

X-rays ray tomography and aggregated analysis for Bavay treasure bronze statuettes analysis

Clotilde Boust, Elsa Lambert, Charlotte Hochart, Benoit Mille
Center of research and restoration for French museums -C2RMF,
14 quai Francois Mitterrand 75001 Paris
contact : clotilde.boust@culture.gouv.fr

ABSTRACT

X-ray imaging is one of the oldest techniques used in art analysis. X-Radiography is now completed with tomography. Used on bronze sculptures, it gives unrivalled information on state of conservation or fabrication process. The treasure of Bavay, discovered in 1969 in the north of France, is a hoard consisting of 371 bronze objects dated from the 1st to 3rd century AD. Among objects of various shape and use, an exceptional set of Roman statuettes was discovered. Two Mercury statuettes were studied and, apart the fact that they are hollow, their characteristics are very different. The metal walls are thin and even for the Lysippean Mercury and it could only have been made by the indirect lost wax casting process. On the other hand, Indigenous Mercury still has its own inner refractory core made of clay, whose shape is a very simple evocation of the statue. Here the direct lost-wax process was used, with a previous core shaping, on which wax was directly carved. In some cases, spatial information is difficult to read on flat 2D radiographies, so complementary images are made thanks to 3D tomography. Reconstruction algorithms generate a 3D object issued from 720X-Ray images, showing the internal and the external surfaces. Virtual cutting can show any part of the object, allowing a detailed sight of the inner parts. For example, the Jupiter statue in tomography shows on the inner surfaces metal infiltration and a secondary casting of a lead-tin. Further analysis can be added to tomographic model: capturing the surface with a 3D scanner can add more precision on external surface representation: it was achieved for the Jupiter statue. In some cases also, photography for surface color information, or X-ray fluorescence chemical maps can also be placed on 3D models for a better localization of materials.

Keywords: Bavay treasure, Bronze sculpture, X-Rays, Tomography, 3D, XRF map

1. INTRODUCTION

The treasure of Bavay, discovered in 1969 in the north of France, is a hoard constituted by 371 bronze objects dated from the 1st to 3rd century AD. The hoard was buried at the end of the 3rd century AD, during the abandonment of the Roman forum. Among objects of very diverse shape and function (appliques and accessories for furniture, vehicle, and architecture, weighing balances, lamps, vessels), an exceptional set of Roman statuettes was discovered [1].

This article describes imaging technics used to understand those objects. Those technics are more and more used in Cultural Heritage because they are non invasive [2, 3, 4, 5]. We begun to aggregate them to construct complete virtual objects.

X-ray imaging is one of the oldest technic used in art analysis in C2RMF [6, 7, 8] and is now completed with X-rays tomography. Used on bronze sculptures, it gives unrivalled information on state of conservation or fabrication process [9]. On one particularly interesting Jupiter sculpture, we added to those X-rays data the 3D surface form and chemical XRF map to obtain a more complete object material representation.

2. ROMAN STATUETTES STUDIED WITH X RADIOGRAPHY

As part of the Bavay treasure study, we made X-Rays imaging of around 15 statuettes. Although those objects were discovered in the same place, we do not exactly know the period and the place of their production. X-Radiography was used to discover technical characteristics of those objects, and help to compare them one another.

2.1 X-Rays analysis on bronze sculpture

X-Rays imaging is often used to study bronze objects because it gives unrivalled informations about their state of conservation and their production techniques. The secrets of objects creation are usually not visible to the naked eye, because of the presence of corrosion layers in particular on the surface. In addition, operations made in the casting studio have precisely the objective to make disappear technical signs. For example, polishing is made to homogenize the surface, or the fettling that repair or hide the manufacturing defaults. At last, beyond some size (10cm high), bronze statuary is often with hollow, saving quantities of the precious material. X-rays examination are then often the only way to see and describe the metallic wall and the inside of the artwork.

The aim of the X-radiography on Bavay sculpture was to reveal technical characteristics and compare statuettes to each others : are they solid or hollow? what is the wall thickness and the shape of the inner core? from how many pieces are they made? how are they joined? Can we see casting defaults? Have they been they repaired?

2.2 X-Rays production

To produce a radiography, the object is put between X-rays generator and a detector (silver halide film or digital detector). The X-ray beam goes through the object and expose the detector. The resulting image is in grey levels, showing variation of the X-ray absorption. Dark areas show low absorption of x-rays indicate little thickness or low density of the materials. Light areas show more material thickness or higher density (with high atomic number). For the x-rays of the statuettes, the C2RMF used the 400 KV generator ISOVOLT SIEFERT and the silver halide film MX 125 PB Carestream. The parameters used were : 350Kv, 4mA, 7 minutes, distance of 2 meters, a 3 mm copper filter.

2.3 Comparing the two Mercury statuettes

We focus here on two Mercury statuettes: Lysippean (inv. n° 1969 BR 12, h : 35 cm) and Indigeneous Mercury (inv. n° 1969 BR 13, h : 21,5 cm). Apart that they are hollow, their characteristics are very different (Figure 1). For Lysippean statue, the metal walls are thin and could only have been done by the indirect lost wax casting process. It has been cast in 6 separate pieces (head, arms, legs, torso), then joined by a very elaborated welding process. On the other hand, Indigenous Mercury is still in possession of its inner refractory core made of clay, whose shape is a very simple evocation of the statue. Here the direct lost-wax process was used, with first the core shaping, on which wax was directly carved. Proof of the inexperience of the sculptor, there is no frame or nails in the core, leading the core to move in the mould when the metal was poured. Those images are a key contribution the Bavay bronze study, bringing responses to several art conservation questions.

3. X-RAYS TOMOGRAPHY OF JUPITER STATUE

In some cases, spatial information is difficult to read on flat 2D radiographies, so complementary images are made with 3D tomography to refine our interpretations.

3.1 X tomography production

The same principle as x-rays radiography is applied, but (minimum) 720 images are made by rotating the object in front of the detector every half degrees. Next, reconstruction algorithms generate a 3D object issued from the X-Ray signals, including the internal and the external surfaces. Visual appearance of the volume is close to the real object, it shows the external surface of the statue. Virtual cutting can show any part of the object, allowing a detailed visualization of the inner parts. The C2RMF is using for tomography the 400 KV generator ISOVOLT SIEFERT and the FlashScan 35 detector from Thales (120 microns details, 2400x3200 pixels). The rotating table is from Newport. The acquisition software is DigiSens DigiAcq, the reconstruction software is DigiXCT, and the image treatment one is VG studio max.

3.2 Jupiter statue analysis

The Jupiter statue from the Bavay treasure showed with tomography the inner and external surfaces (Figure 2). In inner surfaces, metal infiltration caused by the welding of the arms can be detected. A secondary casting of a lead-tin alloy can be localised with its white dense response, its goal was to fill a gap in the left leg. The 3D tomography virtual object allows to see localisation of numerous porosity, the location of welding, infiltration of welding metal. Tomography also permits measurements of the metal wall thickness that are impossible otherwise (it is possible with tomography software that allows metrology tools on virtual object). All those indications which, associated with stylistic study and elementary analysis help to discover the mystery of the statuettes.

As all images, careful attention must be done on interpretation. Indeed, the tomographic representation is made with x-rays images. X-rays imaging renders materials depending on two parameters: thickness and density (atomic number) [10]. In traditional photography, you cannot register a very bright and a very dark area correctly on the same picture with a single light exposure. You have to choose exposition for one area (bright or dark) and the over part will be over or under exposed. In x-rays images you encounter the same phenomenon, it could be difficult to register very heterogeneous objects in density on the same x-ray image. Exposure could be correct for one range of density, leading other parts to be over or under exposed and low information to be recorded on those zones. In the back of Jupiter, we can see a hole in the inner surface in tomography. This hole could have been repaired with the same alloy but more thinner to fill in the surface. Or it could be full of another alloy we don't detect with the imaging parameters we used.

4. ADDING 3D SURFACE TO TOMOGRAPHY

Other analysis can be added to the tomographic model: the surface 3D acquired with a scanner add more precision on external surface representation: it was made for the Jupiter statue.

4.1 3D surface production

Surface scanners use structured light (laser, blue light...) to project on the object and calculate the distance to the sensor viewing the light back. With triangulation, it constructs a point cloud that represents the surface of the object, the number of points depends on the scanner resolution. It results in a virtual 3D surface representation of the object. We made the surface scan with the Minolta range 7, a laser scanner with 50 micrometer precision. We used Rangeviewer and Geomagic softwares to scan and assemble point cloud of the different angles of view.

4.2 On Jupiter statue

We obtained the 3D external shape of the Jupiter statue with very high precision. This image is useful to make a record of the state of the art at one moment, and also because bronze technicians detect repairs with virtual raking light on the surface. We then added 3D shape to tomography to obtain a virtual Jupiter statue with mixed data, the external surface was acquired with laser scanner and the internal structure of the object with X tomography (video 1). Mixed data enhance precision of the virtual object to study.

5. 3D REPRESENTATION OF XRF CHEMICAL ELEMENTS

Jupiter statue was also analyzed regarding its chemical composition. Elementary elements were detected with XRF analysis.

5.1 XRF map production

X-Ray Fluorescence –XRF analysis is a non-invasive method to detect chemical elements. X-rays produced by the device excite atoms to the analyzed point and when returning to balance, atoms emit x-rays with characteristic energy. We obtain at this point an energy dispersion spectra where we measure intensity and energy of x-rays. C2RMF uses x-ray generator Molybdène (BRUKER X1), with a SDD detector (Amptek X123 25-mm²) [11]. This point analysis is put on a moving device, allowing to produce a cartography of the chemical elements. PyMCA software is used to normalize the intensity points of a particular element and to transform them into a single channel image in black and white, redistributing intensity levels to 255 units scale for an 8 bits image. With three channels corresponding to 3 chemical element responses, we can construct an RGB image in Photoshop (Figure 3). We obtain a chemical image in false colors where the red represents the XRF response of the copper, the green is the tin (L line) and the blue is the silver (K line).

5.2 Adding XRF to 3D on Jupiter statue

The Jupiter statue is in bronze, with inlay of silver for eyes and copper for lips. It shows several places of corrosion (tin and copper oxides) and it has been cleaned over 70 years. The nose, face and may be hair have probably been rubbed, taking off partially or totally corrosion layers. The rendering of surface elements today do not lead to clearly understand what is belonging to original composition, corrosion or cleaning. Another difficulty is that the XRF maps results depends on the distance of the measure, as chemical elements have attenuation responses. Because the object is in 3D, we suggested to calculate the distance object-detector, thanks to 3D surface model. We mapped the chemical map to the 3D surface virtual object. 3D software Geomagic allows placing the chemical map on the 3D objects, with detection of the exact angle of measure. We placed a virtual plane corresponding to the detector x-y movements, and the software could

give use the distance to each point of the statue (Figure 4). By applying the attenuation table for each element, we can recalculate the amount of each elements. Unfortunately the resulting maps do not give us a more clear understanding of the state of the statue in terms of original/corrosion elements. This 3D correction for chemical maps is actually tested on other objects, focusing on geometrical bias and correct mapping.

6. CONCLUSION

Multimodal images made with non invasive devices allow us to understand objects safely and with more precision. With aggregation on the same object, it gives powerful tools to conservation sciences. Several research are actually conducted to construct meaningful and complete virtual representation of CH objects, mixing 3D, optical and chemical images, trying to resolve the bias of measures and digital representation [12, 13].

AUTHORS' CONTRIBUTIONS

EL performed X-Rays and tomography datas acquisitions, treatments, interpretations and the video, CH made the surface 3D data acquisition, treatments and mapping. BM interpreted the images and linked them to bronze technics and art history. CB supervised imaging team, made XRF correction with 3D and wrote the manuscript.

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REFERENCES

- [1] De Chavagnac L., Mille B., [Nouveaux regards sur le Trésor des bronzes de Bavay], Silvana Editoriale, 13/09/2019
- [2] Hess M. et al., « Application of multi-modal 2D and 3D imaging and analytical techniques to document and examine coins on the example of two Roman silver denarii », Heritage Science, December 2018, 6:5
- [3] IPERION-CH, “3D Imaging in Cultural Heritage conference”, Thursday 9th – Friday 10th November 2017, The British Museum
- [4] Re A. et al. “X-ray tomography of a soil block: a useful tool for the restoration of archaeological finds”, Heritage Science (2015)
- [5] N. Mélard et al. “Comparison of imaging techniques used in the microanalysis of Paleolithic mobiliary art”, Journal of Archaeological Science, Volume 10, December 2016, Pages 903-909
- [6] « Centre de Recherche et de Restauration des Musées de France website », www.c2rmf.fr, (03 May 2019)
- [7] Mohen J-P. Et al., [Mona Lisa: Inside the Painting], Harry N. Abrams, Inc., September 1, 2006
- [8] Borel T., "La radiographie des objets d'art", Thierry Borel, Techné n°2, 1995
- [9] Collectif, « CASTING, Framework that will facilitate advances in the understanding of bronze sculptures », 2016, <http://www.cast-ing.org/> , (03 May 2019). In particular, see the chapter “X-Rays analysis” by Elsa Lambert is under publication.
- [10] Collectif, [Radiography in modern industry], fourth edition, Eastman Kodak company, 1980
- [11] Calligaro T. and al., « Development of a versatile XRF scanner for the elemental imaging of paintworks », Applied Physics A 122(1), December 2016
- [12] Calligaro T. et al., “A new 3D positioner for the analytical mapping of non-flat objects under accelerator beams”, Nuclear Instruments and Methods in Physics Research, under publication
- [13] CHANGE EU ITN Marie Curie 2019-2023, <https://change-itn.eu/>, The main scientific objective of CHANGE is to develop a methodology to assess and monitor any change to which CH artifacts are faced with a multi scale and multi modal approach in both acquisition and processing. (03 May 2019)

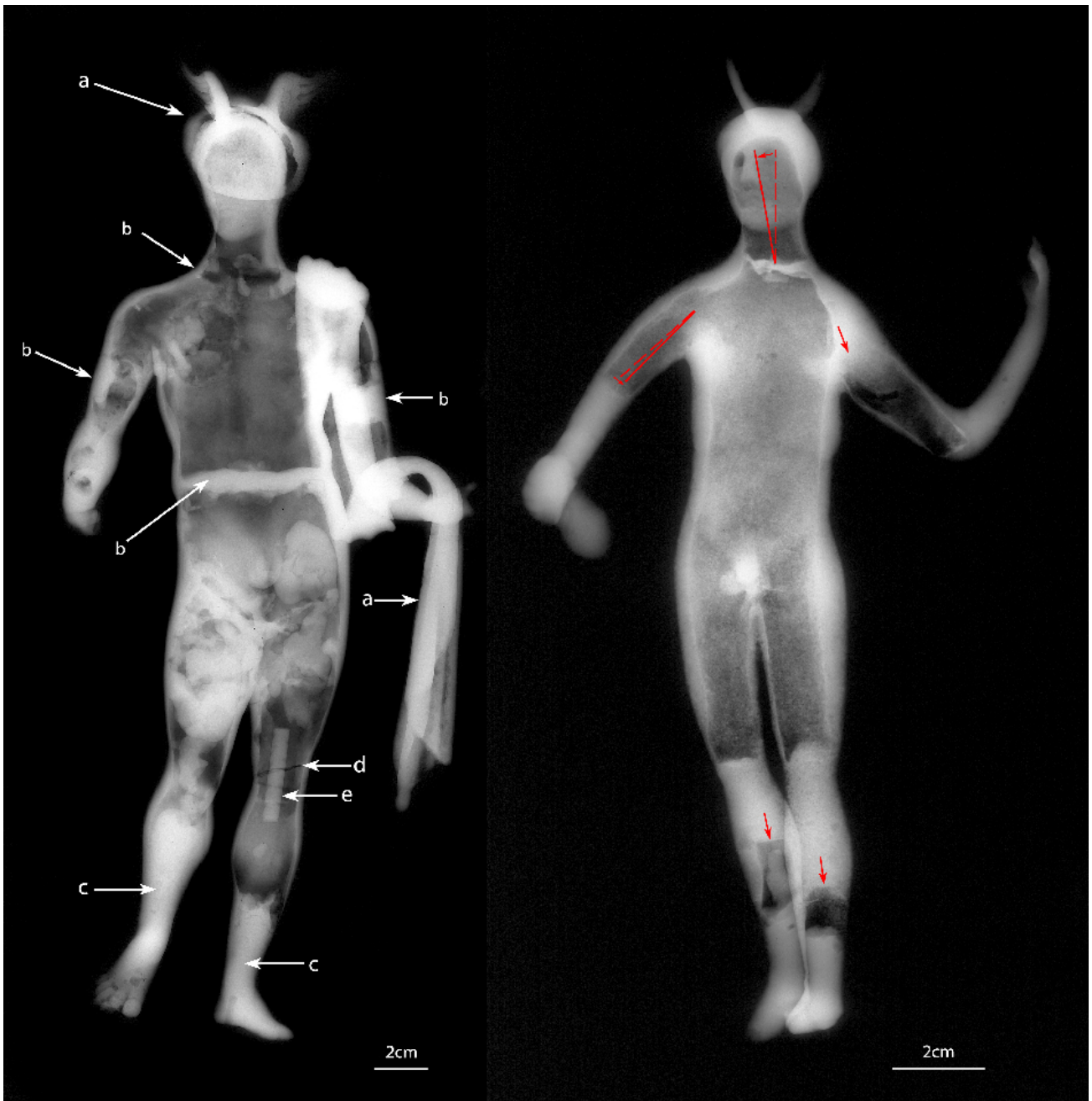


Figure 1. X-rays radiography of two statuettes from Bavay Treasure (image Elsa Lambert, C2RMF). On left, Lysippean Mercury with localization of a) added elements (pétase hat, chlamyde clothe), b) welding, c) full extremity, d) break, e) modern dowel. On the right, Indigenous Mercury : note the aberrant position of cores on bottom of legs (supposed to be on tibia) and in left arm, went down to elbow. The core is also cracked on the level of the neck and is off center in the right harm.



Figure 2. X Tomography of Jupiter statuette, with two virtual sectional plans. (images Elsa Lambert et Jérôme Rumolo , C2RMF). Those images show a) numerous porosity, b) location of welding, c) infiltration of welding metal d) thickness of wall, e) secondary cast of fettling (an alloy of lead and tin)



Video 1. On left : 3D surface acquired with laser scanner (image: Charlotte Hochart C2RMF). On right : x-ray imaging of same acquisition angle (image Elsa Lambert and Jérôme Rumolo C2RMF). The video shows the mix of the 3D surface with X tomography to construct a more comprehensive 3D representation of the object.. <http://dx.doi.org/11058-18>

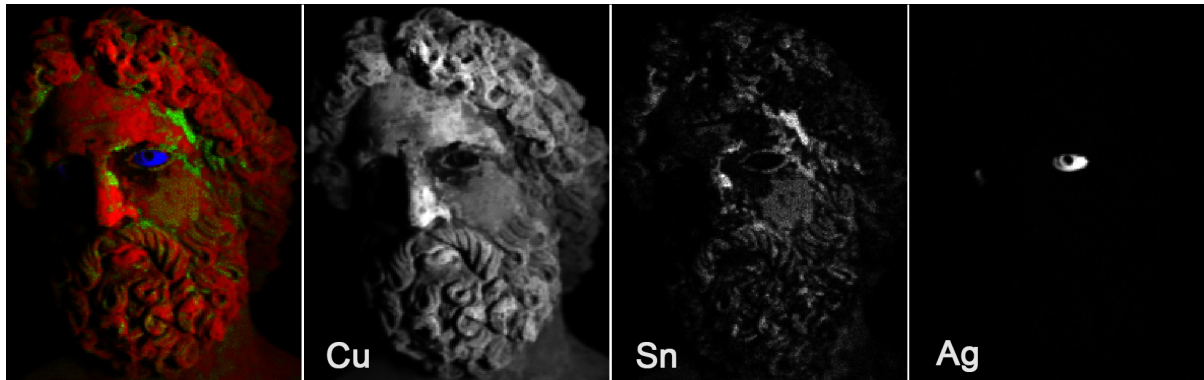


Figure 3. The 3 images on right are the XRF map of the Jupiter statue, showing the response of the elements Copper Cu, Tin Sn (L line) and Silver Ag (K line). The RGB image on left is made with three channels corresponding to each chemical image. The red represents the XRF response of copper, the green is tin and the blue is silver.

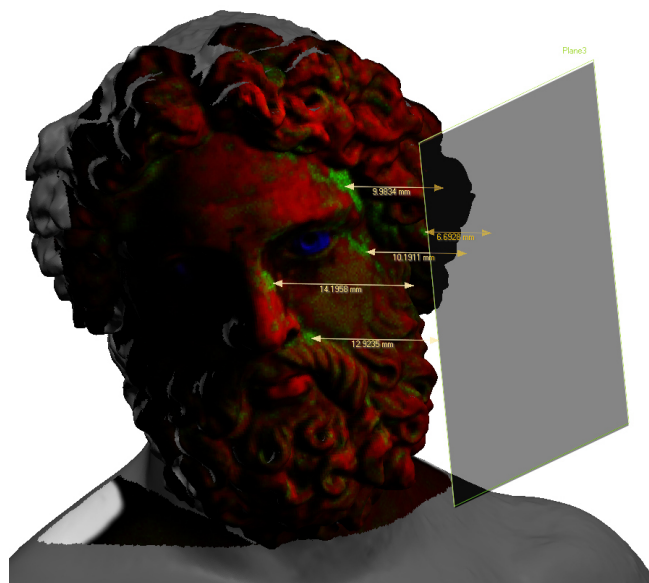


Figure 4. The XRF RGB image is mapped to the 3D surface virtual object. The grey plan represents the position of the XRF detector. 3D software can calculate the distance from any point of the statue to plan detector, making possible corrections of XRF elements response with their distance attenuation.