A small bronze statue from the Archaeological Museum of Thessaloniki; exploring its authenticity

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ABSTRACT
This study explores the authentication of a bronze statue by means of the evaluation of technical evidence and investigation of patinas formation. The statue was identified by the police as a product of illicit excavation and handed to the Archaeological Museum of Thessaloniki. The visual examination reveals technical features that are consistent with those commonly found on ancient bronze statues while the physicochemical character of the corrosion was in accordance with typical bronze corrosion mechanisms (decuprification). Original features like the metal microstructure were detected on the corrosion layers, showing the complexity and long lasting character of their formation. The metal composition was determined by XRF and the corrosion products were analysed by XRF and SEM-EDS.

KEYWORDS
Authentication; ancient bronze statuary; lost–wax technique; decuprification; portable XRF; SEM-EDX

Introduction
The Archaeological Museum of Thessaloniki (AMTh) like all State Archaeological Museums in Greece, is responsible for the study, safeguarding, publication and exhibition of antiquities that in most cases are brought to light by official excavations. This fact gives museums an important advantage as it allows them to use excavation data both for research and for material used to explain the finds to the public. Hence antiquities are displayed within their archaeological context to help the general public understand and appreciate their historical and cultural value. In contrast, the interpretation and exhibition of objects that lack their excavation context, like those museum artefacts that had been handed in or confiscated, present significant difficulties both in terms of understanding them as well as in terms of certifying their authenticity.

This study examines one such case, consisting of a small bronze statue that was identified by the police as a product of illicit excavations together with other objects that were handed in to the Archaeological Museum of Thessaloniki in 2010. The results of the preliminary archaeological and archaeometric examination conducted (Karydas and Kantarellou 2010; Maniatis 2010; Michalopoulou 2010; Nazlis 2010) show that it is most probably a work of ancient bronze statuary while stylistic peculiarities noted on the head and other technological issues remain under examination. The statue along with other objects deriving also from illicit excavations, was included in the temporary exhibition organized in April 2012, by the Archaeological Museum of Thessaloniki and the Directorate for the Documentation and Protection of Cultural Goods (Hellenic Ministry of Culture featuring the problem of illicit trafficking of antiquities) (Adam-Veleni 2012).

In the framework of the systematic archaeometric examination of bronze artefacts in the AMTh collections, many of these objects are being examined in detail. Regarding the bronze statue, the discovery that the head and the body were glued together with a modern adhesive, led to a new discussion about and investigation of its authenticity. In general, four categories of
alteration made with fraudulent intent can be identified; a forgery that is a whole new work in imitation of something else, a fake that is an object that has been altered to appear more valuable, a paste object that is made up of unrelated pieces and the last case is of a genuine object that has been restored usually to conceal previous wear or damage (Craddock 2009, 11). In order to examine the above and to determine the authenticity of bronze objects, it should also be taken into consideration that many of their authentic characteristics can be artificially reproduced to a large extent e.g. artificial irradiated clay core (Rasmussen 2007, 5) or artificially developed patinas (Constantinides et al. 2002). Hence, a general framework known as authentication procedure, usually includes the examination of stylistic features, technological characteristics as well as the examination of the physicochemical characteristics of the corrosion products. Data gathered through this procedure should at first be consistent. Then special characteristics are sought among them which can be considered as conclusive evidence of authenticity.

Thus, the bronze statue discussed here was examined regarding its technological characteristics. Physicochemical examination of the corrosion layers was also conducted and it shows that the decuprification process, which occurs to historical, ancient bronze exposed in various environments, (Robbiola, Blengino, and Fiaud 1998) is the prevailing mechanism of their formation. In addition, the known tendency of bronze for epitaxial growth (Scott 2002) favored the preservation of authentic characteristics of the metal microstructure between the corrosion layers, thus exhibiting a slow and long lasting formation of corrosion that cannot be artificially reproduced.

Description-technical considerations

The statue is 0.60 m tall; as it was handed to the AMTh. It depicts a standing male figure, which is shown with his right leg engaged and the left one relaxed according to ancient principles (contrapposto). The right arm is raised and the left is held on the side, the palms and the object or objects held are missing (Figure 1a,b).

It is widely accepted that the techniques used in antiquity for the production of cast bronze statues was the lost wax technique which had two versions, the indirect and the direct one. When using the direct process, a clay core of the approximate size and shape of the intended statue is made. On top of this model, a layer of wax was spread, on which the details were executed until the statue took its final form. Then the wax tubes and gates were created, which were attached on the wax model to key positions for pouring the molten metal. Afterwards the entire model was covered with many layers of fine clay and with the help of metal rods and chaplets, the clay core was fastened to the outer clay investment mold. The clay invested model was heated to remove all the wax creating a hollow matrix between the clay core and the outer clay investment, into which the molten metal was finally poured.

With the indirect method, the first stage was the construction of the initial model, which is a finished work in all its details. Molds are created for every part of it, which are later joined together. The next stage is the lining of the inner surface of the molds with beeswax, applied by brushing or in the shape of rectangular pieces that the craftsman would finger-press on the mold. After that, the waxed molds were filled with clay that was poured inside. The molds were then disassembled and the so-called wax working model was revealed to which some details could be added by hand.

For objects made by the indirect processes the interior surface corresponds to the interior of the wax working model where traces of the way the wax was fixed to the model may be preserved. The great advantage of the indirect method is that the original model is not lost in the casting process, therefore it is possible to recast and to make a series of the same statue (Hemingway 2004).

Methodology

The examination of the authenticity of the statue under study is twofold. The first part examines the manufacturing technique and compares our already acquired knowledge from ancient artworks. The artefact was visually examined which was also augmented by X-radiography. Prior to the latter, the interior was examined to make sure no clay core survives which would help date the artefact and hence should not be irradiated.

The second part of the investigation involved physicochemical examination of the metal, the corrosion and the organic material found on the interior of the
object to see whether or not they are consistent. In particular, the chemical nature of the corroded surfaces (and the organic material) was investigated in relation to the corrosion process of decuprification; which is characterized by the selective dissolution of copper (Cu) from the bronze alloy into the burial environment and the associated formation of tin compounds remaining in the corrosion layers (Robbiola and Portier 2006). In the literature, the corroded surfaces that are formed with that process have been divided into two types; an even and a coarse one, also called patina Type I and Type II. In patina Type I the outermost layer is characterized as a passive layer, a pseudo-morphic replacement of the original surface, which is enriched with tin and soil compounds. Type II is not protective and is characterized by complex structure; the outermost layer of which consists of copper compounds and no tin while the internal layer contains relatively more tin than the bulk alloy and high concentration of soil elements (Robbiola, Blengino, and Fiaud 1998). The same results have been found in leaded bronze as the lead content has no influence on the decuprification process (Robbiola and Fiaud 1993, 161).

The surface of the statue was examined visually and both patina types were observed. The corrosion was then examined under the stereomicroscope to understand its natural characteristics and its stratigraphy. The chemical composition of the metal was determined by X-ray Fluorescence (XRF) analysis using a portable XRF Fluorescence Analyzer (Bruker, Tracer IV equipped with a Silicon Drift (SDD)) detector and Light Alloys FP software. The samples analysed were taken from the head, the left foot and the left arm. Microsamples were also taken from the two patina types from various parts of the statue. The analysis was conducted by XRF and Scanning Electron Microscopy and Energy Dispersive Spectrometry (SEM-EDS). Specifically, from patina Type I, nine samples were taken; seven were analysed by XRF (Table 2, nos1-7) and two by SEM-EDS (Table 3, S1, S2). From patina Type II, three samples from the external layer (Table 2, nos. 8-10) and thirteen from the internal were taken and analysed by XRF (Table 2, nos 11-23). Three more samples of the patina Type II were analysed from the side that was attached to the bulk metal using SEM-EDS (Table 3, S3-S5). Three small fragments of wood were also analysed by XRF (Table 2, nos 24-26) and one by SEM-EDS (Table 3, S 6).

Apart from the investigation concerning the origin of the body and head, their physical and structural relation were also examined in order to clarify whether the two parts belong to the same object or they are two independent pieces (pastiche). The analyses were performed at the laboratories of the Department of Management and Conservation of Ecclesiastical Cultural Heritage Objects, University Ecclesiastical Academy of Thessaloniki (UEATH).

**Manufacture technique - Results and discussion**

**Visual examination and X-radiography**

An important piece of the information obtained by the X-radiography is that the head and the body were glued together using a modern adhesive (Figure 2). Externally, the area of the conjunction was carefully masked with a material made by mixing a synthetic adhesive with particles from the encrustation of the object’s surface. The two parts were detached which allowed for a better examination of the interior and the understanding of the main stages of its manufacture.

The body was cast mid-neck, the hands are missing at the wrists and the genitals and the toes are solid; there is also an opening on the left foot. The right arm is seen to be joined to the body at the point of the shoulder by a welding flow join (Figure 3a). As is apparent from the visual examination the wax left arm was attached into the left armpit and angled across that arm just below the shoulder before the statue was cast (Figure 3b). Above the elbow of that arm a flash line, where molten bronze entered a crack in the core, can be seen on the X-radiograph as well as through the opening on the underside of the arm (Figure 4).

On the body the walls are thin with even thickness; the interior contour following the exterior shape. Where measurable, from neck and sole openings, the thickness is similar and ranges from 2.7 mm to 3.6 mm. The break at the hands is irregular in thickness corresponds roughly with the line of an original join.

On the head the walls are thicker than the body walls and uneven, the interior contour follows roughly the exterior; the edges of the hair, and the nose are solid, as are the ears and mouth which show no Figure 2. X-radiograph, the arrow indicates the head’s misalignment.
indentations on the interior. The details of the eyes and the hairstyle were done on the wax working model before the actual casting. The interior of both parts contains drip marks (Figure 5a,b), nodules of various sizes and also on the hair, and protuberances. In addition, on the interior there are brush marks on the head side of the neck (Figure 6).

The edge of the head on the left side corresponds to the cast end (maximum height 11.1 cm), where there are two stub tenons (Figure 7a). The rest of the edge seems to be broken and corresponds roughly with the line of join (Figure 7b). The edge of the mid-neck on the body has an uneven contour, which corresponds to a join end. However, it has no corresponding projections to interlock with the head’s tenons (Figure 8a). When the two parts are placed in the right position the front tenon of the head is loosely placed on the curved cavity while the side tenon is not used (Figure 8b). On the front and the right side some material seems to be missing; a gap exists between the two parts (Figure 8a,c,d).

The X-ray showed that the cast exhibits porosity only in the lower part while on the surface there are a few very small pores scattered in various places. On the back side of the left shoulder a heavily mineralized area preserves a polygonal or cast patch, or the mark of what was left from the patch (Figure 9). Similarly, a relatively small cast patch was used to repair a hole on the left shin (Figure 4). Dents are noticed on the left sole (Figure 10), on the inner side of the right knee, on the left arm and on the hair (Figure 7a).

One final detail is that the whole statue in the condition it was handed to the museum, that is with the head glued on the body, displays a proper weight distribution, which allows it to stand on its own on the left foot, actually on the tips of the toes and the periphery of the heel of the left foot, and the tip of the toe of the right foot. An interesting point is the natural way the underside of the left foot is depicted, even though it cannot be seen (Figure 10).

Discussion

The separately cast sections, the homogeneity in wall-thickness, the close match of the interior and the exterior contour, the cast wax drip marks, and the
nodules are typical characteristics of the lost-wax indirect technique (Hemingway 2004; Tzachou-Alexandri 2000, 88). Other features like the cast repairs, the surface porosity, the flash lines, the sole opening, the natural rendering of the underside of the standing feet are common in both procedures and typical to well-known ancient bronze statuary. It is generally agreed that the direct process was used by the end of the 6th B.C. for the construction of large statues while the indirect is considered an invention of the early Hellenistic era (Hemingway 2004, 7).

The choice in the manufacture of these separate cast sections is entirely logical and in accordance with what

Figure 5. The interior of the body, the white arrow indicates a long drip mark, the black indicates wood fragments attached to the corrosion (b) The interior of the head the arrow indicates a long drip mark

Figure 6. Microphotograph showing pseudomorph brush mark preserved under a crust of soil on head interior surface (neck area).

Figure 7. The head of the statue; (a) the left profile; the arrow indicates a dent, (b) the right profile.

Figure 8. The upper part of the statue with head placed in correct position (a) three quarters view, (b) detail from the left view showing the two tenons (c) the right side view and (d) the rear view.

Figure 9. Detail from the back side of the statue showing a patch.

is known for ancient statues. In particular, the raised arm (right) was constructed separately as its relation to the body would make the handling of the mold difficult, while a basic reason why the head is cast
separately is that the opening at the base of the neck allows for the filling of the wax model with the clay core, (Hoffmann and Konstam 2002, 157, note 14). The wax to wax join that was used for the left arm is similar to that described for the statue of Hypnos, in the Shelby White and Leon Levy Collection, no 250, (From the catalogue of the exhibition ‘The Fire of Hephaistos’ (1996) catalogue no 27).

The welding join is a characteristic which theoretically can be reproduced, although it is more complicated compared to the other aspect of the lost wax technique. In fact, it seems to be difficult for a modern craftsman to have the practical knowledge of flow welding joining as attachments nowadays are solely done with a blowtorch. It can be considered as a conventional indication of authentication rather than a sufficient necessary criterion. In any case is a characteristic worth noticing as in certain cases the ‘forgers’ devise ways to join sections of a casting so that when X-rayed they would appear authentic (Figure 3), (Cavanagh 1990, 41).

The break at the hands corresponds roughly with the line of an original join, but there no clear indication to confirm that the hands were attached to the arms as is often the case in ancient bronzes. Possible signs of a join could be the increased thickness of the metal, at this area (maximum 4.5 mm) compared to the rest of the cast and the semi ovals contour of the edge that resemble the "basin" technique (Figure 11a). According to this technique, the ancient craftsman adds wax on the exterior surface of the ‘wax working model’ in order to increase the thickness of the metal wall and strengthen the edge-to-edge join. When the bronze caster came to attach the hand to the arm, he cut shallow half-ovals in the outer surface of the bronze on either side of the join so that, when brought together they formed oval basins (Figure 11b). The welding metal fills the basin as well as the join thus increasing its hold (Haynes 1992, 95). Such joins are known from at least the fifth century BC to the third century AD. (Benoit and Descamps-Lequime 2017, 356). The thickness of the cast can offer some information regarding the dating of the statue. In particular, the thickness of the metal wall (2.7 mm to 3.6 mm) is chronologically more compatible with that of Classical and Hellenistic statues which are on average 6 mm thick (Haynes 1992, 68). Roman statues are less thick (1.5-2 mm) and medieval are extremely thick (often measure 2 cm) (Giumilia-Mair 2016, 172).

The X-ray showed that the cast is of good quality, exhibiting porosity only in the lower part, which
suggests that the figure could have been cast upside down. The dents on the sole, knee and arm can be attributed either to later usage or to accidental manipulation on the wax working model in places where a corresponding void on the core also exists. Similar dents on the head were probably made during working on the wax model since they cannot have been done after casting because this would have damaged the hairstyle details. The opening on the bottom of the left foot was usually made by the bronze caster, by cutting out a piece of the wax in order to enable the clay core to be supported directly by the clay investment mold in the firing process. After casting and the removal of the core from the interior, the opening was then used for mounting the statue on a stone base.

The head is also an indirect casting as attested by the drip marks and the brush marks on the interior, as well as the fact that its wall thickness is thinner than would be expected for a direct cast. However, many details in the rendition of the facial and hair characteristics were handmade on the wax working model before the actual casting as testified by the thickness of the cast in those areas, showing that elements of both techniques were used. The combination of both techniques for portraits is not rare and can be detected over a long period of time until the late Roman era (Giumilia-Mair 2016). This technical characteristic in the construction of the head – portrait also explains the differentiation in the rendition of details found in the two parts. The body is the identical replica of a master model while the head only follows the general anatomical characteristics. The details that determine the style of the artwork are made freely by hand on the 'wax working model' and they are original and unique as in the cases of direct casting.

The technique used for the joining of the two parts appears to have combined mechanical interlocking with metallurgical type of join, flow welding or soft soldering (Haynes 1992, 95). There are several different examples of such combinations. The most famous example for the presence of a tenon is «The Head of a Philosopher» from the Porticello shipwreck where only one tenon exists on the right side of the head (Eiseman and Ridgway 1987, Figures 5.3, 5.5, 5.6) and the Antikythera arm (Haynes 1992, 104).

The parallel contour of the edges (Figure 8a, c, d) and the good match of the anatomical details on the front of the neck (Figure 8a) are strong indications that the two parts once belonged together. In addition, as mentioned above they present similar technical details, as the long drip marks, as well as similar imperfections like dents. Even if the possibility that two different original pieces were glued together (pastiche) cannot be definitively excluded it would have been very difficult to find two different pieces sharing so many common morphological and technical characteristics. The analytical results below reinforce further this view.

Regarding the gap found between the two parts it is probably due to a loss of material from the joining area, the welding material or an extra part which would have facilitated the connection. In order to fill this gap between the two pieces, the modern «restorer» placed the head slightly lower and this placement caused a misalignment of the two parts which was then covered with the use of a synthetic material.

**Physicochemical examination of the metal and the corrosion - Results and discussion**

*Visual examination*

In general, an even patina is noticed mainly on the front side of the statue almost until the level of the right knee (Figure 1a) while the coarse patina appears on the rest of the surfaces; beside that, areas where even surfaces are adjoined by coarse surfaces are noticed on the front and back sides (Figure 12).
In particular, on the front the even and lustrous patina appears on the face, the neck, the body, the arms and the upper part of the thighs. This corrosion structure consists of a single layer that corresponds to the original surface. In many places, original features like the striation lines from polishing (Figure 12) or the brush marks from the wax application (Figure 6) are preserved; the dendritic pattern of the metal microstructure which corresponds to as-cast condition is also visible (Figure 13). The predominant colour is olive-green to green, with small black spots; except for certain areas on the arms and the neck which are mainly black.

On the rest of the statue, that is, on the rear sides, the two legs and the feet and almost all the back side including the hair, a coarse patina or as it is also called, Type II patina has developed (Figure 1b). This patina presents a disfiguring non protective external layer under which the original surface has been destroyed. Its structure is layered, consisting mainly of two external layers and the innermost which integrated with the bulk metal. This stratigraphy presents deviations like areas where multilayer structures appear or others where the two external layers are integrated with each other and their limits cannot be defined visually. All the corrosion layers are dense, coherent, of medium hardness and uneven thickness; the colour of the layer is green separated by a red cuprite layer which in most cases is the innermost layer. Large areas with iron rust are noticed above and between the various corrosion layers in many places. Original features like the dendritic pattern of the alloy, are also preserved in the innermost layer (Figures 14, 5a).

On the interior surfaces the corrosion layers are relatively thin and even, the colour is green; iron corrosion products (rust) and earth encrustations are noticed in many places. Small fragments of wood are found either attached to the corroded surface or embedded into corrosion layers (patina Type II) (Figure 15).

**Chemical analysis**

The alloy was found to be a leaded (Pb) bronze with an average content of 85% Cu, 5.1% Sn and 3% Pb (Table 1). The composition analysis of samples taken from patina Type I show low copper content and relatively high tin amount similar to that of the bulk metal. This layer is also enriched with soil elements as confirmed by the results of the SEM-EDS analysis (Table 3). From the results of the samples taken from the outer layer of patina Type II, (Tables 2 and 3) the high content of copper (Cu) and the absence of tin were noticed on the external layers while the tin enrichment relative to the bulk metal, was detected in the internal layer. The same results were obtained from the EDS analysis (Table 3), (Figure 16) where an increased amount of soil elements that penetrated the corrosion structure were also identified. The detection of iron probably suggests the presence of an iron object in the burial environment. The samples of the organic material contain cooper (Cu) and low amounts of tin (Sn) and lead (Pb), due to the fact that copper ions are the main cationic species diffused into the soil.

**Discussion**

The metal composition is common for bronze statuary after the end of the 4th B.C. when leaded bronze
makes its appearance sporadically (Giumlia-Mair 2016, 167). The results are in relatively good agreement with those taken in the past by XRF by the A.M.Th. chemist Nazlis (2010). The two results differ in the quantity of tin (up to 4%) and lead, which is not uncommon for ancient cast objects (Scott and Podany 1990, 41). The results from the examination of two samples possibly deriving from the edge of the opening of the left foot were different. The specimens were examined in the laboratories of the National Center of Scientific Research “Demokritos” by Maniatis (2010) with SEM-EDS and by Karydas and Kantarelloú (2010) with XRF. The results in both researches gave copper (Cu) and a small quantity of lead (Pb). In addition, the chemical pattern and the total amount of the impurities of the analysed metal sample found to be in accordance with known ancient cooper ingots (Karydas and Kantarelloú 2010). The presence of unalloyed copper in ancient bronze artefacts is mostly associated with the corrosion process (Bosi et al. 2002). The intense corrosion noted in the area in combination with the very small thickness of the cast at this point (>0.5 mm) can explain this result.

The chemical nature of the alloy, the corrosion layers and the organic material are internally consistent, and in agreement with the decuprification process. The general aspect of the surface is similar to excavated bronze found in moderately aggressive burial environments where their general shape is well retained but the original surface has been partially preserved. The coexistence of the two corrosion types on the same object and the way they were spread on the statue’s surface is usually observed on a natural corroded surface and has been attributed to a local shift of the corrosive environment from mild to more aggressive (Schweizer 1994). Specifically for leaded bronze, experimental research shows that...
intrinsic reasons might also be responsible for this coexistence (Constantinides et al. 2002).

The complexity of the patina formation is testified by the fact that original features like the dendritic pattern, were found on tin-rich surfaces which exhibit resistance properties and retain the metal structure after the migration of copper (Cu) cations into the environment (Piccardo, Mille, and Robbiola 2007). Generally, this and similar features are preserved in various places on the statue such as the metal microstructure that have been located on the body (Figures 13, 14) the brush marks on the head (Figure 6) and the extraneous material (wood fragment) trapped in corrosion surfaces on the interior (Figure 5a); consequently, the assumption that one of the two pieces might be a modern product cannot be supported. When the statue is examined as a whole, body and head, it is obvious that, the two parts have similar metal composition, similar corrosion composition and morphological characteristics, colour texture and corrosion microstructure, so it appears they belong together as previously discussed in the technical examination.

Conclusions

This study has shown that the technological features of the statue, the alloy composition, the manufacturing technique and other technical details are chronologically compatible and cover a fairly long period of time from the late 4th B.C. to the Roman era. It was also shown that the above characteristics are present on artefacts of documented provenance. Furthermore, the corrosion process revealed original structural characteristics which cannot be artificially reproduced. Hence, the data creates a strong profile of genuine characteristics that answer the questions regarding the authenticity and the stylistic peculiarity of the object. The technical examination is still at an early stage, and new features concerning the manufacturing process might appear, which will help towards a more precise dating of the statue.

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No potential conflict of interest was reported by the authors.

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