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Upgrade of the x-ray imaging set-up at CCR "La Venaria Reale": the case study of an Egyptian wooden statuette

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Abstract **– X-ray based imaging techniques (digital radiography and computed tomography) are widely used in the field of Cultural Heritage and beyond, above all thanks to their non-invasiveness. The high penetrating power of X-rays allows us to investigate the internal structure of the analysed objects, thus obtaining valuable information related to the history of artistic and archaeological finds. In particular, CT provides data that are more significant when objects with a not negligible volume are studied. Even the use of advanced instruments can help having better final data from which getting more information. In this paper, we will show the case study of an Ancient Egyptian wooden statuette representing a "bearer", for which an upgraded version of the X-ray imaging apparatus located in the Centro Conservazione e Restauro "La Venaria Reale" (CCR) was used for the first time. Thanks to this, much information on the technique of execution was obtained, especially from the tomographic analysis.**

I.INTRODUCTION

Radiographic (DR) and tomographic (CT) techniques gained increasing importance since the discovery of X-rays by Röntgen in 1895, thanks to their non-invasiveness, in various fields of application. X-ray imaging techniques are widely used in the Cultural Heritage field thanks to the possibility of investigating the inner part of the objects, not otherwise visible, without any type of damage. In fact, digital radiographic and CT analysis have been performed over the years on different types of archaeological and anthropological finds [1-4] and also by means of synchrotron equipment [5] in order to evaluate the state of preservation and to get a more detailed knowledge of ancient objects. In this paper the results of the X-ray DR and CT analysis performed at CCR on an Ancient Egyptian wooden statuette are presented. The figurine belongs to the collection of Museo Egizio in Turin, and the measurements have been conducted before its conservation treatment. The fixed X-ray imaging set-up at CCR was developed in the context of the neu_ART project [6-8] and optimized for CT of large artefacts as, for example, furniture [9], wooden coffins [10] and objects difficult to analyze in normal medical systems, e.g. soil blocks [11]. The works of art variability of physical characteristics like material, size, shape and state of conservation can be extremely wide. For this reason, an X-ray imaging system should be optimized or adapted for specific objects or to a class of objects, allowing to perform a suitable analysis on works of art. For this specific study, a X-ray flat panel detector with a higher spatial resolution than the previous one has been used for the first time. It is suitable for small objects, and the better resolution is a more advantageous tool in the Cultural Heritage field, because of high quality images and consequently better interpretation of data.

II.MATERIALS AND METHODS

The statuette, representing an offering bearer (S.8795, Fig.1), was found during the 1908 excavation season of the Italian Archaeological Mission, directed by Ernesto Schiaparelli, in the necropolis of Asyut (Egypt), a site situated some 375 km south of Cairo. The statuette was part of the conspicuous funerary assemblage of the so-called "tomb of Minhotep", which included more statuettes of offering bearers, larger wooden statues, a model bakery, boat models, as well as coffins, wooden sticks, a bow with arrows and numerous terracotta jars and bowls [12]. Most of the equipment derived from specialized workshops operating in Asyut during the early Middle Kingdom (ca. 1980-1900 BCE).

Fig.1. The analysed "Bearer" statuette (S. 08795), frontal and lateral views after the conservation treatment.

The analysis was conducted at the CCR, in a shielded room created to house the necessary equipment for X-ray imaging investigations. The instrumentation mainly consists of a General Electric Eresco 42MF4 X-ray source, a rotating platform on which the object is placed, allowing the acquisition of multi-angle images, and a Hamamatsu C9750-20TCN linear X-ray detector of 200 µm x 200 µm pixel dimension that scans at about 0.2-6 m/min over an area of about 2×2 m². Generally linear detectors are usually suited for large objects imaging analysis, despite requires a longer time for image formation, as it requires a scan in motion. Details on the experimental set up and on performance in term of spatial resolution, scan speed and image quality are given in [8]. For this work, a flat panel (FP) Shad-o-Box 6K HS by Teledyne Dalsa that upgrade the previous apparatus was employed for the first time and placed, at requirement, in correspondence with the linear one generally used in CCR's equipment. Having an area of only about 160 cm² FP is more suitable for small object or for part of large objects where a higher resolution is needed. As a matter of fact, in this specific case study we calculated a voxel (the 3D equivalent of pixel) dimension of 46 µm³ for the CT reconstruction versus the 187 µm³ voxel that we would have obtained using the linear detector. To cover large areas it is possible to exploit the precision scanning system already present to acquire images in different positions (tile scanning). The main characteristics of the two detectors are summarized in Table 1.

Table 1. Comparison of some specifications between the flat panel (FP) and the detector for large objects already present at CCR (Linear)

	FP	Linear
Pixel number	2304×2940	2560 × 1
Active area (cm × cm)	11.4 × 14.6	51.2 × 0.2
Pixel dimension (µm)	49.5	200
A/D converter	14 bit	12 bit
Energy range (source kV)	15-225	25-200
Scintillator	CsI	CsI
Image dimension/resolution (Mb/m²)	~800/50 µm	~50/200 µm

In order to evaluate the potential of this new flat panel detector, a comparison between radiographic images acquired with the two different set up already described was performed. Observing the radiographic images of the entire statuette (Fig.2a and b), no great differences are noticed between the results obtained with the two types of detectors; however, going to higher magnifications to highlight some smaller details or areas of interest (Fig.2c-f), individual pixels can be seen in the images obtained with the linear detector (the single pixel size is 200 µm) and so most of the information is lost in terms of spatial resolution of the resulting images, leading to an incomplete knowledge of the object features,

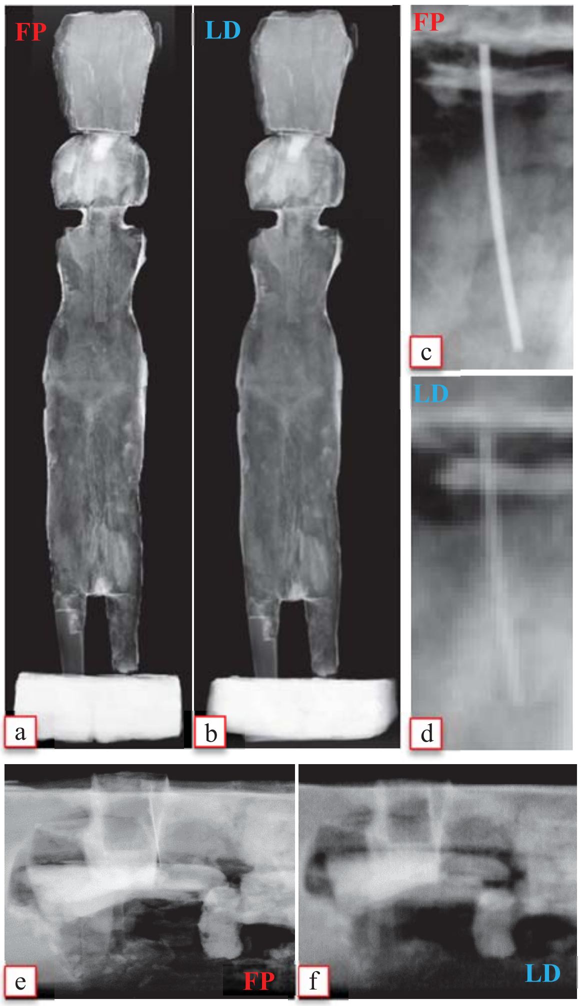

Fig.2. Comparison of the flat panel (FP) and linear (LD) detector resulting images: (a),(b). radiographic images of the entire statuette; (c), (d) detail of the statuette's head; (e), (f) detail of the statuette's base.

Therefore by means of the new set-up, radiographic analysis were performed on the whole statuette in order to evaluate the optimal parameters and the most interesting areas for tomographic measurements. In both DR and CT phases, the object has been positioned as close as possible to the detector in order to minimize the penumbra effect. The radiographs were acquired both frontally and laterally to have a more accurate view of all the components of the figurine. Due to the larger size of the entire object compared to the active volume of the FP detector, several images were collected (8 in frontal view and 10 in lateral view), then assembled during the processing phase by means of the ImageAssembler software by PanaVue. On the basis of radiography results, it was decided to perform CT analysis only for the upper part of the figurine.

The tomographic analysis was performed by setting the integration time and the angular step on all the 360° inorder to optimize the quality of the final reconstruction. The acquisitions were divided into 3 scan phases, one for each portion: the basket, the head and the body. The main experimental details of this measurement are summarized in Table 2. The reconstruction of the CT sections was made using a filtered back-projection algorithm by means of a non-commercial software-utility developed by Dan Schneberk of the Lawrence Livermore National Laboratory (USA), while the 3D rendering and segmentation are still under processing using VGStudio MAX 2.2 from Volume Graphics.

Table 2. CT experimental details

Statuette dimension	60 cm ×12.5 cm ×25.5 cm
Source-Detector distance (SDD)	3.75 m
Source-Object distance (SOD)	3.51 m
Magnification	1.07
Voxel dimension	46 μm
Tube voltage	80 kV
Tube current	10 mA
Integration time	1.75 s
Scan phases (portions)	3
Projection/portion	1440
Angular step	0.25°

III.RESULTS AND DISCUSSION

Thanks to the higher resolution achievable with the new flat panel detector, it was possible to visualize details and features of the analysed object with greater accuracy, and therefore especially in the tomographic analysis, it allow to obtain important information on the technique of execution and previous interventions carried out on this statuette.. As mentioned before, the data of the CT scans were acquired starting from the basket up to the hips. At first glance, it is possible to notice areas of the radiographic images with different radiopacity over the entire volume of the body (Fig.3). This reflects (i) the distribution of the preparatory layer, which is more radiopaque than the wooden support underneath, and (ii) the presence of some deep gaps in this layer. Thanks to the CT slices it is possible to observe the presence of a double layer of preparation (confirmed by the conservation interventions) in some points with different thicknesses.

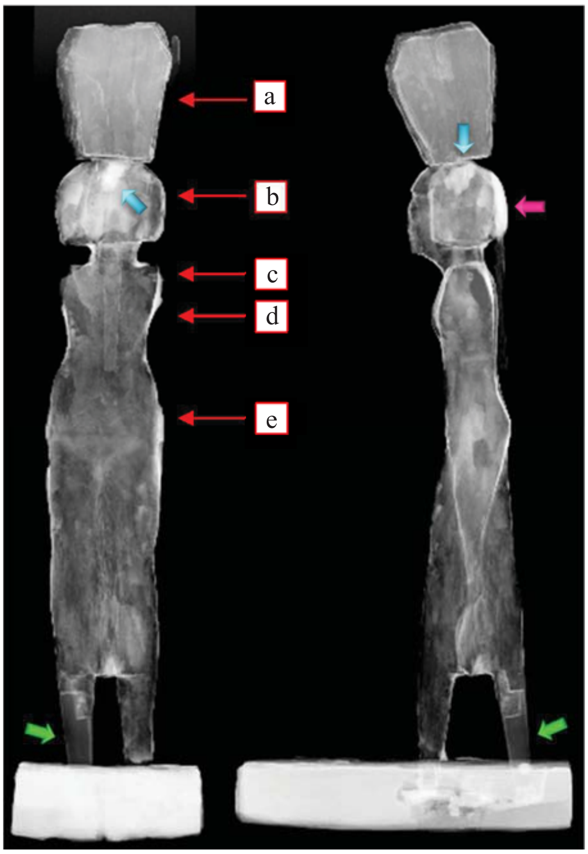

Fig.3. The DR of the statuette, frontal and lateral views (blue arrows: wooden joints; green arrows: wooden portion joined to the body; pink arrow: thicker preparation layer; red arrows: height of the CT slices reported in Fig.3 and 4 with the correspondence letters)

In general, it is possible to affirm that the preparation material has contributed to partially correct the modelling technique (e.g. breasts and hips), and the volumes due to defects of the building blocks, while where the carving was enough refined to obtain the correct shape, a single preparation layer has been laid (Fig. 5e).

As regards the assembly between the basket and the head, the junction has been realized by means of wooden dowels insertions as the radiographic, but even better the tomographic images, have shown (Fig.4a). From the tomographic sections of the head (Fig.5b), multiple portions assembled by wooden dowels is observed, in order to achieve the final volume. Furthermore, the same double preparation layer as in the breast is evident from the head slice (probably to correct wood defects and damage during the carving, see Fig.4b and 5b). Also in correspondence with the bodyheight of the right breast, the same type of assembly technique can be seen: the observation of the internal growth rings trend allows recognizing this insertion as a remediation for a material detachment probably in the notching phase (Fig.5d). The same anchoring system is evident in correspondence of the missing arms, as shown in Fig.4c.

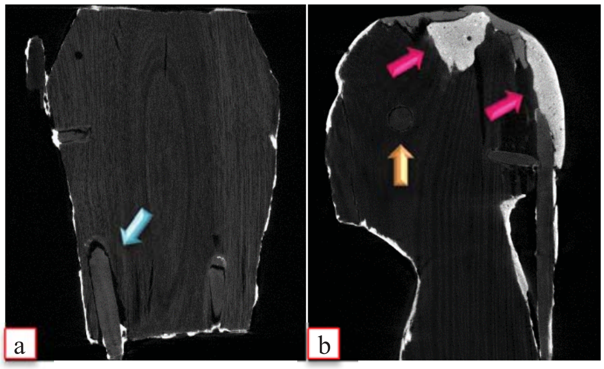

Fig.4. CT vertical slices of the statuette: (a) basket; (b) head. (orange arrows: wooden dowels for assemblage; blue arrows: wooden joints; pink arrows: thicker preparation layer)

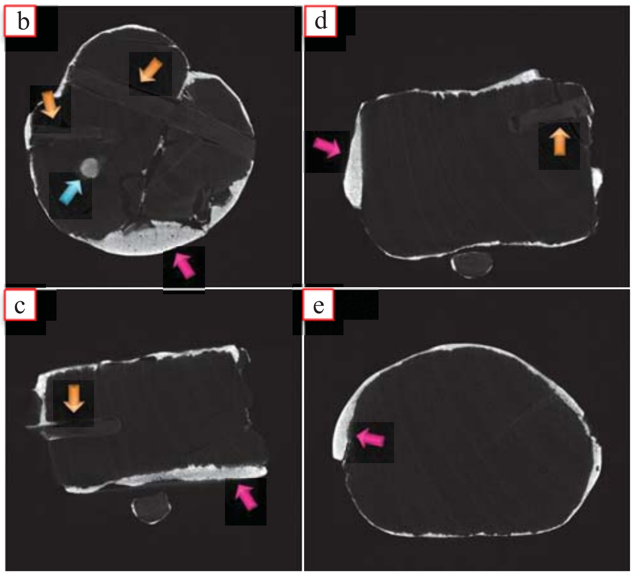

Fig.5. CT horizontal slice of the statuette: (b) head; (c), (d),(e) body. (orange arrows: wooden dowels for assemblage; blue arrows: wooden joints; pink arrows: thicker preparation layer)

For the lower part of the statuette, the radiographic analysis is useful to study some peculiarities of the object. In particular, there is evidence of a fracture of the wooden matter in the right leg of the bearer and, at the calf level, a tongue and rebate joint for the completion of the leg anatomy is visible (Fig.3), superficially retouched in occasion of a previous intervention. In occasion of the cleaning treatment, that pursued the recovery of the original materials without any mimetic pictorial integration, it has been possible to observe a slight difference in colour and porosity of the wood in this

portion compared to that of the original parts. This could suggest its belonging to a previous intervention, even if more insights should be provided to ascertain this.
In the base of the statuette, the DR images allow to distinguish a portion of material that reaches about half the total thickness of the base that correspond to a different wooden insertion in the housing area of the sculpture due to previous interventions. Furthermore, the X-ray analyses are also able to define how the wooden inserts were applied and fix: in fact, two holes made to accommodate the end portions of the two legs can be identified. The legs were inserted and then fixed by means of application of filler material, that have more pronounced radiopacity respect to the wooden material (Fig.6).

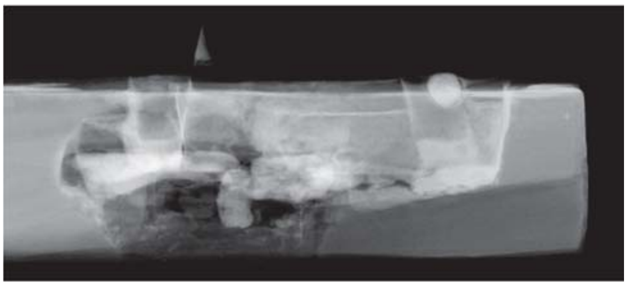

Fig.6. Particular of radiographic image of the statuette base

IV.CONCLUSION

The most used x-ray detectors for imaging analysis are essentially of two typology: area (flat panel) or linear detector. The CCR linear detector is generally used for large object analysis for which its resolution (200 µm pixel) allow to obtain useful data. For this specific case study the use of a high resolution FP detector was more advantageous taking into account the object dimension and the final goal of this study. The smaller pixel dimension and the higher integration time of the flat panel, compared to the setup developed in neu_ART projects, permitted to obtain new information on small wooden artefacts. The studies performed on the Egyptian "Bearer" statuette provided valuable information about the techniques of assembly, technique of execution and previous interventions, probably not obtainable with the previous setup. Most of the evidences came out from CT measurement, that allow to obtain more useful information about the inner structures of wooden finds.

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REFERENCES

[1]M.P. Morigi et al. "*Application of X-ray Computed Tomography to Cultural Heritage diagnostics*", Applied Physics A, 100, 2010, pp. 653-661.

[2]A. Otte et al., "*Computed tomography alone reveals the secrets of ancient mummies in medical archaeology*", Hellenic Journal of Nuclear Medicine, 16(2), 2013, pp. 148-149

[3]M. Bettuzzi et al., **"***Computed tomography of a medium size Roman bronze statue of Cupid***"**, Appl. Phys. A (2015) 118:1161–1169

[4]M.C. Martina et al., *"Petamenophis (Padiamenemipet), an Egyptian Child Mummy Protected for Eternity: Revelation by Multidetector Computed Tomography"*, Journal of Computer Assisted Tomography: 3/4 2018 - Volume 42 - Issue 2 - p 178-183

[5]G. Fiocco et al*., "Synchrotron radiation micro-computed tomography for the investigation of finishing treatments in historical bowed string instruments: issues and perspectives",* European Physical Journal Plus (2018) 133: 525

[6]A. Re et al., "*Results of the Italian neu_ART project*", IOP Conference Series: Materials Science and Engineering 37, 2012, 012007.

[7]M. Nervo, "*Il Progetto neu_ART. Studi e applicazioni/Neutron and X-ray Tomography and Imaging for Cultural Heritage*", Cronache, 4, Editris, Torino, 2013

[8]A. Lo Giudice et al., *"A new digital radiography system for paintings on canvas and on wooden panels of large dimensions"* 2017, IEEE International Instrumentation and Measurement Technology Conference (I2MTC 2017), Proceedings, IEEE (NJ, USA)

[9]A. Re et al., "*X-ray tomography of large wooden artworks: the case study of "Doppio corpo" by Pietro Piffetti*", Heritage Science, 2(19), 2014, pp. 1-9.

[10]A.Re et al., "*The importance of tomography studying wooden artefacts: a comparison with radiography in the case of a coffin lid from ancient Egypt*", Internation Journal of Conservation Science, Volume 7, Special Issue 2, 2016: 935-944

[11]A. Re et al., "*X-ray tomography of a soil block: a useful tool for the restoration of archaeological finds*", Heritage Science, 3(4), 2015, pp. 1-7.

[12]J. Kahl et al., "*Asyut. The excavations of the Italian Archaeological Mission (1906-1913)"*, Modena, 2019