From the lab to the field: 3D technology supporting study and conservation processes on Ancient Egyptian artefacts

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ABSTRACT

In this paper we will report on the importance of 3D documentation as a tool for study and communication in Cultural Heritage, with particular reference to the experience grown up at Centro Conservazione e Restauro *La Venaria Reale* (in the text: CCR *La Venaria Reale*) and to its application on Egyptian artefacts.
We will focus on the purpose-built virtual viewer, set up in order to solve specific operational needs of the working group. We will consider for that significant case studies for innovation that 3D technology has brought in terms of streamlining processes and sharing results.
We will also focus on technical advantages obtained by the realization of a 3D model of the remains of a 22nd dynasty cartonnage, found by the Italian Archaeological Mission at the area of the Temple of Millions of Years of Amenhotep II (Luxor, West bank, Egypt), and on the benefit in using 3D documentation on archaeological excavations.

Keywords: 3D technology, coffins, Egyptian art, conservation, archaeology

INTRODUCTION

Since 2014 the CCR *La Venaria Reale* has established close cooperation with the Museo Egizio in Turin for the study and conservation of polychrome wooden coffins. From the beginning, the carried out activities and the obtained results were placed in a larger international research project (Vatican Coffin Project), with partners such as The Vatican Museums (project coordinators), the Musée du Louvre, the Centre de Recherche et de Restauration des Musées de France, the Rijksmuseum Van Oudheden in Leiden, the Museo Egizio in Turin. The project has the aim of joint study of the different museums' collections, shared definition of diagnostic protocols and intervention guidelines, with particular focus on a specific typology of coffins dating back to 21st-22nd dynasty.
The need to make easier the planning of conservation activities, the strong will of sharing specific information and research's results between institutions and the desire to obtain an even remotely usable documentation, pushed the CCR *La Venaria Reale*'s working group to develop a program for three-dimensional display of the artefacts under study.
Furthermore, in 2016 the CCR *La Venaria Reale* started a cooperation with the Centro Egittologico Francesco Ballerini (CEFB, Como, Italy), which mainly carries out excavations in Egypt and dissemination activities on Italian territory. This collaboration started for the year 2016/17 with the design and implementation of a conservative intervention on a cartonnage of the 22nd dynasty, aimed at the securing of the original materials, at their detachment without interference with the underlying skeleton and at their positioning on a new mould. In this paper we will report on the cartonnage and enviroment's 3D model which made possible to hypothesize the operational phases even without the possibility of prior inspection of the intervention, and on the operational difficulties encountered due to the impossibility of realization of a mould starting from the 3D data.

3D TECHNOLOGIES. STATE OF ART IN CULTURAL HERITAGE

3D technologies may be a tool for designing, documenting and monitoring, as well as disseminating in cultural heritage's field.
In recent years, new technologies support and integrate conservation and restoration activities, getting easier and more accessible information sharing even in the form of databases and making possible the construction of structural supports realized starting from 3D models.
The three-dimensional acquisition of artworks, especially in the case of architectural elements or statuary, has been consolidating for years. However, there are still many unclear points about the most appropriate and cost-effective workflow, both in terms of acquisition methods and data usage. Most common 3D acquisitions are laser scanning, structured light capture and photogrammetry. The first two generate high quality three-dimensional data and measurable models but do not record textures or apply them with questionable colorimetric and geometric precision. Photogrammetric survey does not

reach the accuracy level of some very expensive apparels and does not generate measurable models (except thanks to metric references placed within the shooting). On the other hand, it is an extremely versatile and economical technique, and it records accurate textures basing on photographic shots. In the field of works of art's documentation and study three-dimensional models, virtual reality and multimedia applications represent a compendium to classical documentation. The reason of this can be a relative recent development of 3D technologies and, probably, the need of great computing capability to manage the large amount of data. This can create considerable difficulties in displaying results in case of not extremely powerful computers and, frequently, navigating within a three-dimensional environment and manipulating objects is not immediate and clear to all users.

In recent years, some museums and institutions (e.g. British Museum) have begun to use three-dimensional data display web platforms (e.g. Sketchfab). To permit a quick navigation, these 3D models present a reduction in number of polygons, thus losing much of the morphological characteristics that justify a three-dimensional professional acquisition. The use of such models does not, therefore, allow a reading of the morphology of the work; through the application of relatively detailed colour data it is possible to visually compensate this gap only partially (fig. 1)

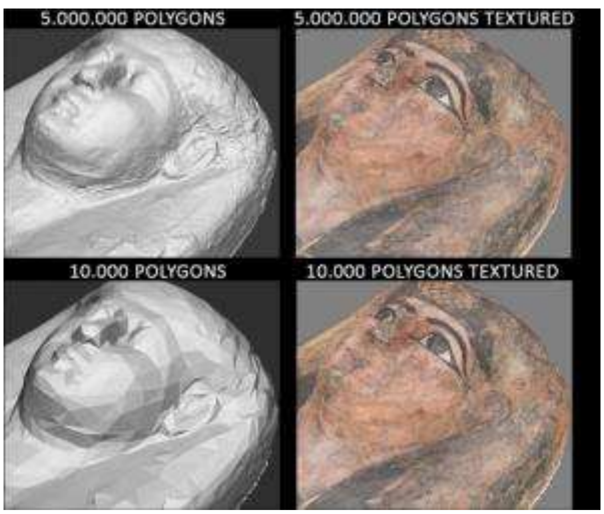

Fig. 1. Comparison between a high resolution' 3D model with a low resolution' one. M.E. S. 05243

The management of large amounts of three-dimensional data, therefore, poses a problem of usability. Considering that, CCR *La Venaria Reale* structured a viewer based on QuickTime VR Object technology that allows virtually manipulate the artefact's 3D model in an easier way and is enriched by links to other surveys through interactive hotspots. The main goal was to provide a tool that would facilitate the exchange of information between multiple users, and would represent a valid alternative to direct observation, based on 3D technology.

3D MODELS IN DIFFERENT BANDS OF THE ELECTOMAGNETIC SPECTRUM

Each conservation process involves a large preliminary phase of planning intervention, which is usually based on photographic documentation of the artefact considered in visible light and in the multispectral bands. In particular, the latter results useful to make first hypothesis on the nature of the constituent materials, from the drawing (NIR1 and NIR2) to the finishes layer (UVF, that permits first evaluations on superficial layers, such as varnishes, and NIR1-FC and NIR2-FC, that contribute in identifying pigments and, eventually, dyes used). These analysis are generally acquired photographically in the above spectrum bands for each portion of the work of art (head, feet, sides, inner portions) obtaining a large number of independent and non-overlapping images, whose management is not always easy.

Photogrammetric acquisitions gave us the chance to obtain measurable objects, chromatically consistent with the original, and provided, with the appropriate tools, the ability to capture in different electromagnetic bands (like infrared and ultraviolet).

Multispectral photogrammetry allows in fact creating models in the field of visible, infrared and ultraviolet light, thus effectively replacing classic photographic acquisition in those bands. Moreover, being these images orthogonal projections, they don't show lens distortion, typical of the photographs (due to the lens' lens structure and the shooting point) (fig. 2).

Fig. 2. Example of 3D models in different bands of the electromagnetic spectrum. M.E. S. 05243.

The benefits of this innovative system include the heterogeneity of contents available to the consultation, as well as the possibility of extreme detail in case of magnification, with a very high resolution for each interface.

Designing an intervention project starting from this documentation and, therefore, acquiring images on site as a first step, can contribute to a more punctual description and interpretation of the problems detected. Moreover, a punctual verification of the conservation status of the entire surface of the artefact even at a distance (after the preliminary observation on site) is in this way possible. Finally, it can help the comparison of data coming from different analyses and referring always to a same point, such as characterization of overlapping substances or areas affected by specific alterations, in order to better structure the operational phases and intervention.

Technical data

The meshes generated thanks to photogrammetric software and textured with different wavelengths were aligned and finally rendered by 3D modeling software. Each mesh were rendered 35 times through an orto camera with rotational steps of 10 degrees in order to reach a full 360-degree view of the subject. A 10-centimeter grid helps measure the object in any position.

VR VIEWERS

The use of photogrammetry makes possible the creation of environments virtually visited even at a distance, from which it is possible to extrapolate the single objects, rotatable and viewable even within the structure.

An option, thought for Egyptian coffins, is to model virtual environments where placing the finds, even those kept in different museums and often in inaccessible storehouses. These virtual, navigable and interrogative structures could recover objects presenting affinities in technique of execution, or, in alternative, objects chronologically compatible, favouring the study of researchers and professionals. In essence each environment can be organized strictly responding to specific needs of study (fig. 3).

Fig. 3. A hypothesis of virtual environment

This chance allows, in case works of art kept in not always open storage, to expand the study having easy access to objects at a distance, while avoiding the continues handling of the objects, burdensome activity for the museum staff and often superimposed to the regular course of work.
Another possibility might be the virtual reconstruction of tombs whose objects are currently exposed or stored in different museums, even very distant from each other. This would allow users to study entire virtual collections directly within a single multimedia tool (fig. 4).

Fig. 4. Example of a possible virtual reconstruction of a tomb.

With the aim of designing viewers that allow the user to examine and study three-dimensional works, we propose to link the two QTVR and VR Object technologies, creating QTVR virtual environments within which an object can be displayed and, eventually, selected, thus opening the object of VR object viewers connected (fig. 5).

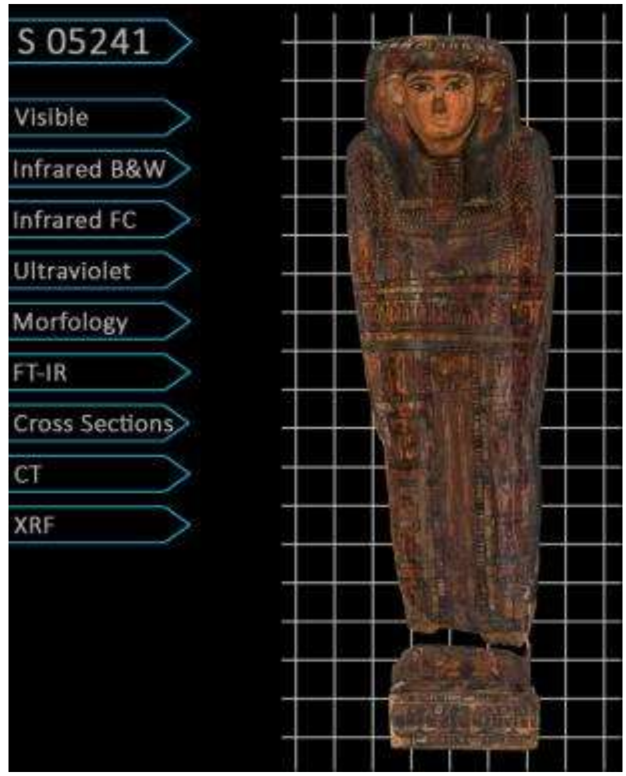

Fig. 5. Interactive single object viewer. M.E. S. 05241.

Technical data
After positioning the meshes of the coffins inside two different 3d modelled environments, a virtual panoramic camera has been able to shoot 360-degree scenes. Working with virtual 360-degree panoramas and virtual objects software builders it was possible to create interactive tour in which the modelled scenes with the coffins are linked to VR Object viewers thanks to the placement of interactive hotspots directly inside the panoramic views.

VIRTUAL RTI

The possibility of detailed photogrammetric acquisition also led to increase tests conducted in order to verify the possibility of obtaining information (in virtual mode) relating also to surface morphology and, especially, in cases where the analysis generally delegate to this task meets technical and practical limits (Reflection Transformation Imaging, RTI).
Reflection Transformation Imaging is a computational photographic technique invented by Tom Malzbender and Dan Gelb, researchers at Hewlett-Packard Labs. A landmark paper describing these first tools and methods was published in 2001 [2].
RTI captures the surface shape and colours of a subject and enables the interactive re-lighting of it from every direction with the possibility of emphasizing some attributes of the image by means of particular tools based on mathematical algorithms.
In particular, technical limits for a direct RTI acquisition are:
a. Presence of projection elements that prevent the positioning of light.
b. Position, size or morphology of the work that prevents the correct positioning of the camera and/or light (fig. 6)

Fig. 6. Example of morphology of the artefact that prevents the correct positioning of the light. M.E. S. 05224

In addition to this, not always the need for detail far below the millimetre is necessary, both from a point of view of the product's knowledge and of the specific conservative needs. In this case a detailed photogrammetric campaign can be considered sufficient and, thanks to the tests carried out, can represent a valid alternative in the processing of virtual detail images, with particular emphasis on surface morphology.
The innovation of Virtual RTI allows, unlike the traditional one, to create a texture projectable on the 3D model correctly, being orthogonal. Moreover, this technique allows to create animated textures (with multiple light positions and RTI rendering algorithms), even in this case projected on the 3D model (fig. 7).

Fig. 7. Virtual RTI.

Technical data
In order to be able to reproduce the RTI technique in a 3D virtual environment the first step was to select and delete some parts of the object that prevent the correct positioning of lights, leaving only the area that is involved in the analysis. In the 3d scene were reproduced exactly the same set of a classical RTI, with black glossy spheres, several positioning of spot lights in order to get (in this case) 60 rendered images and an orthogonal camera pointing perpendicularly to the surface of the object. Virtual images thus obtained were processed by the RTI builder software as if they were taken directly on the real subject (Fig. 8).

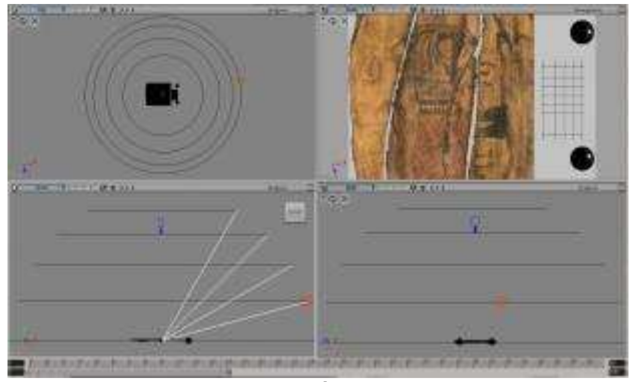

Fig. 8. Virtual RTI set up

APPLICATION EXPERIENCES

In occasion of the numerous co-operations with the Museo Egizio of Turin, securing and conservation activities have been often structured considering specific requirements for permanent or temporary exhibitions and characterized by particularly intense timelines over relatively short time periods.
Conservation processes, always included in the frame of the Vatican Coffin Project, were backed by imaging and scientific insights, functional to a better understanding of artefacts' technique of execution and state of preservation. All the results were associated in a single file: the availability of a so structured 3D model allowed the prosecution of the specific study even after the end of the activities and the delivery of the artefacts to the purchasers.
Moreover, we consider 3D models as a precious instrument for monitoring the state of preservation of the artefacts, providing photogrammetric models captured at the end of the conservative treatments.
Finally, the reworking of the three-dimensional data, especially on archaeological artefacts, is to be considered helpful also in case of fragmented pieces, usually stored in separated portions: both a virtual representation of the assembly of the individual portions, both the creation -by 3D printing- of auxiliary supports is realizable thanks to 3D technology. In particular, the use of auxiliary support allows the simultaneous handling of all the fragments, and the exposure of the object as well reassembled, without the need for any invasive procedure on the original object's constituent materials.
Concerning the work of the Italian Mission at the Temple of Amenhotep II (Luxor, West bamk, Egypt), high resolution three-dimensional models from photogrammetric processing of sets of digital images are generated on the field in addition to the traditional and digital documentation.
Since 2006, almost all plans, especially those for the recording of the remains of coffins, cartonnages and the related human remains (as any other complex archaeological contexts) has been undertaken using photo-rectification and photo-mosaics (fig. 9).

Fig. 9. Photo-mosaic of the cartonnage from D21 tomb.

The item was documented with one or more zenithal photographs. The individual images were imported into special software and ortho-rectified. The image obtained has been georeferenced in the Temple project GIS and vectorised with all details needed for the creation of the final traditional plan already available in digital form. The photo-mosaics thus allow archaeologists to have complete documentation, including photographs, of the excavated area.

During the last field seasons, however, we start using Computer Vision techniques based on "Structure from Motion" in order to create 3D models of archaeological surfaces. In fact, on the one hand the three-dimensional model can be used for the production of ortho-images, which are afterwards used for vectorising plans in the same way as photo-mosaics. On the other, it can also be exploited for measuring the volume of the find and recording the state of preservation at the time of discovery. Moreover, in contrast to traditional photographs, a 3D model provides a comprehensive and high-resolution view of the archaeological evidence and can be explored at different levels of detail both during field activities and post-excavation analysis, guiding excavation and conservation strategies.

This recording process has been applied also to the 22^{nd} dynasty coffin and to the inner cartonnage came to light in one of the tombs found in the area under investigation, creating 3D models of these two items. In addition to the above mentioned potential of this kind of documentation, this choice boosted the defining of the conservation project for the cartonnage, which was the best preserved so far on the area, even if in a very poor condition

The total disappearance of the organic materials – linen or wood - that once supported pastes and pigments, and the sudden deterioration of which these items typically suffer once they have been exposed, make the consolidation and preservation of these vanishing traces almost impossible, given the conservation interventions available on site. However, the 3D model provided to the CCR *La Venaria Reale* (fig. 10) allowed to better plan the activities, the materials and the methods of intervention, considering that the access to the excavation area was not possible before the incoming archaeological field season.

Fig. 10. 3D model of the inner cartonnage.

Thank to this tool, we found a solution to remove and preserve the existing materials, despite their poor state of preservation.

The fragments of paste have been pre-consolidated and detached by mechanical action with soft stress from the back, removing in a first step the sand between the preparation layer and the skeleton. Subsequently, to resolve the deformation of the pictorial layer, the material has been stretched out, gradually applying nebulised water on the back. Once applied a new textile support, that allowed the handling of the fragments, we provided their safe repositioning on a model specifically designed (plastered polystyrene) inspired by a cartonnage chronologically and iconographical compatible with the one object of intervention. In this case, however, considering that the cartonnage was totally altered in shape and size by its state of conservation, it seemed unhelpful to produce the support starting from the 3D model. The uncertainty in its correspondence with the real model represented, in fact, a too high risk compared to the high cost of the operation and the possible difficulties we encountered in carrying it on the field. The realization, therefore, was completely crafted (fig. 11).

Fig. 11. Craft realization of the mould (gypsed polystyrene).

The low precision of the size of the mould in comparison to the original one has strongly influenced the final yield of the fragment reassembly, which is now to be considered satisfactory but still temporary (fig. 12)

Fig. 12 Positioning of the fragments on the plastered mould.

CONCLUSIONS

We therefore thought that the acquisition of three-dimensional data could contribute to innovation processes in the design of intervention phase, in studying activity and in communicating the data acquired.

Purpose-built multimedia applications that leverage virtual reality technologies can be a response to the issues mentioned. If appropriately designed, they can provide comprehensive, easy-to-understand and shareable documentation on many platforms (including social networking). Displaying three-dimensional data through QuickTime Virtual Reality and Virtual Reality Object technologies ensures a high level of interaction with three-dimensional environments and objects, while maintaining ease of use, fluent handling and examination very close to the photographic documentation. Such viewers are based on immersive image reproduction or sequences of images (environments or 3D objects), giving to the user the impression of navigating or handling objects directly in a 3D environment.

The ability to create user-friendly interfaces with navigation buttons, text links, videos, images and websites, as well as the ability to navigate in the environment or display an object in the various electromagnetic spectrum bands, provide a quick but detailed analysis of the works. Further advantages in presenting and using data in such environments and not directly in 3D environment allows, after the right postproduction, to generate virtual models that also could be rendered in false-colour infrared (imaging analysis useful to characterize pigments).

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