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Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

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To cite this article: Luisa Vigorelli *et al* 2022 *J. Phys.: Conf. Ser.* **2204** 012034

METROARCHAEO 2021 IOP Publishing
Journal of Physics: Conference Series **2204** (2022) 012034 doi:10.1088/1742-6596/2204/1/012034

The study of ancient archaeological finds through X-ray tomography: the case of the "*Tintinnabulum*" from the Museum of Anthropology and Ethnography of Torino

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Abstract. X-ray Computed Tomography (CT) is a widely used diagnostic technique in the field of Cultural Heritage and beyond, above all thanks to its 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 useful data on the entire volume of the objects, to finally obtain a 3D model of the studied artworks. In this field, the goal of the "neu_ART" project, a collaboration among different institutions in Torino funded by Regione Piemonte in 2010, was to develop radio-tomographic set-ups for X-ray imaging analysis dedicated to Cultural Heritage studies. In this paper, a computed tomography investigation on an ancient ceramic rattle from the Museum of Anthropology and Ethnography of the University of Torino is presented. This is the first analysis carried out at the Physics Department of University of Torino, using the imaging set-up based on a TDI linear detector moved by a high precision mechanical system. Thanks to this study, much information on the technique of execution and the state of conservation was obtained.

1. Introduction

Diagnostic imaging techniques based on the use of X-rays allow, in an increasingly efficient way, a non-invasive analysis of the internal structures of the objects and, more generally, the study of the discontinuity or inhomogeneity of the materials [1-3]. In the field of Cultural Heritage, X-ray imaging has found wide diffusion as a non-destructive analysis, both structural and compositional, thanks to the different radiopacity of materials used in works of art. These investigations are often fundamental in solving both archaeometric issues, such as dating, authentication and studies on executive techniques, but also problems related to conservation. One of these methods, the Computed Tomography, is a non-invasive diagnostic technique able to visualize the internal structure of the investigated objects in a three-dimensional way [4,5]. In recent years, some optimized experimental set-ups have been developed [6] for the analysis of these objects, which very often present inhomogeneity in shapes, sizes, materials and thicknesses; the "neu_ART" project, born from the collaboration between the University of Turin, the National Institute of Nuclear Physics (INFN) and the Centro Conservazione e Restauro (CCR) “La Venaria Reale”, Venaria Reale (Torino) and financed by Regione Piemonte (Italy), is part of this research context. Among the project goals there was the construction of an integrated X-ray imaging system to carry out computed tomography (CT) and digital radiography (DR) for applications in the study, restoration, conservation and enhancement of Cultural Heritage [7,8]. The instruments installed at the CCR and at the Physics Department of the University of Torino have been designed for “ad hoc” analysis necessary in the study of works of art with different size, shape and constitutive material. Some recent instrumental upgrades of the systems allow to improve the results on small objects, increasing the resolution and reducing the acquisition time [9]. During and after the end of the neu_ART project, artifacts of different nature, age and size were analyzed [10-13]. In this paper, the tomographic analysis carried out on a particular ceramic archaeological find called "Tintinnabulum", part of the Museum of Anthropology and Ethnography of the University of Torino collections, is presented. The measurements were carried out by means of a prototype of the final instrumentation, within the project progress, in the Physics Department laboratory of the University of Torino.

2. Materials and Methods

2.1. The “Tintinnabulum”

The studied object presented here, called "Tintinnabulum" (figure 1), is one of the archaeological finds of the Cypriot Antiquities Collection of the Museum of Anthropology and Ethnography of the University of Torino. It became part of the museum in 1972, after the acquisition of the Palma da Cesnola collection [14], probably coming from a funerary context of Salamis or Palea Paphos, in Cyprus (excavations carried out in the 1870s) [15]. Based on comparative analysis, the find could be dated back to Iron Age, Cyprus Archaic II period (from 600 BC to 480/75 BC), or Roman period, Roman I period (from 50 BC to 150 AD).

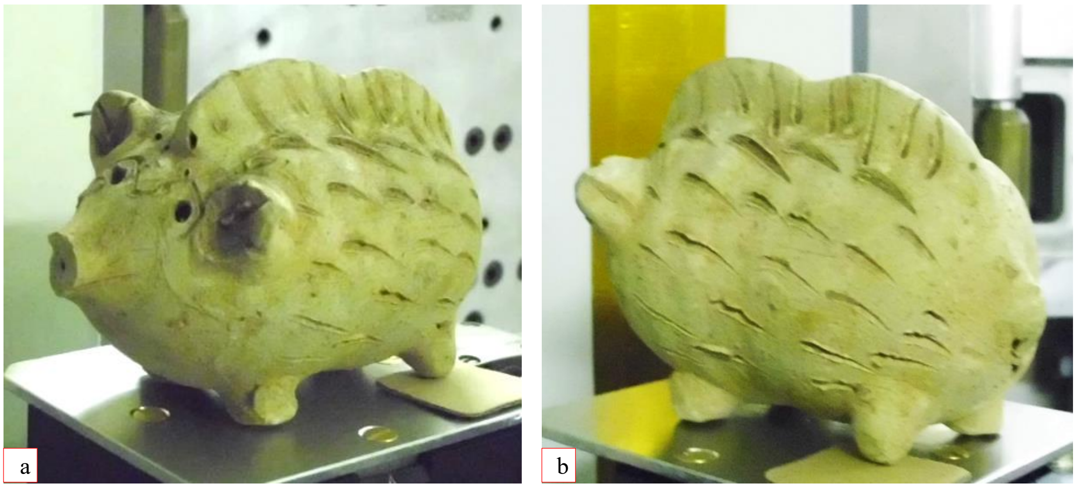

Figure 1. The boar shaped “Tintinnabulum”, frontal (a) and back (b) views during the CT acquisition (inv. n°. MAE39, h. 7.4 cm × l. 11.2 cm × w. 6.2 cm).

The find, boar shaped, is an earthenware realized with the 'dovetail' technique and by hand in the minor parts, and subsequently decorated. The central structure, corresponding to the animal body, has an ovoid shape, with secondary structures as the ears, the legs, the crest and the tail. It is not possible to identify the nose shape as it is largely missing, although presumably it would have a trumpet shape, based also on a comparison with a similar object belonging to the collections of the Museum of Antiquities of Torino [16]. Some elements, separated from the ceramic body, have been placed inside the object, whose presence can be detected by the noise they produce when the object is shaken; this suggests that it could have a rattle function (hence the name "tintinnabulum").

The aims of the CT investigations were to get some evidence about the number, shape and dimensions of the inner bodies and to eventually identify what kind of material was used for their manufacture and, more in general, about the state of conservation, as in [17,18]. This kind of information could have a certain relevance for archaeologists and historians and might help them understand the structure of these artefacts and the way they were produced.

2.2. The tomographic set-up and experimental procedures

The analysis was carried out at the Physics Department of the University of Torino, where a device for DR and CT was installed in a shielded laboratory within the neu_ART project (figure 2). The instrumentation mainly consists of a General Electric Eresco 42MF4 X-ray source, associated with a digital control unit for setting and checking the operating parameters. It has a tungsten anode with a focal spot size of 3 mm and a maximum current of 4.5 mA at the upper voltage of 200 kV, increasing to 10 mA at lower operating voltages (maximum power is 900 W). The detector is a Hamamatsu C10650-321, a linear TDI (Time Delay Integration) CCD detector, coupled with a fiber optic plate and a scintillator, that can scan at 0.2-6.5 m/min. It features a 22 cm long CCD with a pixel size of 48 µm for a total pixel number of 4608×128 and it is designed for operations with X-ray energies lower than to 95 keV. The detector is installed on an automated mechanical movement system that allows horizontal and vertical translation, useful in the case of radiographic scans of large objects. To complete the tomographic set-up, a system for rotating the object on the horizontal plane by 360° is also essential; the rotating platform used in this case allows small displacements (hundredths of a degree). After the preliminary procedures aimed to optimize the acquisition geometry, the experimental parameters for the CT measurement were set as summarized in Table 1.

Table 1. CT experimental details

Parameter	Value
Tube voltage	80 kV
Tube current	10 mA
Source-Detector distance (SDD)	146.5 cm
Source-Object distance (SOD)	136.8 cm
Magnification	1.1
Voxel dimension	90 µm
Binning	2 × 2
Projection number	720
Angular step	0.5°
Pixel integration time	184 ms

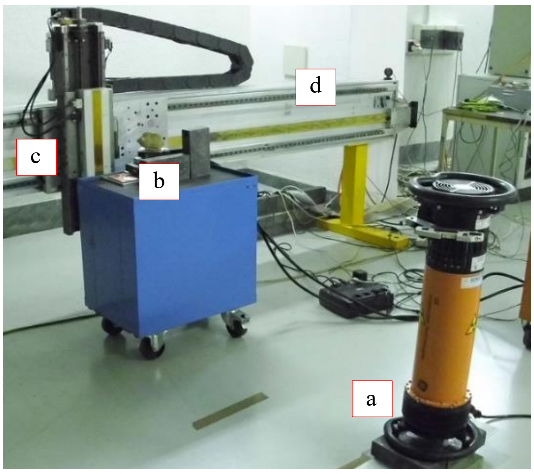

Figure 2. The tomographic set-up used for the analysis (a: source; b: sample; c: detector; d: movement system)

 2204 (2022) 012034 doi:10.1088/1742-6596/2204/1/012034

The reconstruction of the CT sections was made using a filtered back-projection algorithm [19,20] by means of two non-commercial software, one developed within the Physics Department of the University of Bologna and the other developed by Dan Schneberk of the Lawrence Livermore National Laboratory (USA), while the 3D rendering was processed using VGStudio MAX from Volume Graphics.

3. Results and Discussion

Already from the radiographic projections (figure 3a) acquired during the CT scan, the rattles inside the central body and an agglomerate of material near the tail are easily recognizable. The projections were then processed in order to obtain the horizontal slices, representing the different object sections, leading finally to the reconstruction of the three-dimensional volume of the object. From the obtained results, although the general good conservation state, some fractures along the thickness of the ceramic body can be observed: two of them in the middle of the central body and other two near the nose and the tail (figure 3b-c).

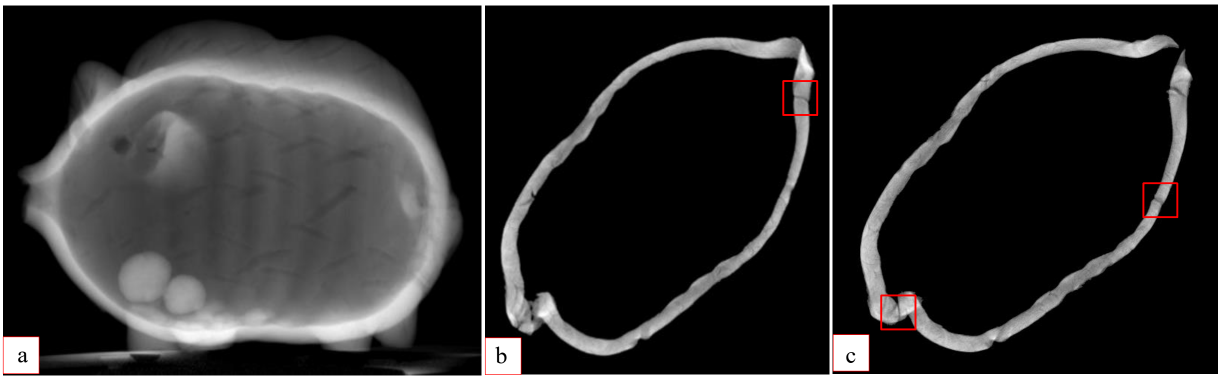

Figure 3. (a) Radiograph of the tintinnabulum; (b) and (c) CT slices where some fractures (red squared) in the ceramic body are visible.

In the images of the lower part of the object, the rattles are clearly visible. From figure 4b it is possible also to notice the presence of different fragments, suggesting that originally at least three rattles had to be present, reduced to two probably because of the continuous shaking. Moreover, the tomographic analysis highlighted some fractures also in the two residual spheres, which are therefore at risk of breaking (figure 4a). From a more detailed analysis of the rattles, it was possible to hypothesize, by a comparison of the grey levels and with a good approximation, that their constitutive material is similar to the one used for the body of the object. Therefore, they would not be small stones, the first hypothesis advanced by previous studies, but made of ceramic. Taking into account the object dimension, the two rattles could be about 13 mm of diameter. From further analysis of the volume close to the tail, a small internal mass of ceramic material is evident, with some small perforations. This detail could be explained as a manufacturing mistake of the object, probably to repair a small hole formed during the tail assemblage. From the CT slices and the 3D model of the object is also possible to estimate the thickness of the ceramic in the different parts of the object: from 2 mm to 11 mm for the crest, about 10 mm for the tail and the nose, and a body thickness from about 3 to 5 mm, where some of the thinnest areas coincide with the grooved parts of the surface (decoration) and others with the manufacture method, both visible especially in the 3D model (figure 4b).

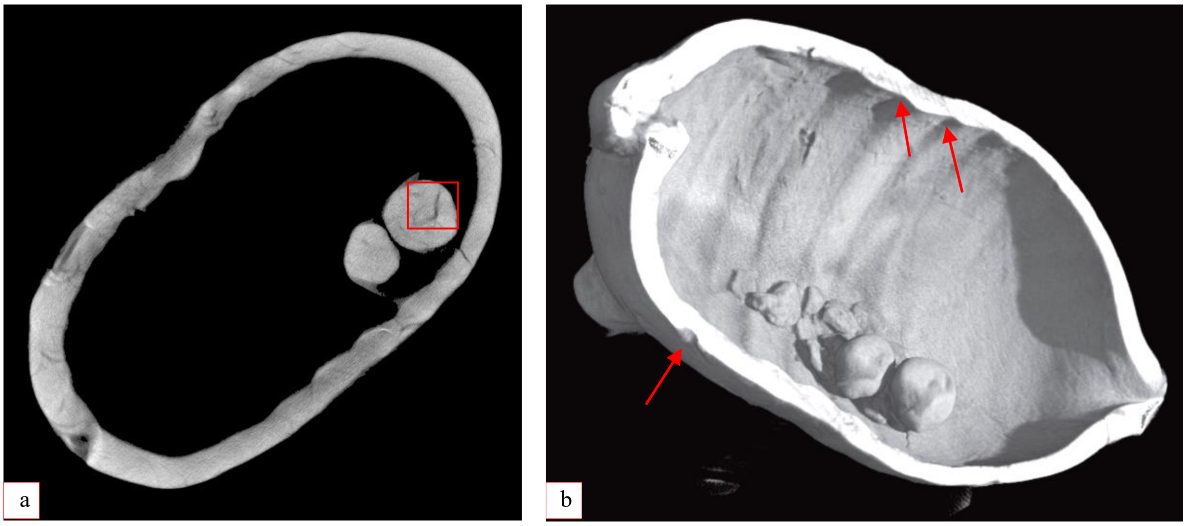

Figure 4. (a) CT slice where the two spheres, with an internal fracture (red squared), are visible; (b) 3D render of the lower part of the object, where some fragments of the rattles and the structure of the object can be distinguished (the arrows indicate the thinnest points).

Then, the study has been extended to the construction method of the tail, placed presumably after the body formation, and of the other additional elements (legs, ears and crest) which, in the dovetail processing, are usually added at a later stage. It was possible to obtain some of these information thanks to the analysis of the radiographic projections, (figure 3) where a clear detachment of the elements with respect to the central body can be noticed, as well as its thickness.

4. Conclusion

The radio-tomographic set-up developed within the neu_ART project, allows the study and analysis of artifacts and works of art of different types in order to meet the needs of restorers, historians and archaeologists. The tomographic examination of the rattle presented in this paper, belonging to the Museum of Anthropology and Ethnography of the University of Torino, unveiled some details about its internal structure. The CT investigations showed that the object contains some spheres, probably made of fired clay, one of which was presumably fragmented due to the shaking action. The CT scan helped in the determination of the composition, shape and size of these inner “balls” and allowed also to recognize some fractures, both inside the spheres and in the animal ceramic body, thus improving the understanding of the state of conservation of this archaeological artefact. Some other future analysis and studies are not excluded on this and other similar objects from the collections of the museums of Torino, in order to gain a deeper characterization and knowledge about this kind of particular finds.

Acknowledgements

The work was performed in the frame of the “neu_ART” project (2011-2013) funded by Regione Piemonte; all the involved Institutions and Cecilia Pennacini, Director of the Museum of Antropology and Ethnography of the University of Turin, are warmly acknowledged.

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