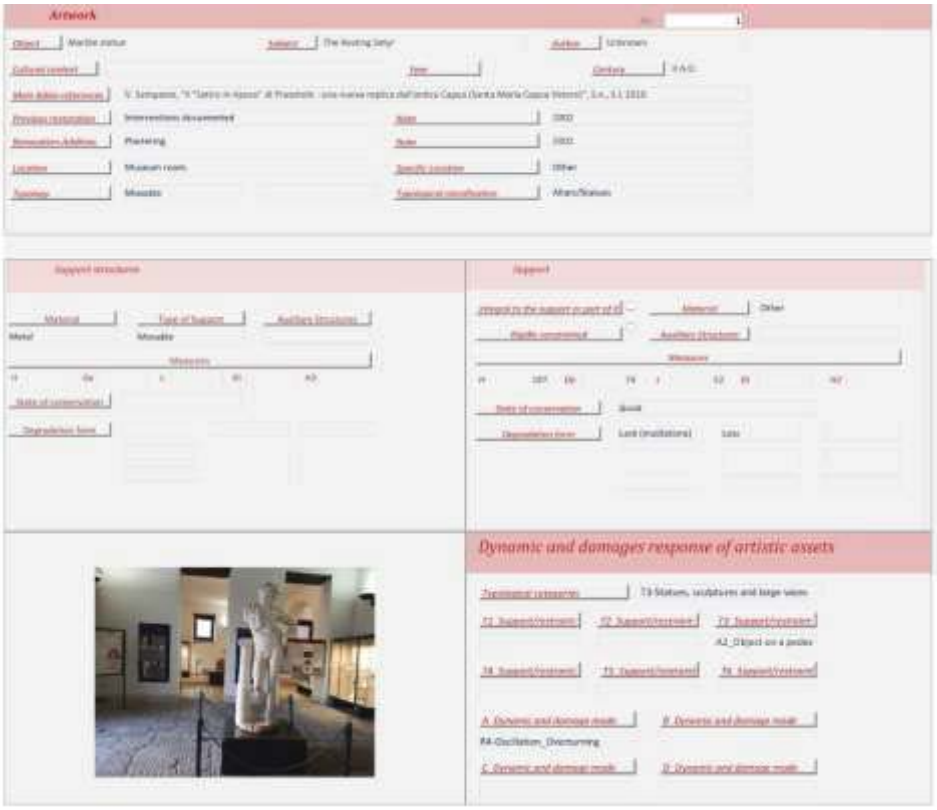

Fig. 4. Example of expeditious documentation by SeVAMH data sheet (photo by authors).

The form (Fig.4) allows to acquire useful information on the state of conservation of each component that characterize the artworks, as well as the main mechanisms of seismic response and damage for each category of artwork identified in the SeVAMH protocol [10]. Thanks to this form, qualitative and quantitative data can be related so as to achieve an in-depth knowledge on the analysed object. The data can be acquired in different phases, due to the level of detail reached, and through direct in-situ investigations or indirectly, obtaining information from secondary sources. When the survey and the analyses are extended to the building and its structural component, the relation between the building and the artworks can be defined in a perspective of "container and content". In this way, it is possible to identify structural models to be used in the seismic vulnerability assessment, as well as the proper measures to mitigate the risks to which these assets are exposed [11] [12]. Indeed, in the form are reported dimensional characteristics and current condition of structural and non-structural components according to Italian Guidelines [1]. This information is useful for the assessment of the so-called Artistic Limit State (SLA) and, as a consequence, the SeVAMH protocol can be used as a tool for the conservation and safeguard of cultural assets, especially if it is integrated with the three-dimensional model of the artefact [13].

IV. RESULTS AND DISCUSSION

The SeVAMH protocol has been applied starting from the information collected during the metric survey and derived from bibliographic sources.

The resting Satyr is housed in one of the first exhibition rooms of the museum introducing the visitor to the exhibition tour and to the knowledge of the history of city and territory. The statue shows a good state of conservation, although there are many lacks due to the damage and alterations suffered by the Satyr over the centuries. Some chromatic alteration can be detected on the oval base, the tree trunk and on the legs, where are also visible the integrations carried out with the last restoration

works. In any case, these alteration forms do not affect the safety of artwork and its preservation. The sculpture rests on a flat support of modest dimensions and has not supporting components or anti-seismic devices. Therefore, in case of an earthquake, the artwork would be susceptible to possible oscillations and overturning mechanisms that could cause the fracture in several parts and, therefore, to the loss of this significant artefact. Modern digital technologies made possible to assess the current state of the Satyr. As previously mentioned, the three-dimensional model obtained from laser scanning has been processed in order to import it into a simulation software able to analyse the structural behaviour of the sculpture. VXModel (by Creaform) software has been used to edit the mesh by sampling data, filling holes, reducing scanning noise and, finally, completing the three-dimensional reconstruction with the creation of the waterproof closed mesh model.

During this scanning process an input filter was applied to data acquired through laser scanning. The final result of the mesh editing process is a mesh model characterized by about 400.000 triangular polygons, then best fitted by about 4.200 faces with higher density where more details occur (Fig. 5). This surface model can be managed better during the simulation phase, as all useful geometric details are kept causing a lower computational effort and shorter processing time.

Fig. 5. Solid model of the resting Satyr (photo by authors).

The solid model is simplified from the point of view of material characteristics. Indeed, in the analysis have been not considered the integrations made with stucco during the last restoration and a homogeneous material has been considered. In Fusion 360 software by Autodesk, which integrates CAD and CAE solutions, on the 3D model imported via Step file two different structural analyses have been implemented, the static stress and the modal analysis.

A static stress analysis has been carried out under the simplified assumption of homogeneous material and absence of damages; it is the basic step for a more detailed analysis of the artistic asset, but is useful to check the feasibility and reliability of the workflow and also to identify critical zones. It has been found that due to the shape and current configuration of the Satyr, stress concentration are located at the connections of the sculpture to the base and to the trunk tree (Fig. 6). In other words, the parts of the sculpture repaired in the past are critical in bearing the loads and need to be further investigated. A detailed mechanical model can be certainly obtained based on the survey presented above, since the interfaces between old and restoration materials are clearly detected. An open issue still holds, since review of statue history confirms the presence of metal bars in the left leg, in the right leg to connect it with the heel, in the connection between the trunk and the right leg and, finally, in the connecting element between the two legs [7] (Fig. 7).

A modal analysis has been also performed in order to assess the dynamic response of the sculpture in the reference undamaged state. It is a useful reference state that can support the condition assessment of the asset by non-destructive vibration-based methods. Fig. 8 reports the results of 15 modal frequencies of the Satyr, along with one of the modal shapes.

The results point out some aspects of the dynamic response, which could be affected by discontinuities and embedded metal components in the restored areas, and are

really useful to guide the design and the execution of experimental modal analyses campaigns aimed at optimising the mechanical model and structural analyses and empower the suite of tools able to cover the need of preservation and maintenance of artistic assets even in seismic areas.

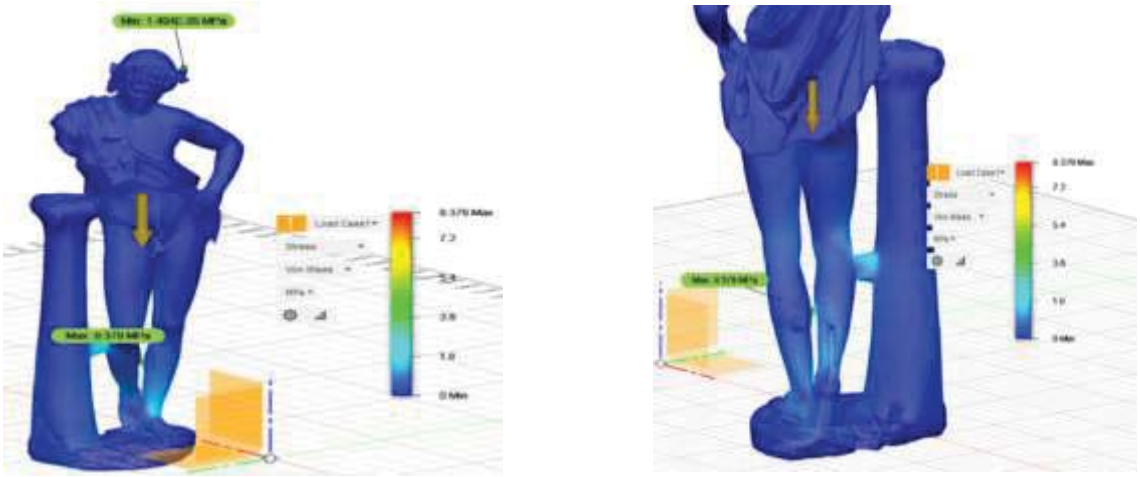

Fig. 6. Results of static stress analysis(photo by authors).

Fig. 7. Results of static stress analysis versus previous restoration works(photo by authors).

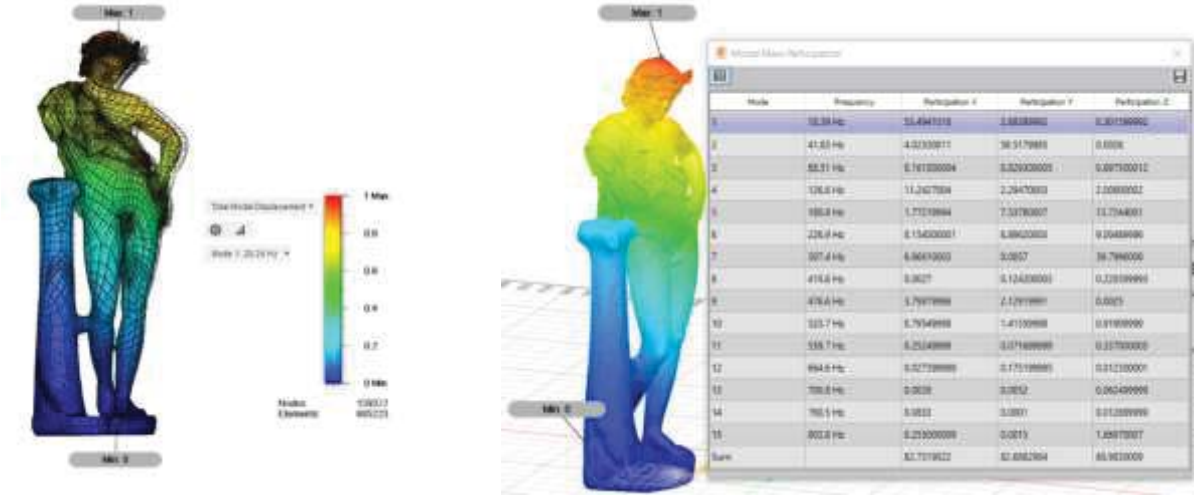

Fig. 8. Results of modal analysis(photo by authors).

V. FINAL REMARKS

The novel digital technologies provided several benefits to the field of cultural heritage [14] [15]. New approaches to knowledge and valorisation have been developed in recent years and novel methodologies and procedures are also being tested and validated for the safeguard and preservation.

The development of three-dimensional model and the implementation of SeVAMH protocol highlights the advantages for the conservation of movable artistic assets deriving form integration of traditional approach with modern and digital technologies.

The result obtained from SeVAMH protocol for the knowledge and the possible damage mechanisms and seismic response of artistic assets are confirmed by the analyses performed through the model obtained from the laser scanning. A high level of detail is achieved in the case of the "Resting Satyr", so that detailed models for quantitative analyses can be associated to qualitative ones in order to improve the capabilities of conservation and safety of movable heritage.

Moreover, the information acquired can be integrated into other system that allow the model to be associated with other database or web platforms, supporting novel procedures for the communication, information, safeguard and valorisation of cultural heritage [15].

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