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Investigating Kha's grave goods by means of a transportable, custom designed X-ray CT system

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ABSTRACT

The tomb of the foreman Kha and his wife Merit is a significant historical site within the necropolis of Deir el-Medina, Egypt. Discovered in 1906 by Ernesto Schiaparelli, then director of the Museo Egizio of Turin, this tomb represents an extraordinary archaeological find. In fact, the burial chamber had never been desecrated and contained over 440 different artefacts, many of which were in an exceptional state of preservation. As part of a multi-disciplinary study project a tomographic measurements campaign was carried out on a selection of wooden caskets, terracotta amphorae and other small objects from the grave goods. The purpose of the tomographic campaign was to uncover the construction technique of the caskets, to reveal the hidden contents in the amphorae and to identify some tools enclosed in a fabric casing. The analyses were performed at the Museo Egizio of Turin, where the finds are exposed, using our transportable custom CT system. A description of the CT system and the scanning of the finds is given in the paper. The campaign produced a huge dataset output and following processing helped to carry out a detailed qualitative but also quantitative study, shedding light on the key features of these buried treasures.

Keywords: Museo Egizio, amphoras, caskets, tomb of Kha, x-ray, computed tomography, mobile system, analysis

1. INTRODUCTION

The Museo Egizio of Turin preserves and displays the finds from the tomb of the architect named Kha and his wife Merit. The burial dates back to the New Kingdom, second half 18th Dynasty (~1450 BCE) and was found in 1906 by Ernesto Schiaparelli in the area called the tomb of the nobles of Thebes near present-day Luxor. It is one of the best-preserved tombs in the world, if we exclude those of the pharaohs, and the grave goods found inside are very rich and precious, able to provide a considerable amount of information about the daily life of the two deceased. In fact, a series of objects of common use were found: beds, clothes, amphorae with food remains, painted wooden caskets and various utensils. In 2017, the Museo Egizio of Turin launched the "TT8 Project", a research program in collaboration with an international community of cultural heritage experts, Egyptologists, restorers, archivists and archaeologists. The project aims to publish a digital data archive and a comprehensive study using archaeological, historical, cultural and conservation data. Within the "TT8 Project", different research groups have studied the different classes of objects and characterized their constituent materials or content [1][2][3][4][5]. As part of this study project, the museum has planned an analysis campaign using x-ray computed tomography on some of the most significant finds. The scanning work focused on a selection of objects: five of the large amphorae; six wooden caskets and three wrappings containing commonly used tools. Some of the amphorae are still sealed so X-ray analysis is particularly interesting in this case. The measurement campaign was carried out at the museum, given the importance, state of conservation and also the number of finds investigated. For this purpose, a transportable tomographic system developed by our research group (University of Bologna and National Institute of Nuclear Physics) was used. The device is able to scan objects up to 1.3 meters in diameter and 1.5 meters in height approximately in fast mode with 200micron pixels. The system installation and scans were carried out in 5 days. The results of the measurement campaign, as well as the description of the work carried out at the museum, will be extensively discussed in this article. However, due to the amount of information provided by CT, we will focus on a few representative objects in greater detail, so that one can appreciate the level of depth achieved with the analysis and describe the other objects in a general way. For this purpose, we have selected a casket and two amphoras among the most interesting on which we will dwell more in the discussion of the results accompanied by a significant number of figures.

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2. MATERIAL AND METHODS

A list of objects to be investigated was preliminarily provided by the Museo Egizio of Turin to plan the measurement campaign. Among these objects, all belonging to the grave goods of the tomb of Kha and Merit, we highlight in particular six wooden caskets, some of which are decorated with figures and inscriptions (Table 1) (fig.1) and five amphoras (Table 2). The caskets are all empty (the content has been removed) and the purpose of the tomographic analysis with X-rays is to verify their state of conservation and above all to determine their structure and construction elements. The dimensions of the caskets are very similar. The bigger one is 54cm, but most of them have dimensions between 30 cm and 50 cm. As for the amphorae, they are made of clay and most of them are full. In particular, one is empty, two of them are filled with material that looks like resin or wax, two others are full of food remains. Although some of them are still sealed, some chemical analyses were done from the outside and confirmed the presence of organic material. One of the amphorae is broken on one side so that part of the content is visible (fig.2). However, this superficial portion does not reveal much of the internal content of the amphora that instead the tomography allows to outline much more clearly and for the entire volume. In addition to the caskets and amphorae, three cases containing metal tools of various types were analyzed. As regards these finds, given the impossibility of opening the container without destroying or damaging it, X-ray analysis first of all allowed for the identification of the content and therefore the type of tool. Table 3 summarizes the description of the three enclosures with metal tool inside.

Table 1. List of the six wooden caskets belonging to Kha and Merit's tomb.

Tomb of Kha and Merit (Museo Egizio of Turin) - Caskets			
Inventory	***Description***	***Materials***	***Size (cm)***
S.08212	Casket depicting Kha and Merit receiving offerings from one of their sons, Nakhttaneb	Wood, plant fibres, paint	34 x 44 x 30
S.08213	Casket depicting Kha and Merit receiving offerings from one of their sons, Nekhetef	Wood, paint	36 x 48.5 x 35
S.08450	Box for the seven sacred oils, with offering formula for Kha	Wood, paint	41 x 37 x 54
S.08514	Box with inscription	Wood, paint	34 x 46.5 x 31.5
S.08515	Sealed casket bearing the cartouche of Pharaoh Thutmose IV	Wood, paint	37 x 40.5 x 30
S.08617	Box containing loincloths, a date seed, a pair of sandals and the seal of the box itself	Wood, paint	41 x 36 x 49

Fig.1: caskets with painted figures and decorations from Kha and Merit's tomb.

Table 2. List of the five amphoras caskets from Kha and Merit's tomb.

Tomb of Kha and Merit (Museo Egizio of Turin) - Amphoras			
Inventory	***Description***	***Material***	***Size (cm)***
S.08526	Amphora possibly containing birds in salt	Terracotta, organic remains	60 x 37
S.08356	Amphora with offering formula for the superintendent of works Kha, sealed with an inverted bowl, papyrus strips and mud	Terracotta, plant fibers	70 x 37
S.08467	Amphora with inscriptions, sealed with clay, papyrus strips	Terracotta, plant fibers	67 x 38
S.08516	Amphora with inscriptions, sealed with clay	Terracotta	67 x 38
S.08618	Amphora with hieratic label, sealed with clay	Terracotta	67 x 37

Table 3. List of the three envelopes with metal tools from Kha and Merit's tomb.

Tomb of Kha and Merit (Museo Egizio of Turin) - Enclosures with metal tools			
Inventory	***Description***	***Material***	***Size (cm)***
S.08379	Two needles in a reed container	Metal / bronze, plant fibers	14.8 x 2.8 x 1.9
S.08496	Four needles fixed on a piece of papyrus stem	Metal / bronze, Cyperus papyrus	16 x 4.1 x 3.3
S.08498	Bronze razors in cane case	Metal / bronze	

Fig.2: a couple of amphoras from Kha and Merit tomb, one of them partly broken with exposed content.

The mobile tomographic system used for the measurement campaign at the Museo Egizio of Turin was entirely developed by the research group of the Department of Physics and Astronomy of the University of Bologna using components that were partly commercial and partly custom-built. The control and data processing software was developed internally by the group and is divided into two parts: mechanical axes control software, scanning software and tomographic reconstruction software (PARREC). The structure of the system, also described in [6][7][8], is an enlarged and detachable version of a typical industrial CT (fig.3). To extend the field of view, a three-axis translation system was created, two for the detector and one for the X-ray tube. The two horizontal and vertical translation axes of the detector have a travel range of 1.5 m while the vertical one for the X-ray tube has a travel range of 1.3 m. In this way, it is possible to scan objects with dimensions of up to 150 cm vertically and up to 130 cm horizontally. The object is placed on a platform connected to a motorized micrometric rotary axis for loads up to 50kg. The specificity of the system is that it can be dismantled into separate components that can be transported quite easily by two operators in a van. One solution for the X-ray tube, which is usually heavy and bulky, was to use construction site tubes for non-destructive testing. There are rather compact and lightweight versions with air cooling, even 200kV as in our case. The Comet Smart EVO 200D X-ray tube we used does not have any particular cooling problems even for long scans. The limitation to one hour of continuous x-ray emission does not normally represent an obstacle for working on large objects, since a single scanning step lasts 3 minutes. In this way, however, the X-ray tube is easy to transport and install and can be lifted by a relatively light motorized vertical axis. With a power of 750W (3.7mA max at 200kV) the tube has a focal spot of 1mm, therefore rather small, and allows to obtain a good spatial resolution even for magnifications equal to 1.3-1.5. The Varian PaxScan 2520D detector is small and light, with 127µm pixels (but in fast mode the pixel becomes 254µm), a sensitive area of 19.5cm × 24.3cm and it has an excellent signal to noise ratio. The object is then scanned in sections using the tile scanning method, moving the detector horizontally to suitably fixed positions so as to cover the entire projection of the object and acquiring images over 360 degrees. For wooden caskets a grid of 5 horizontal positions of the detector was used and 3 section on the vertical axis were required to scan the whole object. For each position 900 projections over 360 degrees have been acquired in fast scanning mode (also referred to as on-the-fly or asynchronous scanning). Each rotation takes 3 minutes. It gives a total 5×3 positions × 3 minutes = 45 minutes of pure acquisition time for the whole object (detector shift and data recording on the disk excluded). For the amphoras the situation is very similar as the grid is 3 horizontal positions and 4 sections on the vertical (3×4×3min = 36min pure acquisition time). Typical scanning parameters for the casket series is 100kV, 3.5mA while for amphoras we used 150kV, 5mA. The source-detector distance (SDd) was fixed at about 2.4m and the source-object distance (SOd) was about 2m with a resulting magnification factor of 1.2. For the three enclosures with tools a different scanning method was used as in this case the objects were small. Thus, the detector remained fixed (no tile-scanning) and step by step scan at full resolution was used. Parameters of the x-ray tube were set to 170kV, 4.4mA. Frame average was also used to enhance signal to noise ratio. A scanning time of 36 minutes for each sample was required for 900 projections over 360 degrees.

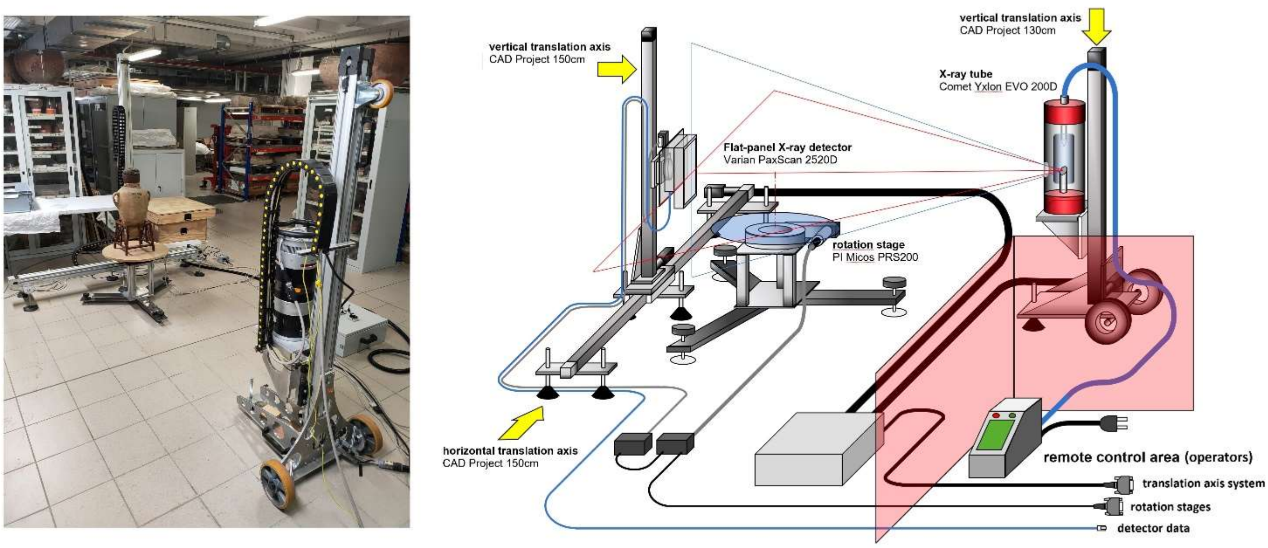

Fig.3: (left) the CT system installed in the basement of the Museum; (right) a schematic of the system.

3. RESULTS AND DISSCUSSION

The acquired data were subjected to a standard processing carried out using the PARREC software, developed internally at our institute. The different horizontal sections are reconstructed separately with a cone-beam filtered back-projection algorithm. They are then joined with a semi-automatic vertical stitching process to form the complete sequence of slices of the entire object. The complete set of slices of an object can then be imported into VGStudioMax 2.1 to create 3D rendering. This is very useful especially for understanding the construction technique of the caskets, but also for the virtual exploration of the amphorae, although excellent information is obtained even from the individual sections. In the case of caskets, the sections provide a detailed view of the construction elements and joints that make up the structure of the chest; in the case of amphorae, it is possible to discover in some of them food remains such as bone fragments, fruit shells and organic residues of various types. For metal tools contained in light material enclosures, CT allows a better understanding of their shape and use, even if the identification itself was already possible using 2D X-rays. To best appreciate the level of detail of CT analysis it is best to focus on just one object for the first category. Figure 4 shows what can be obtained with x-ray tomography in the analysis of the structure of a casket. One axial section at the level of the upper part of the casket number S08212 reveals a system of tenons and mortars used to join the "roof" as well as a simpler joining element made by vertical dowels on the opposite side of the box. The situation is further clarified by the sagittal slices which in our case are parallel to the smaller side of the box (fig.5). From these sections you can appreciate both the tenons and the fixing pins. The tenons do not however appear to be mobile elements such as to allow the lid to be opened. On the opposite side on the other hand, the pegs would not allow the opening. Through the front sections corresponding to the larger walls of the box, the connecting elements of these parts can also be revealed (fig.6). In particular, simple joints with fixing pins from the wall are visible on the vertical elements which also form the legs of the caskets as well as the three fixing pins of the wall to the bottom of the box (fig.6, left). In the front section moved slightly inside the box you can appreciate the internal connection elements (fig.6, right). It is very useful to also examine 3D rendering and virtual sections of the volume to better locate the internal elements and understand their function (fig.7). Two knobs, one located on the top and the other on the small side of the box, would indicate that the box could be opened, however it is not clear to what extent this function was foreseen in the Egyptian belief in the afterlife or whether the availability of food was more symbolic or limited to a period of transition. Certainly, determining a possible opening mechanism as an alternative to a sealed box could provide useful indications in this sense. Apparently, from figure 8 it can be deduced that the two smaller side walls, included the one corresponding to the knob (fig.8, left), are fixed with dowels and therefore impossible to open. CT scans revealed that the floor of the box is made of two parts held together by tenons. The different sections shown here provide a whole series of information on the structure of the casket, however the tomography provides a much larger amount of data that must be carefully evaluated and that cannot be fully reported in a written text. In principle a construction drawing of the casket could be produced on the basis of the CT and therefore constitute the tool for understanding all the functions of the identified elements, supports, joints, fixings. The caskets, being simply wooden boxes, turned out to be rather complex structures that CT is helping a lot to understand, as well as revealing their state of conservation, which in any case appeared to be really good, if we consider that thousand years have passed.

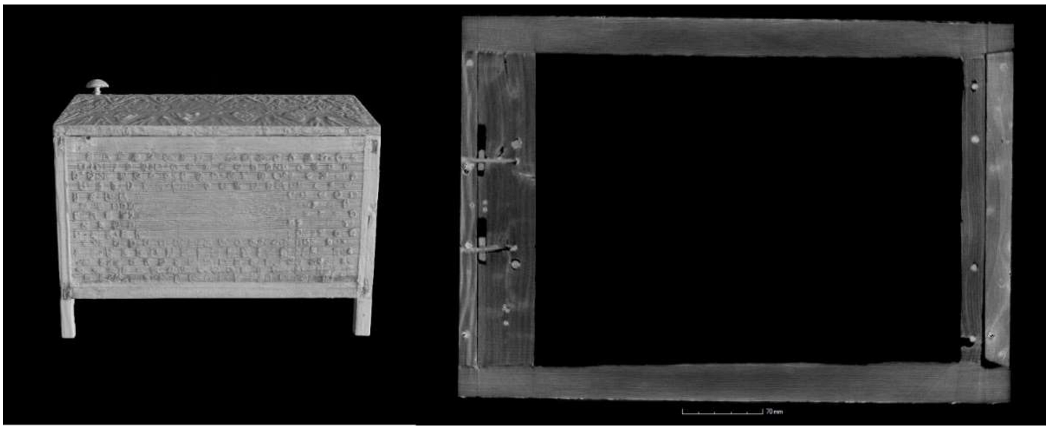

Fig.4: (left) a realistic 3D rendering of the casket as seen from one side covered with decorations; (right) Axial cross-section showing the internal system of tenons and mortises fixed with dowels to join the upper part to the parallelepiped structure of the box on the left side, while on the right side some vertical dowels are visible.

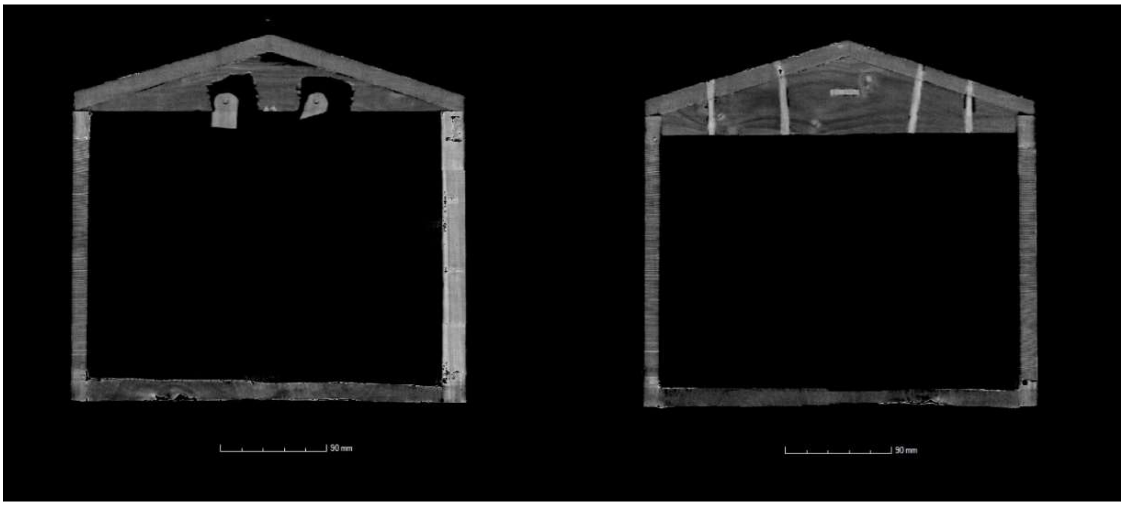

Fig.5: (left) sagittal section of the box corresponding to the side with mortises and tenons; (right) sagittal section of the box on the opposite side where the roof is instead fixed with vertical dowels.

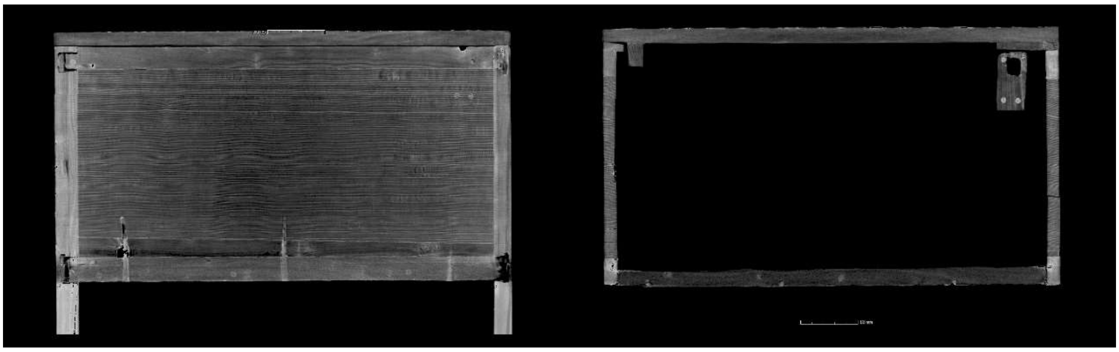

Fig.6: (left) front section of the box corresponding to the side of one of the larger walls showing the dowels that fix the wall to the bottom and the joints with the other two walls on the sides; (right) front section of the box just inside the side wall showing complex joining elements that serve various functions of connecting the internal elements.

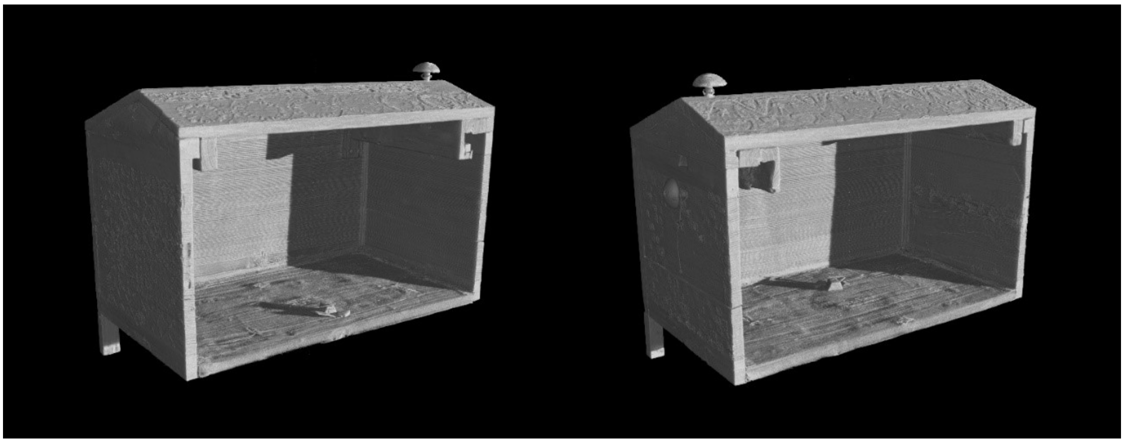

Fig.7: virtual sections on the 3D rendering from the two sides parallel to the larger walls of the box.

Fig.8: (left) the wall corresponding to the knob is fixed at the bottom with a dowel; (right) the wall on the opposite side to the knob has multiple fixings both at the top and bottom. It appears to be composed of two parts held together by tenons.

Fig.9. Sections of three amphoras: (left) number S08618, completely empty; (center) number S08467, filled with wax or resin; (right) number S08516, filled with wax or resin.

Moving on to examine the five amphorae on the list, we will see that only one resulted as completely empty and other two were discovered to be filled with a compact and rather uniform substance, defined as wax or oil-fat of some kind (fig.9). The last two amphorae instead revealed food residues. These large amphoras show an evident mixed organic content. This allows us to try to understand what type of food it might have been, whether any animals whose meat had been used are recognizable, also through the examination of the bones present, and possibly find other useful elements. Four of the amphorae were sealed in various ways, so the contents were not accessible. Previous chemical analyses carried out on the air surrounding the sealing indicated in some cases the presence of organic materials [9]. Moreover, one of these two amphoras was broken on one side thus exposing part of the content. However, CT sections revealed much more about the content type and distribution. At first glance, it seemed that the type of food contained in the two large amphoras was quite different. A closer analysis revealed the presence of bones of a different kind and size, which can be roughly identified as the bones of some type of bird in one of the two (fig.10) and probably of cattle in the other (fig.11). Some of the long bones visible in amphora S08526 have been measured on CT sections and resulted to be about 6cm. A quite big bone found in amphora S08356 resembling a femur resulted instead to be 15cm long. Another bone in S08356, also visible in fig.11 on the right, looks like a scapula bone. The exact type of animal to which the bones found belong has not yet been clarified. In any case, this type of investigation has been a source of important information, especially if we consider that the contents of these amphorae remained hidden for millennia. **S**ome reed casings containing bronze tools were also analyzed. It was thus possible to define more clearly their shape and function. The first revealed a set of four needles, the second a couple of razor blades of different size and the third included a pair of scissors. Scanning of these objects have been made at higher resolution and higher voltage because of their size and material: 170kV, 4.4mA, 4frames average for each pf the 900 projections over 360 degrees.

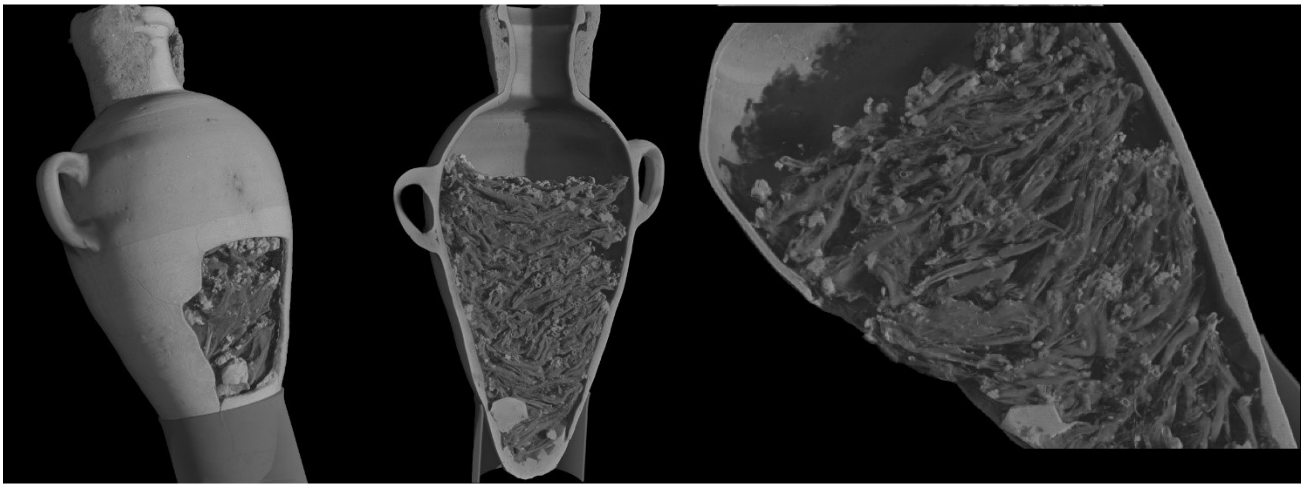

Fig.10: amphora number S08526 with a broken wall and part of the content exposed revealed to be filled with organic material including small nut shells or fruit stones, long thin bones and other soft tissues. Long thin bones can be associated probably to birds.

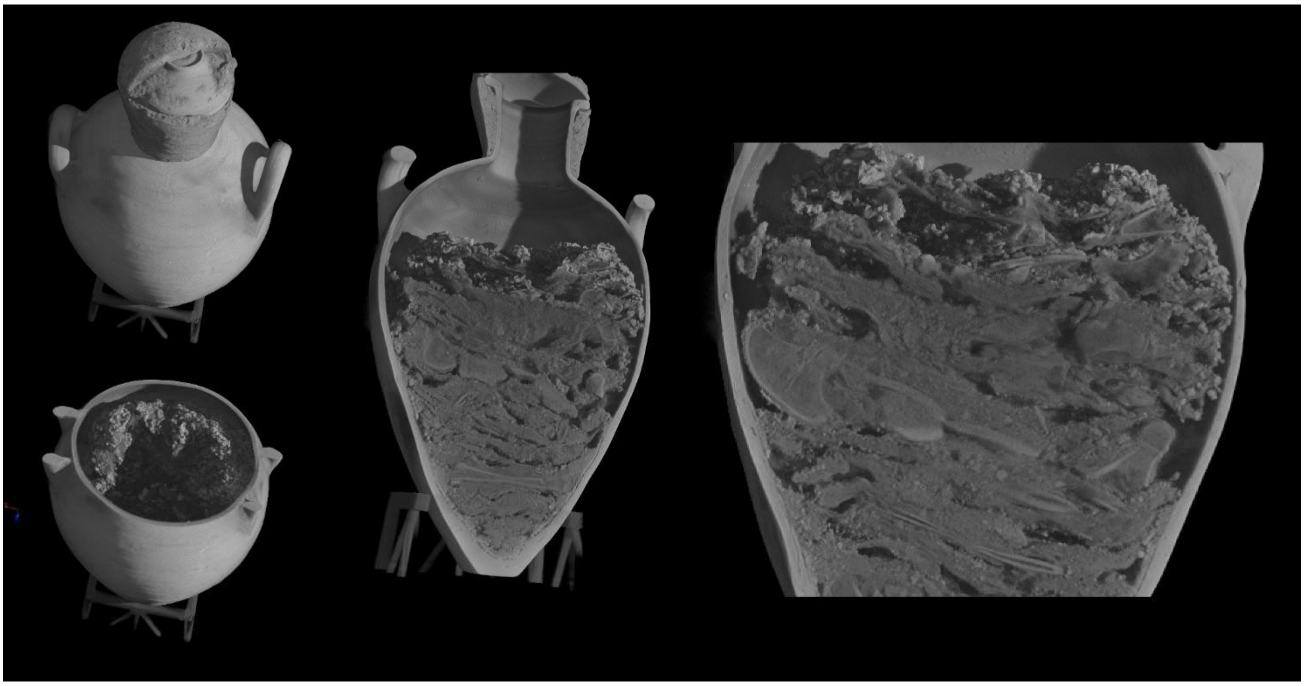

Fig.11: virtual opening of the amphora number S08356 revealing bones ad organic residuals. Size of some bones, appearing quite big and heavy, can indicate cattle of some kind.

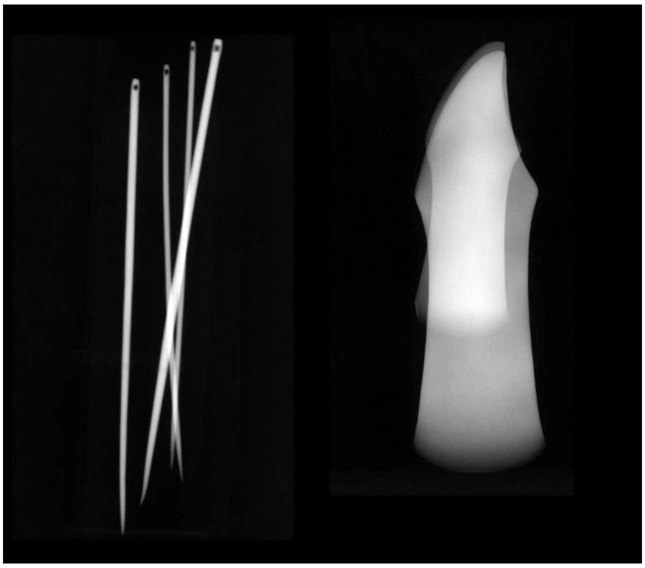

Fig.12: attenuation RX of reed casings with bronze tools inside: (left) a set of five needles; (right) a couple of razors

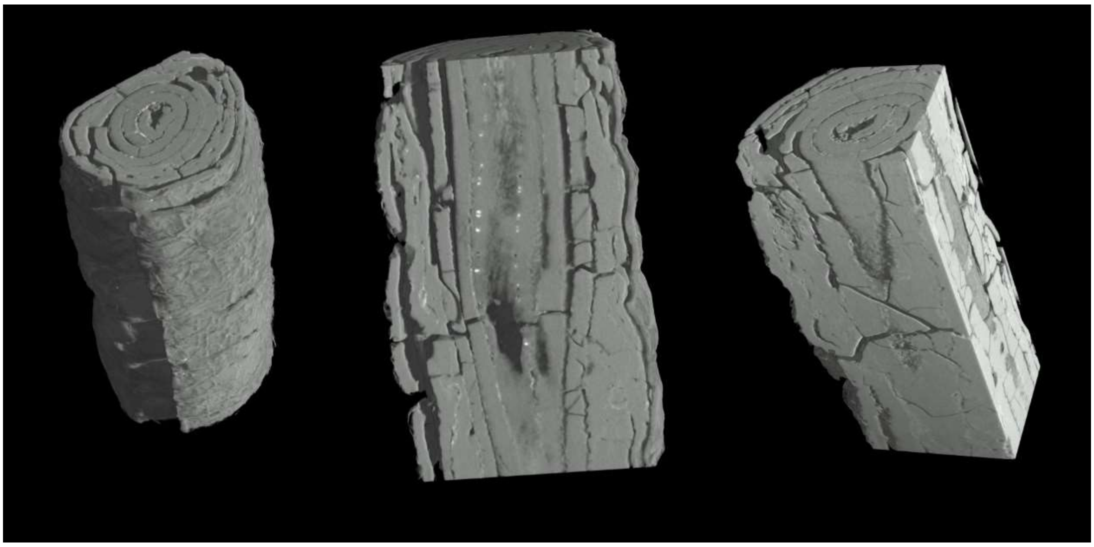

Fig.13: the 3D imaging of a portion of the leather scroll revealed a heavily fragmented outer part and a better preserved inner scroll with the possible presence of papyrus or another type of fabric with binding marks in the core.

Voxel size was 108µm. The tools have been thus easily recognized (as a confirmation) and classified (fig.12). Finally, a high-resolution CT scan was performed of a leather roll with perhaps papyrus inside. Parameters were: 80kV, 6mA, 4 frames average for each of the 900 projection over 360 degrees. Voxel size was 108µm as well in this case. To cover the whole length of the scroll, three scanning have been required. Results are shown in figure 13 for just one portion of the roll in order to appreciate the detail. A demanding processing would be necessary to achieve the virtual unrolling, but attempts to read possible writings on the surface of the scroll or on the inner paper have so far been unsuccessful.

4. CONCLUSIONS

The measurement campaign carried out at the Museo Egizio of Turin and which involved various materials belonging to the collection of the tomb of Kha and Merit was successfully concluded. The work focused on the study of a selection of wooden caskets, six in total, and on a series of large amphorae, five in total. However, other objects have been also analized as few reed enclosures containing bronze tools and a roll of leather. A mobile system for computerized tomography with X-rays was installed inside the museum's storage rooms in safety conditions as required by law. The precision achieved after the alignment of the mobile system was optimal and all scans, even those of the largest objects, were successfully performed. The tomographic reconstructions therefore allow reliable measurements and dimensional evaluations. The data processed after the in situ campaign were provided to the curators and conservators of the museum for their evaluations and studies and constitute an important reference and source of information regarding the objects subjected to analysis which are a very important and significant part of the tomb's grave goods and are all exhibited in the museum. Computed tomography makes it possible to identify all the elements of the casket structure and therefore to carry out measurements on them in order to validate the construction drawings already made, to integrate them or create new ones. The state of conservation of the wood is also very clear and it can be said that it does not cause particular concern. As regards the large amphorae, many of which were still sealed, X-ray tomography was used to visualize their contents and to contribute to increasing knowledge on the subject also from a morphological point of view by integrating previously carried out physical-chemical analyses. The identification of some types of organic residues in them, such as bones, which are very easily recognizable with CT, will allow us to identify more clearly the type of food that was preserved in them. All this obviously without carrying out any invasive intervention on the objects. As for the smaller objects such as the cane cases with bronze tools, the identification and arrangement of the latter inside was very simple and immediate and contributes to increasing the visual information on them, potentially usable also by the public, since it is in fact impossible to open the packages without damaging them. The leather scroll has proven to be the most difficult and mysterious object of all, as reading its surfaces is extremely complex. However, after the first attempts, no particular sign or element inside has yet emerged. The complex experience of in situ tomographic analyses on large objects has also revealed in this case all its potential. However, the preparation of a complete setup for X-ray tomography inside a museum remains a job that requires a series of specific skills and attitudes as well as a certain amount of experience. The case study of the collection of the tomb of Kha and Merit at the Egyptian Museum of Turin is therefore presented in conclusion as an example of success of this specific way of using this technique.

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