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COMPUTED TOMOGRAPHY AND HANDCRAFTING PROCESSES OF AN ANCIENT MUSICAL INSTRUMENT: THE *AULOS* FROM POSEIDONIA[1]

1. Introduction

Among non-invasive investigation methods applied to cultural heritage, the role of radiology is well known. For several years, the definition of diagnostic imaging has mostly been used in medicine in order to highlight the numberless series of available investigative methods in radiology (e.g. computed tomography, magnetic resonance imaging, ultrasound, etc.). Whilst this technological enhancement has improved the work of radiologists, these innovations are still not fully considered or exploited in some fields of research applied to art and cultural heritage, and especially to musical heritage (Pretto *et al.* 2020). In this field of research, only a few museums and institutes for the preservation and restoration of musical instruments have autonomous radiological sections (Swift *et al.* 2021). This could explain the gap between medical radiology and radiology applied to musical heritage, particularly regarding ancient instruments (along with the lack of presence of specialised figures in these institutions) (Bär *et al.* 2018).

Indeed, until recently, although its methods have great potential in the diagnostics and conservation of ancient musical instruments, radiology has been underused in this field of application. Thanks to digital imaging and computed tomography (CT), diagnostic imaging can give us significant results in the study of ancient instruments, providing scholars with valuable information that would be otherwise unavailable. Indeed, CT also enables the study of the instruments' measurements and morphology, quickly generating information and overcoming the limitations presented due to their fragility without jeopardising the integrity of specimens; this method can also measure the thickness of the internal structures (Fuchs *et al.* 2019). Moreover, the CT allows two and three-dimensional reconstructions on coronal, axial and sagittal planes, revealing details of the constructive characteristics of instruments as well as the state of their conservation, allowing for their digital storage and making possible a non-contact re-investigation at any time. CT also ensures the data is collected in a less error-prone form, so that the figures obtained

[1] This article is – in all its parts – the product of a joint effort of both authors. Only for academic purposes, we attribute here the textual part to Angela Bellia and the graphic part to Danilo Paolo Pavone.

from the object can be checked later. Optimally, this amounts to preparing a three-dimensional (3D) digital image: CT serves this purpose extremely well because it also exhibits internal structures of instruments, and allows for a useful evaluation of the instruments' working processes as well as the visualisation of invisible fracture lines and lesions in their structures, showing possible modifications, damage and repairs.

2. Background

Considering the changing framework in ancient instruments studies from one that treats them as images to another that considers them exclusively for their organological characteristics, the aim of our study is to analyse how the application of computational imaging to ancient instruments can provide a new means of understanding, interpreting and disseminating results, and, most importantly, to enable us to study these artefacts as multidimensional entities and three-dimensional material objects that have undergone transformations and forms of handling (Zoran 2011).

That is particularly important given that musical instruments, until recently, have been treated as images, as artistic depictions and objects whose meanings and functionality needs to be surveyed through iconological and organological methods. As such, they have been rendered and represented as two-dimensional, finished and static entities. Their formal qualities, e.g. size, features and proportions, took priority over, say, material processes, technologies of making, postproduction modification, circulation, deposition and discard. Yet, as many studies have shown, musical instruments were continuously modified. Sometimes, they were intentionally fragmented, reshaped and re-introduced into circulation. Moreover, these artefacts were special three-dimensional objects meant to be engaged with in a multi-sensory way: they were handled, interfered with, interacted with by human bodies and with other entities, such as architectural features and spaces as well as other objects and materials.

Despite the image-based discourse on musical instruments being challenged by several studies in the last decade, it has largely shaped the way they are depicted in archaeological and music archaeological publications: it is this corpus of images that has in turn shaped further thinking and discussion on ancient instruments, especially since it has always been the case that very few people have been able to handle the original, three-dimensional, physical objects. Using 3D digital models combined with cutting-edge digital methods, some of the subjective observations typically made by scholars on ancient instruments on the basis of traditional measurements can be substituted by measurable parameters, which also opens up new perspectives for the study of the production processes of instruments. Taking into consideration the *aulos* found at Poseidonia in southern Italy, which dates from the end of the 6th to the beginning of the 5th c. BCE, this article focuses on the process of the creation of ancient instruments through 3D scanning and printing technology, which can be used not only as a methodological case study, but also as a research tool.

3. The *aulos* from Poseidonia

The *aulos* from Poseidonia was found in 1969 in tomb 21 at the necropolis of Tempa del Prete, a few kilometres South of the town outside the ancient city walls, where musical instruments were also discovered in two other graves and in the best-known 'Tomb of the Diver' (Bellia 2016). In the same tomb 21, most likely belonging to an adult man on the basis of the grave goods, a small turtle shell was also found, which most likely was the sound-box of a *barbitos*. The *aulos*, a pair of pipes – with vibrating reeds in their mouthpieces – held out in front of the player, was the omnipresent musical instrument in Greek cults, festivals and funerary rituals (Fig. 1). The different types of *auloi* were classified on the basis of their range, pitch, and origin as well as their material and occasion of musical performance. As in the so-called 'early type' *auloi* – which are defined by the absence of mechanisms for sound production – the wind instrument found in tomb 21 (held today at the National Archaeological Museum of Poseidonia-Paestum, modern Capaccio, Salerno, inv. 23068), was played by covering the holes in the upper part of the two tubes with fingers and by covering the thumbholes placed at the back of the pipes, which form a pair (Fig. 2a-b) (Bellia 2012, 98-99; Psaroudakês 2014).

A peculiarity of the tubes belonging to the instrument from Poseidonia is the presence of two similar small holes (Hagel 2010-2011) (Fig. 3a-b), which would have had expressive purposes given that a musician could use these little holes for modifying resonance and, as a side-effect, the timbre of the instrument or the "colour" of its sound (Barker 2002, 67-70). Moreover, eight sections form the tubes; each section suffers from damage, but on the whole the instrument is well preserved. Understandably, the parts receiving the reeds and the reeds are missing: being made from cane, they are forever lost to us.

According to written sources, deer bones were used to form *auloi* (Pollux, IV, 71): in particular, the tibia of a deer was the most common material used for making *auloi* in ancient times, at least until the Hellenistic age (West 1992, 81-82). Given the texture of material, particularly the adult deer bone could be handled easily, and it required tools and processing techniques similar to those used for working ivory and wood. Moreover, deer bone is usually white or ivory: it could be smoothed, acquiring a lustre tending towards bright white or a golden colour. Being similar to the rare and precious ivory, the deer bone

Fig. 1 – Regional Archaeological Museum of Agrigento. Inv. AG. 22797. *Aulos* player. Particular of the Attic red-figured bell krater from the necropolis of Contrada Pezzino in Akragas. 5th c. BCE.

Fig. 2a-b – National Archaeological Museum of Poseidonia-Paestum, inv. 23068. The *aulos* found in the tomb 21 of Tempa del Prete. 6th -5th c. BCE. From Psaroudakês 2014, 129, figs. 13-14.

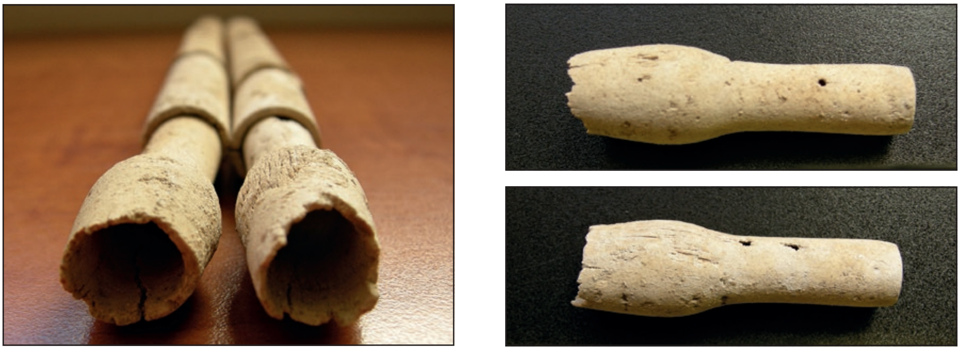

Fig. 3a-c – Small holes in the mouthpieces and outhpieces end of the tubes. From Psaroudakês 2014, 127, figs. 4-5a-b.

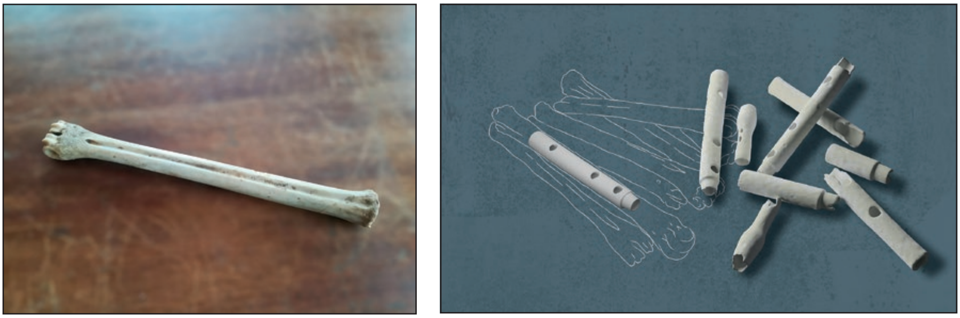

Fig. 4a-b – A deer tibia bone and a hypothesis of how the craftsman could transformed deer bones into musical instruments sections. Photo: Marco Sciascia. Illustrator: Danilo Paolo Pavone.

was not only aesthetically pleasant, but it was also easily available and very low cost, given that it was a form of food waste. For this reason, bone-processing shops were often placed near slaughterhouses or sanctuaries, where deer sacrifices and banquets of meat were held (Angliker 2016).

Some ancient texts focus on the materials used for the handling of the *auloi* in the Greek-Roman ages, highlighting how there were several of them and a variety of uses on the basis of sonic demands and needs, as well as of scales and of the "regionality" of Greek musical practice. Athenaeus (IV, 182d, *FGrHist* 275 F 82) and Pollux (IV, 75-76) mention how the use of deer bone for making *auloi* was a Theban innovation, and Plutarch (*Moralia*, 150e) recalls how Greek (and Roman) craftsmen used medium to large sized animal bones for creating wind instruments. For its shape, the tibia bone is one of the most suitable to be worked not only because of its long bone flaring towards the two epiphyses, but also for its cylindrical inner part, or diaphysis, especially of the sheep, goat and deer bones (Berlinzani 2014). On the basis of their porosity and/or compactness, the tibia bones had a great influence on the instruments' sounds both due to their specific weight and for the allowed speed of sound propagation (Fig. 4a-b).

It is worth noting that bone wind instruments were generally composed of tubes joined together (given the presence of spigots and sockets) so as to be able to create mainly cylindrical tubes, as the preserved instruments found in tombs and sacred areas in Greece and Magna Graecia display. Moreover, as in the case of the *aulos* from Poseidonia, the pipes' workmanship seems to reveal the use of an arched or rope drill used by craftsmen to pierce the surfaces of the tubes. Thanks to 3D CT, we are able to explore the production process of this instrument and how its craftsman transformed deer bones into a precious musical instrument which has been passed down to us.

4. Computational methods for processing the 3D models of the *aulos* from Poseidonia

CT could be used as the primary tool in identifying and cataloguing ancient musical instruments. There is no need to invest huge sums of money in purchasing and developing expensive testing equipment. Medical CT equipment is almost universally available. There is no need to ship instruments to distant laboratories, an expensive and risky business at best. Musical instruments can be also scanned locally or *in situ*, avoiding risky transportation (Albertin *et al.* 2019). The process takes little time, is non-invasive and non-destructive, and produces digital data. This data is unique and can serve as a fool proof "fingerprint" of the instrument. Moreover, this data can also be used not only as a tool in the restoration and conservation of damaged instruments, but also to consider their affordances – the properties of instruments that enabled tubes to be handled and their capacity to produce sound of a particular volume and pitch – and to create replicas of these artefacts. This method could also provide new insights on how craftsmen handled the bones on the basis of their shape and inner structure, as well as on the development of instruments most likely linked to cultural, social and musical changes, especially in the theatrical context.

Information can be retrieved thanks to 2D cross-section images or 3D full-volume images, which allow for the inspection and the exploration of the inner part of the instrument; moreover, by processing tomographic data, a 3D model of the sample can be obtained for virtual reality applications or digital archives storage.

It is worth noting that the use of medical CT scanners gives good results only in the case of analysis of samples with a size and density similar to those of the human body, as in the case of the deer bone. In order to fulfil all these

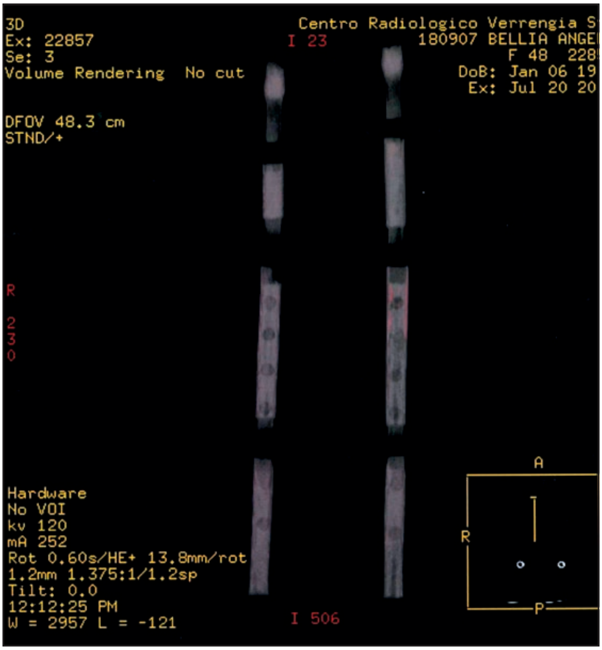

Fig. 5 – CT scan of the bone *aulos* from Poseidonia realised at the Verrengia Radiological Centre in Salerno.

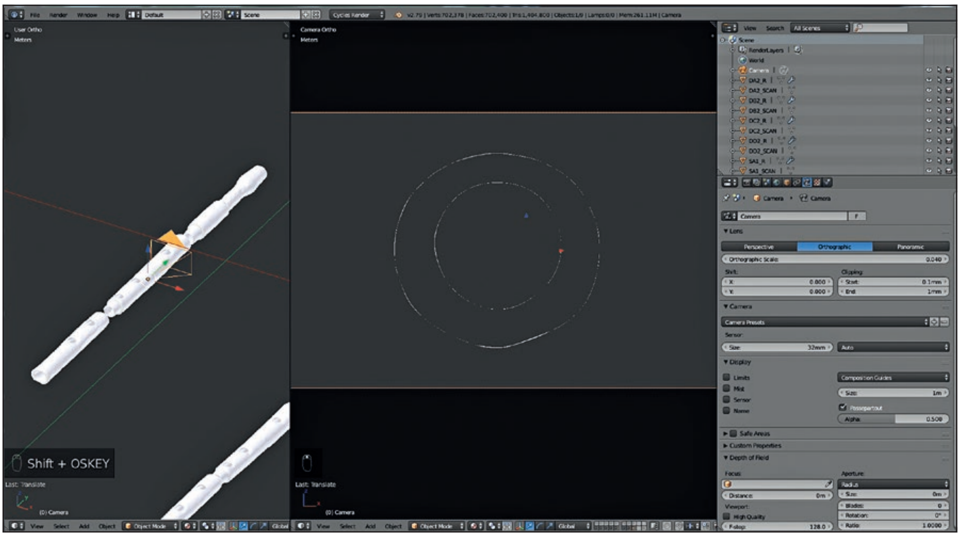

Fig. 6 – Details of the internal structure of the *aulos* from Poseidonia.

needs, after acquiring permission to use the instrument and the pick up of the instrument from the National Archaeological Museum of Poseidonia-Paestum, the CT scan of the bone *aulos* from Poseidonia (Fig. 5) was realised at the Verrengia Radiological Centre in Salerno, under the supervision of our team and of the museum team. Given that for ancient musical instruments, the inner structure contributes significantly to the colouration and amplification of their sound, it was requested that the medical staff – which was formed of radiographers and radiology technologists – focus their attentions on the scanning phase of the inner structure of the musical instrument in order to provide as much visibility as possible (Fig. 6). Moreover, given that inner structure is either hidden to the eye or inaccessible from the outside by conventional methods, we aimed to obtain information about constructional details that pointed to specific construction methods of certain instrument makers, as well as accurate measurements of the internal structure of the *aulos*. Up until that moment it was difficult (if not impossible) to access the internal sections, given that scholars who have previously studied this instrument (Bakogiannis *et al.* 2020, 53189-53192) used only traditional methods to avoid the high risk of damaging the object, providing us with hypothetical and questionable reconstructions of acoustics on the basis of available measurements.

In order to scan the wind instrument, the staff at the Verrengia Radiological Centre used a CT scanner equipped with a rotating X-ray tube. The multiple X-ray measurements of the *aulos* taken from different angles were then processed on a computer using reconstruction algorithms to produce tomographic (cross-sectional) images (virtual “slices”) of the instrument sections. The files (pixel resolution: 0.625mm) were saved in DICOM (Digital Imaging and Communications in Medicine) format, a standard method to transfer images and associated information between different vendor devices, which produces a variety of digital image formats, enabling the integration of imaging devices as well as the exchange and transmission of images to multiple users. Using the Osiris software, the data generated was processed in order to obtain a three-dimensional mesh. The model was exported in STL (Standard Triangulation Language) format.

In the alignment phase, several scans from different views were mosaicked to obtain a model that could be studied in a virtual space, also producing metric measurements. Within this framework, information from the undamaged parts of the objects was utilised in combination with literary and iconographic sources in an attempt to re-create the appearance of the complete instrument.

4.1 *From the three-dimensional model to the two-dimensional drawing*

The post-processing phase focused on the reorganization of the meshes in order to obtain a correct topology of the 3D models by the separation and cleaning of the parts and a subsequent retopology of the surfaces of the models. This method allowed us to obtain a high-resolution model. Moreover, we obtained 3D renderings images of this instrument. The tools we used d are divided into those involving the use of computational methods for processing the 3D models, and those involving the development of interactive tools aimed at engaging users in the exploration of instruments.

2D graphic reference images have been imported into an orthographic camera view as image planes: from the three-dimensional model, imported and composed in the Blender 3D rendering software virtual photo set, we considered each element in the following order: front view, front view section, side view, side view section. They were subsequently composed in a single layout, allowing us to obtain an overall view of the inner thicknesses of the two pipes and of the holes of the instrument. The rendered images (scaled 1:1) have been displayed in two graphic tables (external view/section view) in order to obtain an overall and scaled view of the digitised object.

Having established the 2D viewing space in a graphic table form, the instrument was subjected to an interpretative analysis of its elements. Despite the *aulos* being well preserved, there were some gaps or missing parts as well as some structural deformations of the deer bones, which interfered with the reconstructive prototyping of the instrument. In the graphic tables created, the features of the object, such as the natural curvature of the bone tubes (DC2), were considered, taking into account their uniqueness against the prototyping of a "generic" access model (Fig. 7a-i).

4.2 *Web-based viewer for shared access to the musical instrument*

The *aulos* sections have been also implemented thanks to the 3DHOP viewer (3D Heritage Online Presenter by Visual Computing Laboratory - ISTI - CNR). This open-source framework for the creation of interactive Web presentations of high-resolution 3D models, oriented to the Cultural Heritage field, allows dynamic access to the 3D model, which is usable and measurable on a computer and/or tablet via a web browser, such as Firefox, Safari or Chrome. Moreover, the 3DHOP viewer allows users to virtually interact with the instrument in the rotation movement, activating section planes in the X/Y/Z-axes and in the measurements of the instrument's surfaces (Fig. 8a-b).

4.3 *From the reconstructive prototype to the access model*

The inner and external measurements extracted from the digitized model were essential for the creation of the reconstructive prototype. These measurements were also essential for the process of discretization and simplification of the sections of the *aulos*. Therefore, a discretized reconstruction of the actual instrument was obtained, keeping the main features of the object and modifying some deformations of single elements.

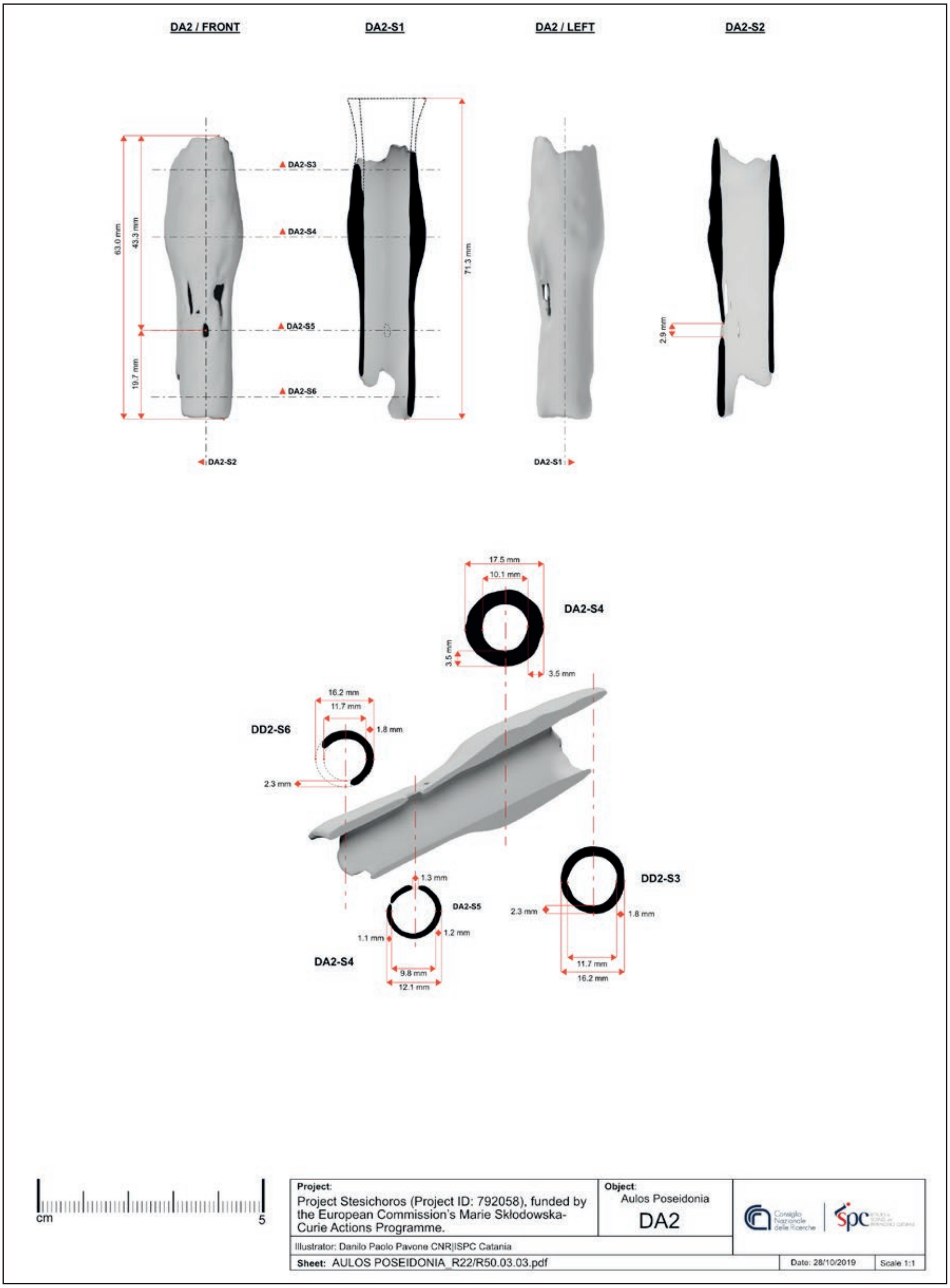

Fig. 7a – Graphic tables of the two tubes of the *aulos* from Poseidonia. Illustrator: Danilo Paolo Pavone.

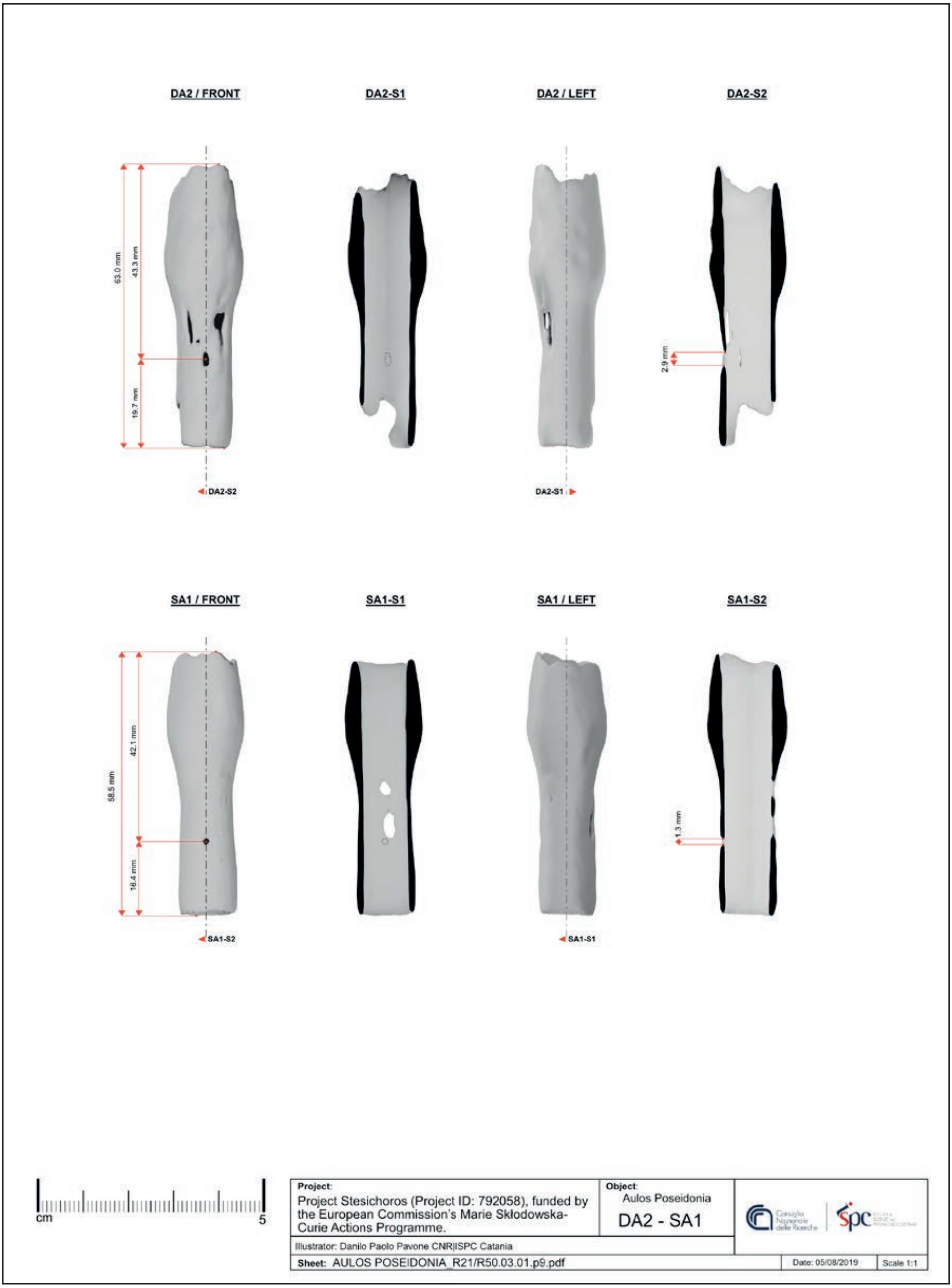

Fig. 7b – Graphic tables of the two tubes of the *aulos* from Poseidonia. Illustrator: Danilo Paolo Pavone.

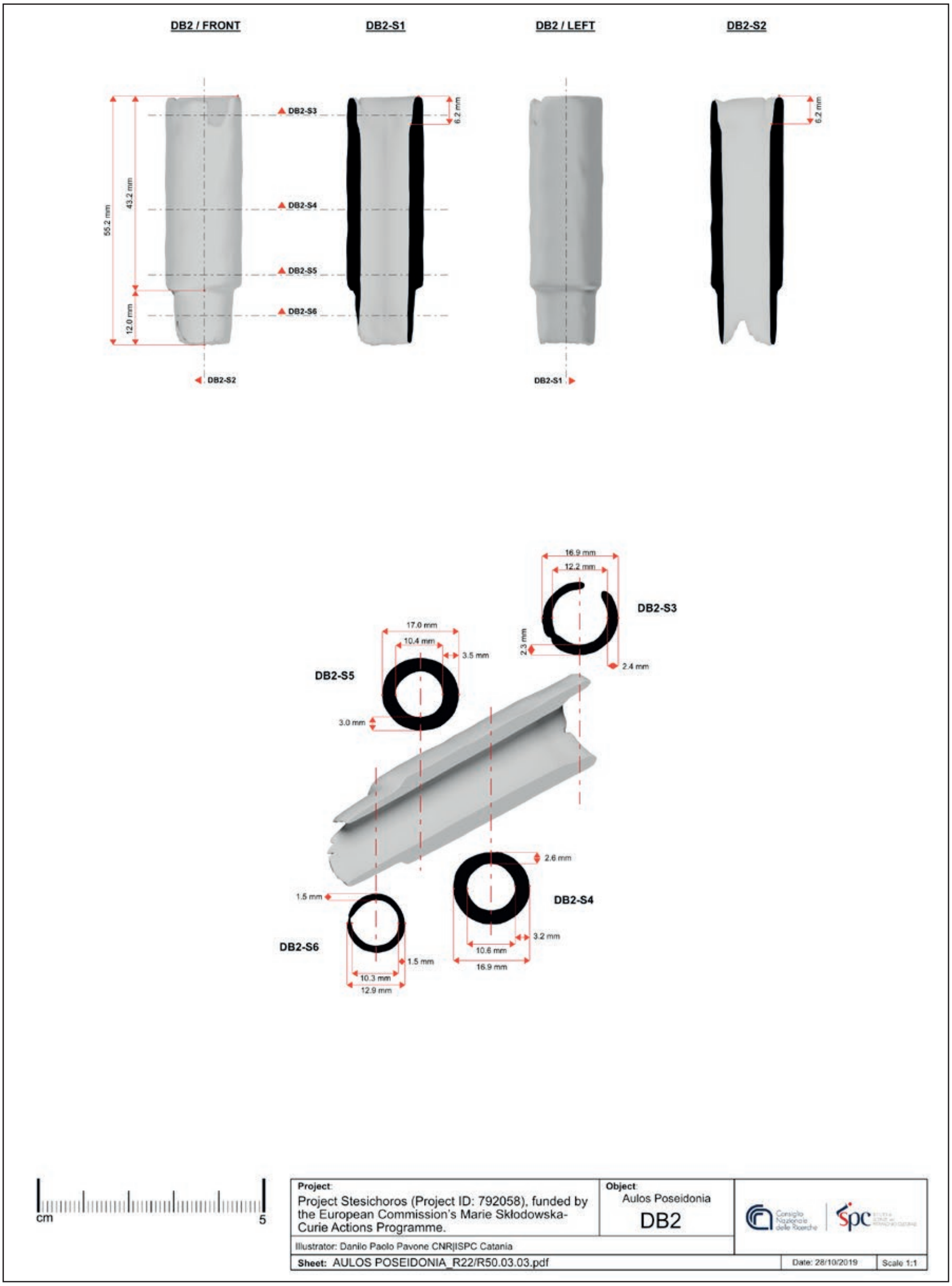

Fig. 7c – Graphic tables of the two tubes of the *aulos* from Poseidonia. Illustrator: Danilo Paolo Pavone.

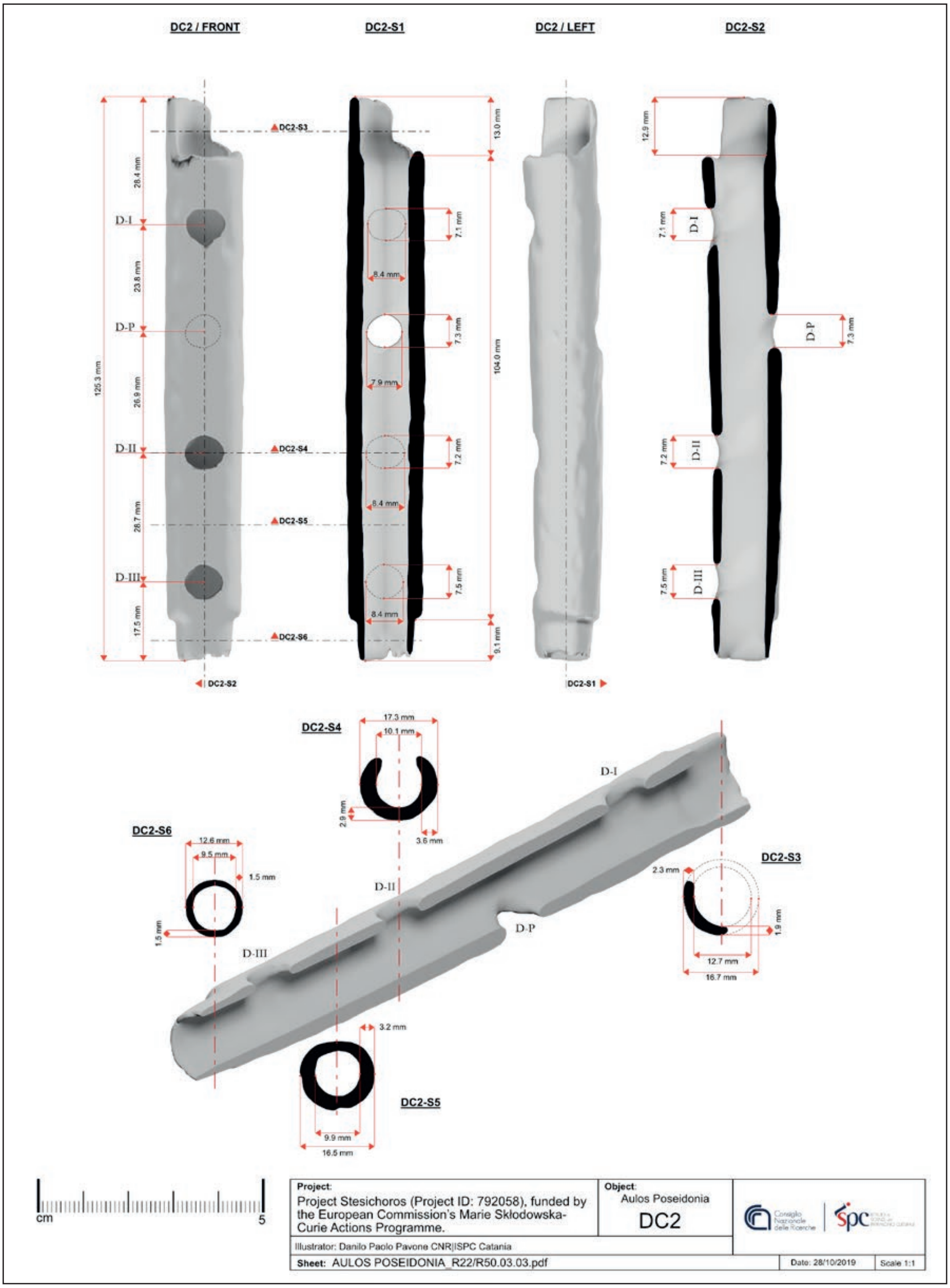

Fig. 7d – Graphic tables of the two tubes of the *aulos* from Poseidonia. Illustrator: Danilo Paolo Pavone.

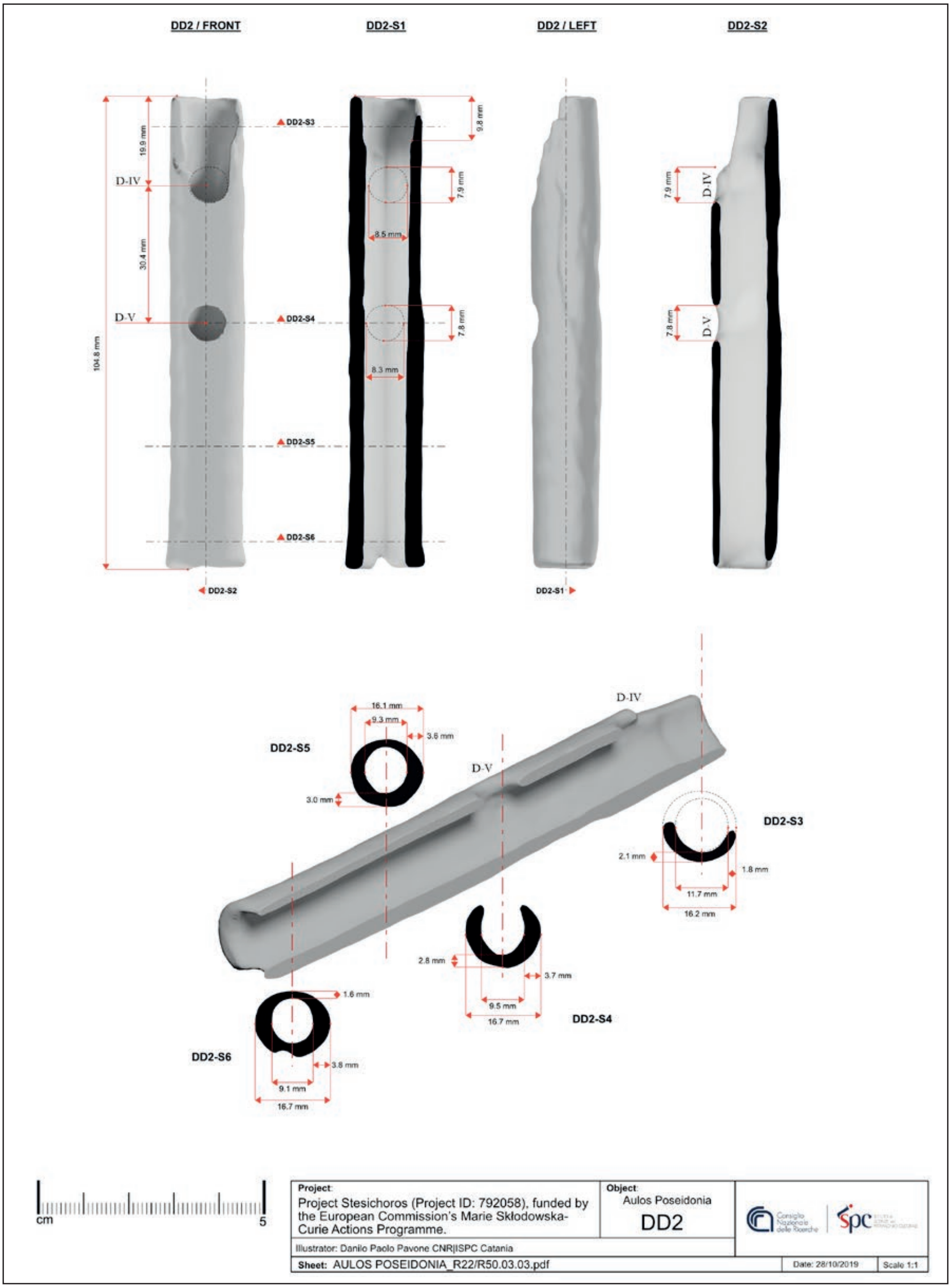

Fig. 7e – Graphic tables of the two tubes of the *aulos* from Poseidonia. Illustrator: Danilo Paolo Pavone.

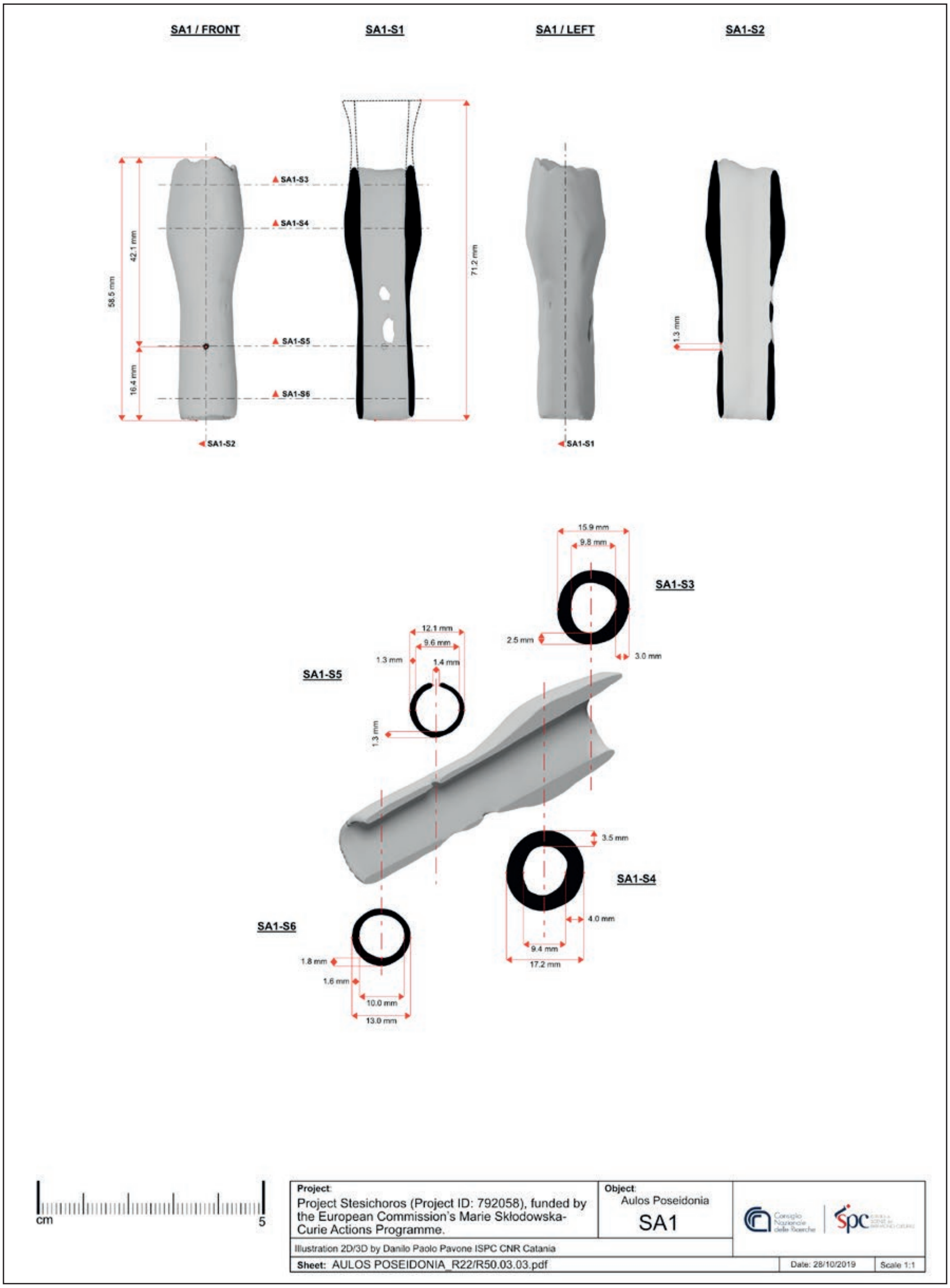

Fig. 7f – Graphic tables of the two tubes of the *aulos* from Poseidonia. Illustrator: Danilo Paolo Pavone.

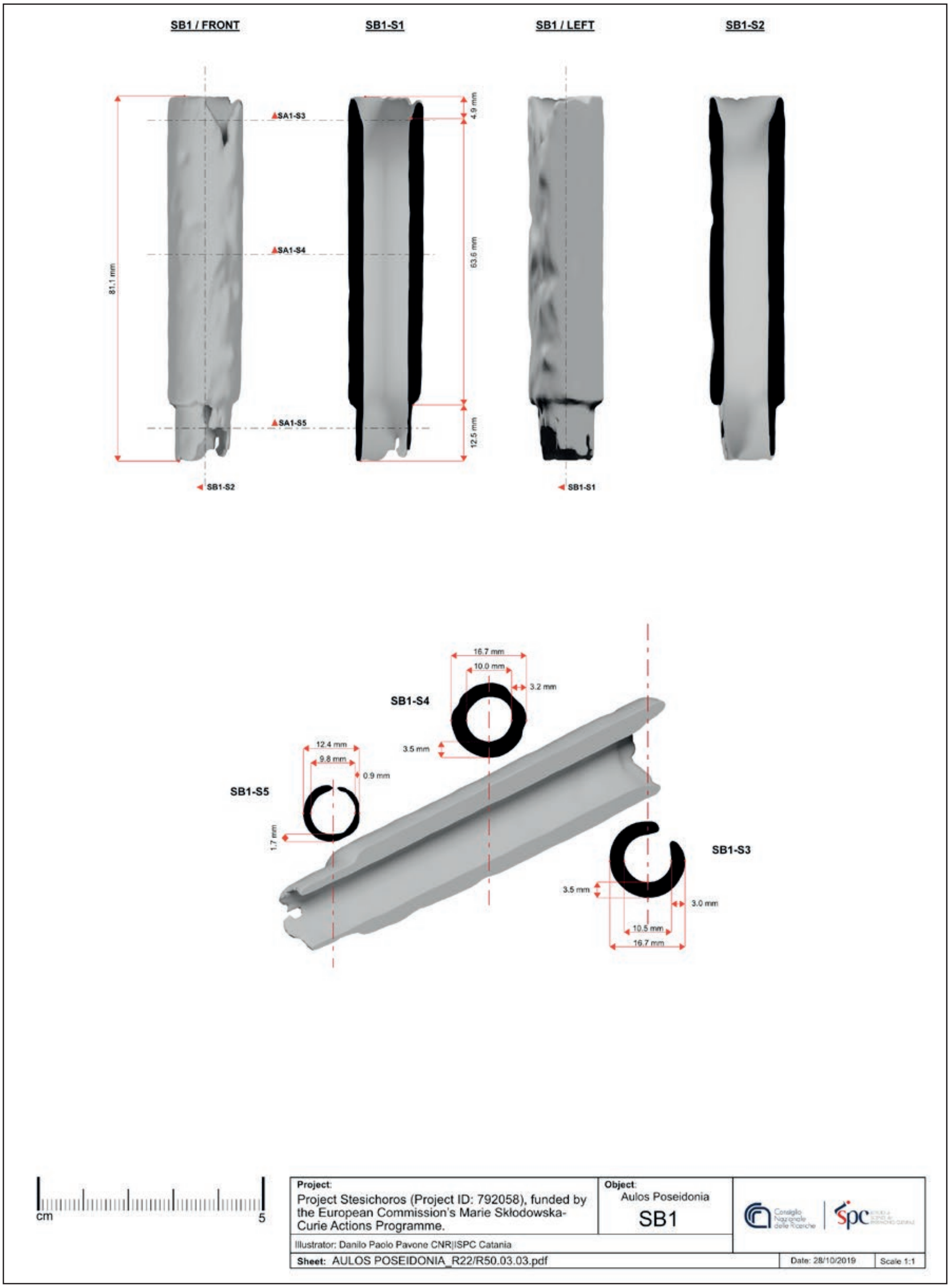

Fig. 7g – Graphic tables of the two tubes of the *aulos* from Poseidonia. Illustrator: Danilo Paolo Pavone.

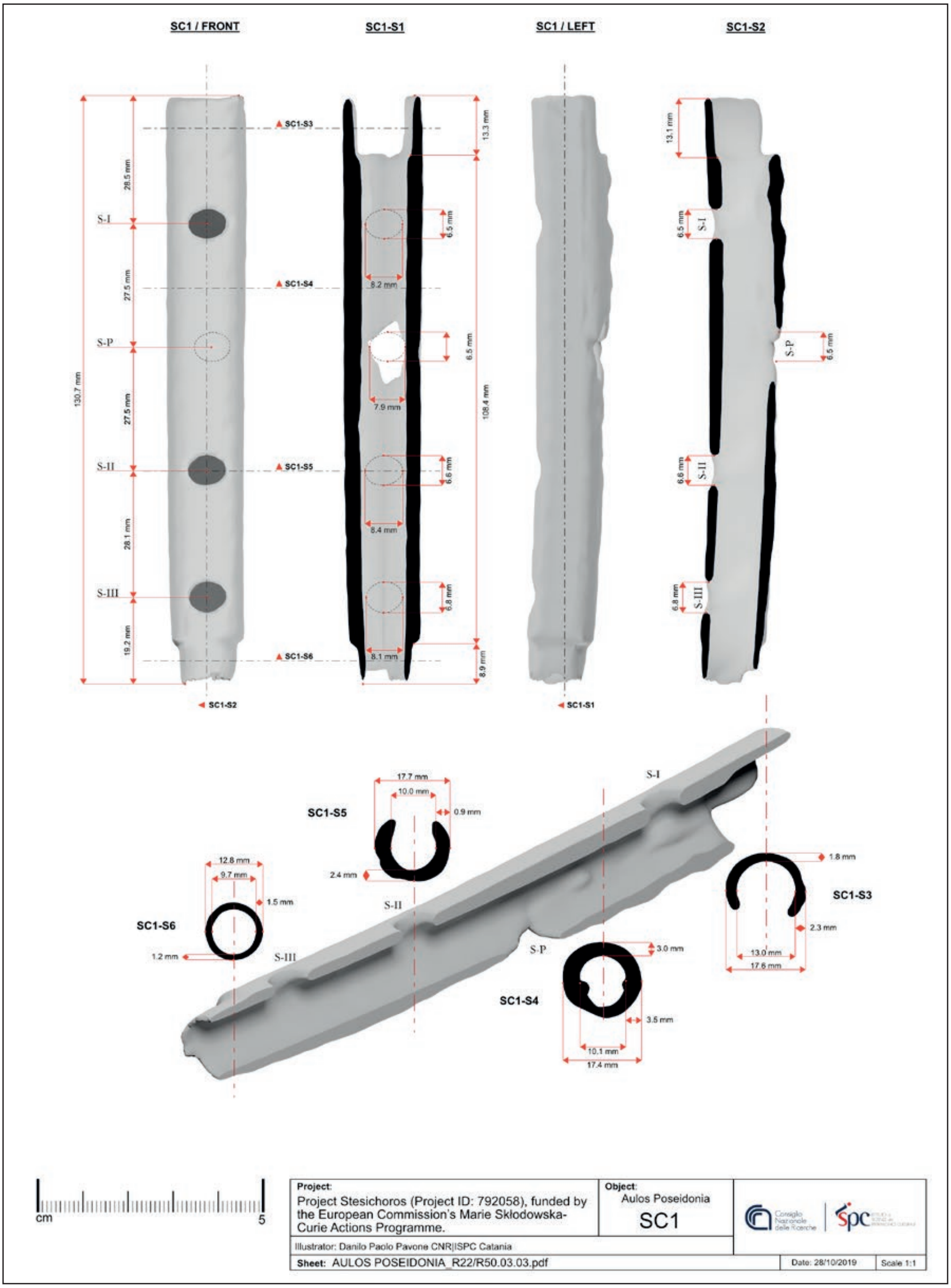

Fig. 7h – Graphic tables of the two tubes of the *aulos* from Poseidonia. Illustrator: Danilo Paolo Pavone.

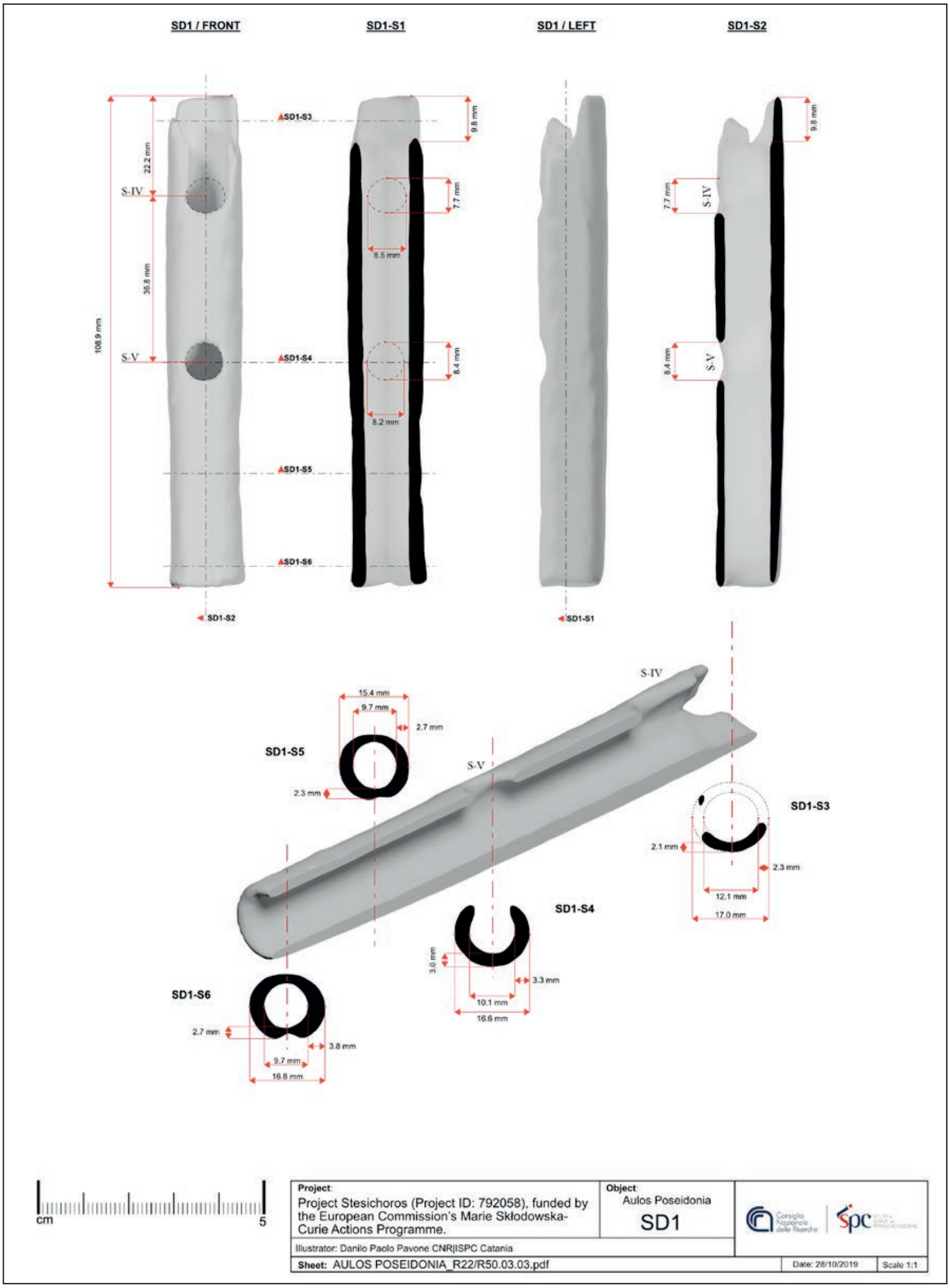

Fig. 7i – Graphic tables of the two tubes of the *aulos* from Poseidonia. Illustrator: Danilo Paolo Pavone.

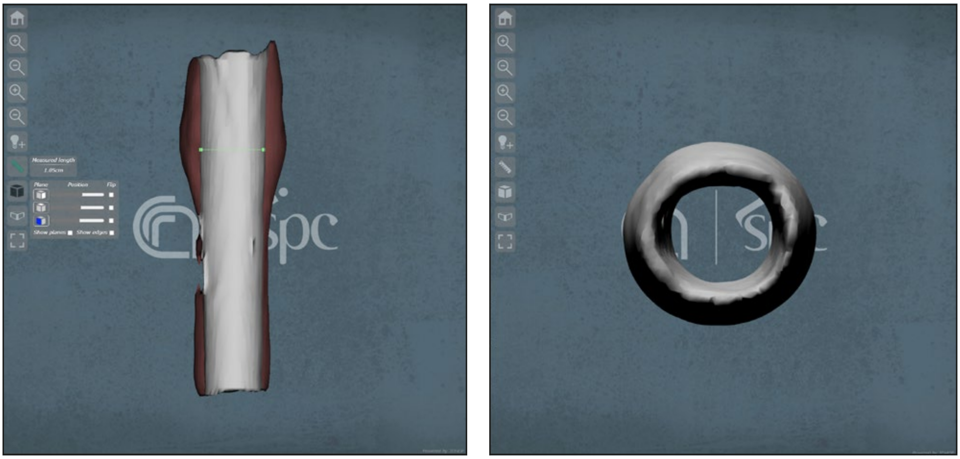

Fig. 8a-b – The 3DHOP viewer allows users to virtually interact with the instrument in the rotation movement, activating section planes in the X/Y/Z-axes and in the measurements of the instrument's surfaces. Illustrator: Danilo Paolo Pavone.

After that, the completed model was considered finished. The digital model was translated into original and restored copies, and two printed copies of the original and of the restored instrument were created in polymer material (Fig. 9a-c). Moreover, on the basis of measurements of the 3D model, an instrument maker specialised in the reconstructions of ancient musical instruments (Marco Sciascia), reconstructed the *aulos* from Poseidonia. The measurements of the 3D model of this instrument were compared with other similar instruments, especially the "early type" *auloi* dated to the 6^{th}-5^{th} c. BCE found in the *Persephoneion* in Locri (Bellia 2018, 91-92) under Temple R (Bellia 2019) at the sanctuary of *Malophoros* in Selinunte (Bellia 2017): these fragmented instruments have been subjected to CT scanning and previous research. These surveys provided us new insights within a larger music-historical picture of the development of ancient instruments, including the evolution of wind instruments' shape and the related craftsmanship.

5. Discovering the handcrafting processes of the musical instrument from Poseidonia

Whilst the interdependence between musical practice, composers, performers, teachers and instrument makers in antiquity has been understudied, these various activities were part of a complex network of interaction, as written sources remind us and archaeological specimens of musical instruments suggest, which highlight how the development and the evolution of

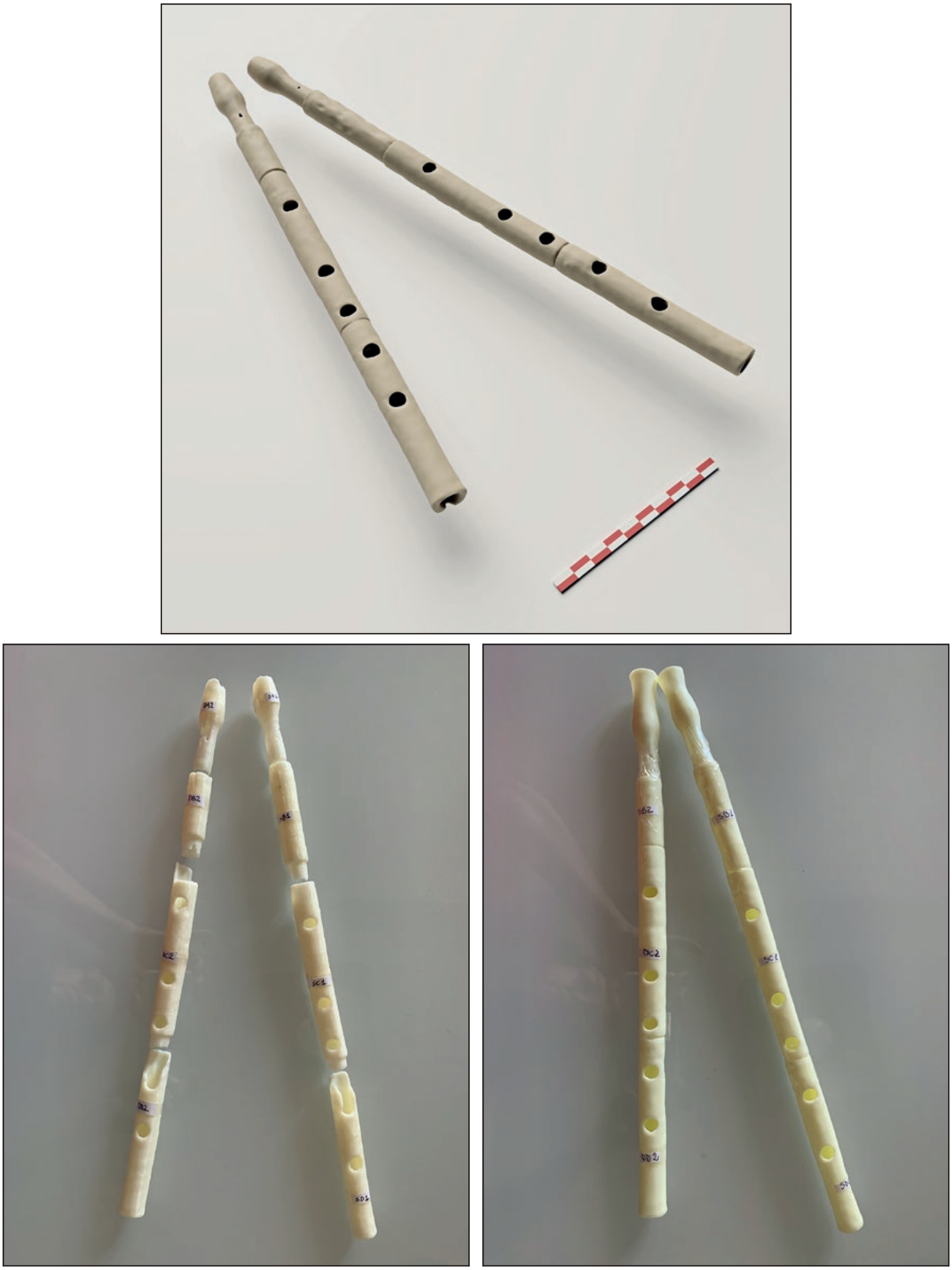

Fig. 9a-c – Discretized reconstruction of the actual instrument and printed copies of the original and of the restored instrument created in polymer material. Illustrator: Danilo Paolo Pavone.

these special objects was in a strong relationship with cultural, social and performative contexts. The methods for processing 3D models of musical instruments provide us with useful information on the techniques used by craftsmen engaged in designing and handling instruments (Safa *et al.* 2016). In some cases, it is not only possible to discover the procedures useful to the craftsmen for shaping a musical instrument from raw bones, but also to investigate the technique and type of tools used during the working phases: this is useful in reconstructing the chain of the technical progress of instruments. Concerning the *aulos* from Poseidonia, the study seems reveal that for the construction of this instrument, the craftsman proceeded through at least three main phases of workmanship: the preparation of the bone, the shaping of the bones and the finishing of the sections of the instrument.

5.1 *Preparation of the deer bone*

As regards to the tools used by craftsmen, on the basis of the handling traces left on the bones visible on the 3D scans, they could be bow or rope drills. Given that the spigots and sockets were very well defined and processed – and for this reason very fragile – it is most likely that the first phase of the processing consisted of the preparation of the bone for creating the sections of the instrument's pipes, which could be refined both internally and externally through the next step. As in Fig. 10a-b, the ends of some sections of the *aulos* are shaped with straight grooves: a metal blade for sawing could have been used by artisans for cutting these sections perpendicularly to the bone. Using the metal blade, therefore, a cylindrical support in the form of a tube

Fig. 10a-b – Section of the *aulos* from Poseidonia shaped with straight groove and internal parts of the section. Illustrator: Danilo Paolo Pavone.

could have been obtained from along the bone by removing the two porous ends. Furthermore, the metal saw could also have been effectively used to cut the bone into smaller pieces (Ravani, Thun Hohenstein 2010) to obtain a *holmos* and the other shorter sections.

It is worth noting that the metal saw was used by artisans who worked hard materials of animal origin since the Metal Age, however, we are not able to establish when it was used in the crafting of bone musical instruments. In workshops dated to the Archaic and Classical Ages, where processing waste has been found, this technique is documented by the presence of sawn off and discarded proximal and distal epiphyses, and diaphyses prepared for subsequent processing (De Grossi Mazzorin, Epifani 2012). Traces of this type of processing can be found on some fragments of wind instruments found in workshops in Sicily (Bellia 2012, 96-97) and Delos (Angliker 2016, 30).

5.2 *Making and shaping pipes*

To shape the sections of the deer bone instrument, tools almost identical to those still in use today by modern craftsmen working with bone or ivory were used. The chisel, as with the preparation of the support, could be useful for shaping operations because it allowed the instrument to be put into a precise shape through a series of successive notches, deepening recesses or eliminating the discontinuous surface layer of the material whilst keeping the original shape of the bone.

The final shape of the instrument sections could also have been modelled by abrasion, that is, by rubbing the object on an abrasive surface, with a circular “to and fro” movement, most likely with a metal file. Abrasion should not be confused with sanding (or polishing) since, if the first is done in the phase of shaping the object, removing a large amount of material, the second is carried out as a final finishing operation and does not transform the object’s form (De Grossi Mazzorin, Epifani 2012). Given that the flat surface allowed the *aulos* player to gain a better grip on the tube, by facilitating their alternation on the holes, the abrasion technique seems to have been used by the craftsman to obtain the flatter surfaces on the upper part of the tubes sections of the.

Given the accuracy of the crafting handling of the inner and external sections of the musical instrument, it cannot be excluded that, especially for the longer sections, the craftsman used a lathe to work on the sections of the bone, making it rotate by means of a belt or a strap wrapped around the object. It is worth noting that the deer bones could have been subjected to a softening technique. As in the case of this procedure applied to horn, mentioned by written sources, softening was practiced in order to modify the shape of the bones (or parts of musical instruments made in bone), which were then moulded to the desired shape (Barker 2002, 77-81). To achieve this, bones were immersed in water. This preliminary operation made bones easier to work, without causing irreversible alterations in the composition of the bone fabric. Alternatively, it was possible to boil the bones briefly, for about fifteen minutes, so as not to alter the quality of the bone tissue itself. These procedures could be useful for working the holes of the wind instrument, which required great precision by the craftsman, as the 3D images highlight.

One of the interventions on the *aulos* sections in the shaping phase could be the perforation of the internal part: this was a delicate operation that was also essential for drilling the holes in the pipe sections. The basic principle was to drill the inside of the bone so it could be emptied in several places. Taking into account that, as it is evident in the 3D images, the internal walls of the instrument have vertical streaks, it is very likely that the craftsman pierced the bone through a rotary movement of an arched bow or of a rope drill consisting of a cylindrical stick with a sharp tip, making rotate it on the inside the bone by rubbing between the palms of the hands or by turning the spindle on the workpiece. As it is possible to observe on the 3D model, working traces of a tip correspond to the holes in the internal parts of the sections (Fig. 10b).

5.3 *Refining and polishing the instrument*

Through the final polishing of the tubes, the craftsman may have eliminated all traces of processing left on the surface of the instrument sections. This may have been done with an abrasive material. According to written sources (Pliny, *Naturalis Historia*, IX, 40), the bone objects were smoothed with the rough skin of a shark (shagreen) or of a ray fish. Alternatively, other materials of an organic nature could have been used, such as bone ash, coal dust and skins covered with sand. It cannot be excluded that this procedure was also used by the craftsman to ensure the surface of the bones used to make the Poseidonia *aulos* were perfectly smooth: given that the surface of the object is on the whole compact, it is possible that the traces left by the earlier production procedures were erased, strengthening the object and enhancing it aesthetically. However, some parts of the sections, especially those close to the holes and to the spigots and sockets, are very fragile: in these areas cracks and fractures in the bone are evident and concentrated.

6. Conclusion

As a non-destructive method that facilitates new insights into ancient musical instruments, CT allows us to obtain useful data that could not be gained by other means without disassembling the object or the risk of damaging it. The variety of sizes, shapes and materials of ancient instruments pose various challenges for CT scans. These issues have to be addressed by selecting appropriate CT parameters, scan procedures and data and image processing algorithms to obtain not only a high quality in the reconstructed volume images, but also useful information related to the craftsmanship of musical instruments. The processes of 3D scanning, 3D model creation, 3D printing, and craft reconstruction of the *aulos* from Poseidonia can facilitate the parameterisation and further processing of future scans of similar instruments and can be used to create a set of replica instruments to be considered as reasonably veracious 'functional replicas' (Swift *et al.* 2021). Thanks to these 'functional replicas', we will also be able to evaluate (to a certain extent) how far the craftsmen tailored their work to the needs of individual musicians and how they designed instruments on the basis of models or instruments transported in the ancient Mediterranean.

From a research perspective, the exploration of production processes can facilitate an enhanced understanding of the development of musical instruments used and requested in a particular social and musical context, allowing us to evaluate how shapes, craftsmanship, and evolution of instruments can be related to the development of spaces of performances, theatres, and architectural structures in antiquity.

It is worth noting that small variations in the measurements of instruments could significantly affect pitch (Avanzini *et al.* 2015; Avanzini *et al.* 2016). For this reason, the manufacturing process should be evaluated from different points of view using 3D scanning data for future use in ancient sound simulations (Sun *et al.* 2020); the data could possibly be made available for public engagement (Micheloni *et al.* 2016), and for scholars working in different disciplines, given that musical instruments research is undoubtedly an interdisciplinary field of survey which involves physics of instruments, material science, manufacturing methods and acoustics (Damodaran *et al.* 2021). In this regard, the re-creation of a plausible acoustic environment, for example, an ancient theatrical space contemporary to the instruments in which *auloi* were most likely played, could provide an insight into the acoustics of the space (Tronchin 2020), and the effect of the sounds of these instruments in a virtual environment (Farina, Tronchin 2013): this challenge could enable us to consider wider aspects of the experience of soundscapes in antiquity (Geoffroy-Schwinden 2018).

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ABSTRACT

This paper aims to explore how digital imaging and computed tomography (CT) can provide us with significant results and valuable information otherwise unavailable in the study of ancient instruments. Whilst its methods provide great potential in terms of the diagnostics and preservation of ancient musical instruments, radiology has been underused in this field of application. As an improved method for the visualisation and analysis of the material density of instruments and of their surfaces and volumes, CT allows for a useful evaluation of the handcrafting process of instruments as well as the visualisation of invisible fracture lines and lesions in their structures, showing possible modifications, damages and repairs.