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Imaging and conservation strategies for archaeological iron objects

ABSTRACT

Iron objects are important in archaeological research due to properties such as their typology, manufacturing traces, and related organic remains. Due to the voluminous corrosion products and the decay of organic materials, the information contained in these objects is generally not accessible when they are left untreated. The decision is often made between either full treatment of all objects or no treatment at all.

This research offers an alternative solution to the question of treatment versus no treatment. X-ray and µCT imaging techniques were applied to iron objects from the early Medieval cemetery of Lentseveld (in The Netherlands), and these methods were combined with selective, investigative, and full cleaning. These methods and techniques vary in their approaches and results, and combining them can be useful. The strategy depends on the needs of a particular project and specific research questions. Objects from such a context often have no metal left at all. After many centuries of post-depositional processes, they consist almost entirely of corrosion products. Of particular interest for this paper are the results that can be obtained using techniques such as µCT to see through corrosion and soil.

The results include object outlines; internal structures and cross-sections; related objects; and associated materials. This research shows that applying and combining methods in a pragmatic manner has a clear advantage in terms of the achievable duration and obtainable information compared with the traditional strategy. It also suggests that µCT can contribute to both the conservation and interpretation of archaeological iron objects, especially larger object assemblages.

KEYWORDS: *archaeology, conservation, x-ray imaging, micro-CT, iron, early medieval*

INTRODUCTION

Iron objects can be important in archaeological research due to properties such as their typology, manufacturing traces, and related organic remains. Due to the voluminous corrosion products and the decay of organic materials, the information contained in these objects is often inaccessible when they are left untreated. This is a rather universal problem, mostly stemming from soil conditions, especially in north-western European countries, such as The Netherlands, Belgium, and Germany. Currently, a decision is often made between either full treatment of all objects or no treatment at all, and alternative methods are left unexplored. Applying conservation treatments to every single object is time-consuming and expensive, while leaving objects untreated can result in missing important information.

Research has been undertaken with the aim of finding a solution to the question of treatment versus no treatment.[1] The main goal of this research has been to investigate the available methods and strategies for gathering information from archaeological iron objects. The main lines of research are as follows: the collection of information contained in archaeological iron objects using digital means and various cleaning strategies; a comparison of these methods; and the design of a strategy to extract the optimal amount of information from these objects after they have been excavated. This was done using the varied collection of iron objects from the early medieval cemetery of Lentseveld (in the municipality of Nijmegen, The Netherlands). There are several ways of accessing information in these objects: selective, investigative, and full cleaning; X-rays; and μCT. They vary in their approaches and results, and combining them can be useful. The proposed strategy largely depends on the needs of a particular project and the specific research questions. This paper mostly focuses on the results that can be obtained using imaging methods such as μCT.

NIJMEGEN LENTSEVELD

In this research, objects from the early medieval Merovingian cemetery at Lentseveld were used. It was excavated in 2011 and was found to have consisted predominantly of late fifth – sixth-century CE graves, including 50 inhumation graves, with several complex examples containing object ensembles and organic remains.[2] The processing of this excavation has taken a significant amount of time, partially due to the complexity of the graves and their object assemblages. This is a normal process for such a complicated project: The process from excavation to a final report is not straightforward, and it involves a great deal of time and money.

The iron objects in the case study were chosen due to the varied excavation conditions. Some objects were in relatively good condition and were fully excavated on site. In other cases, some objects were too fragile, several objects were found together, or organic remains were present.[3] In these cases, the objects were excavated as a block so that they could be examined in detail in the conservation lab. This variety provided the author with the opportunity to employ and test different methods. It also is a relatively common situation for Dutch early medieval archaeology in sandy soils, where there are complex graves with fragile metal objects and object ensembles. This context provided an excellent opportunity to explore new methods of gathering information while also providing possibilities for the post-excavation exploration of such datasets.

The primary use of such objects is the establishment of the date and provenance of the site, usually done by using a typology, for which both the shape and the material of the object are important.[4] The main issue with these objects is the existence of their voluminous corrosion products. In the last decade, a significant decrease in condition of objects in the soil has occurred, probably due to the increase in agricultural contamination.[5] Iron corrosion products often expand, sometimes more than doubling the size of the object. This is a problem in interpretation, which is usually based on shapes and the ratios between the various components obtained from archaeological drawings made according to relatively uniform standards.[6] Although the abandonment surface (representing the shape of the object when it was deposited) can still be present in the various corrosion layers, often, a metallic core is no longer present.[7] The object has been completely mineralised, and the organic materials have decayed, or in some cases, been replaced by corrosion.[8] This means that the information that is preserved in these objects is generally inaccessible. In order to access this information, the objects need to be cleaned, or other methods of obtaining the information need to be applied.[9]

METHODOLOGY

At sites like Nijmegen Lentseveld, the objects are usually fragile, or there are object assemblages that consist of several objects clustered together which are often from a variety of materials. The traditional approach in this situation is as follows: Initially, these objects are lifted by means of a block excavation, then X-rays are created, and then a long cleaning process in the lab can start. During a block excavation, the object is carefully removed together with its surrounding soil, thereby creating a block and covering this block with plastic and plaster in order to preserve the context and maintain its stability during transport. Sometimes, entire graves are lifted and transported in such a manner so that they can be excavated in more detail in the conservation lab. Single objects that are in good condition are generally excavated individually and then follow the same process: with X-rays and cleaning. The exposure of the abandonment surface can take a very long time and does not always have good results. In some cases, outdated methods and materials are used. This results in a significant loss of information and can be a danger to the object, especially over time.

The research presented here offers a different approach. The objects under study were divided into two groups: individual objects and block excavations. Cleaning and imaging were carried out in three consecutive processing phases of the studied objects. The first phase was an inventory phase, wherein only the identification of the object and the determination of the research potential were established. For this purpose, creating an X-ray is a crucial step that is now compulsory in national regulations of countries such as The Netherlands.[10] The next phase was the investigative phase, wherein the object and research potential form the basis for further research with help from selective, investigative, or full cleaning[11] or with μCT. In this research, the term 'selective cleaning' means only exposing a few predetermined sections of the abandonment surface,[12] while 'investigative cleaning' looks for specific features, such as decorations or organic remains. The third and final phase was a presentation phase in which the objects received further cleaning for exhibitions or publications. This usually means removing the superficial corrosion layers in order to expose the abandonment surface or related organic remains.

The research presented in this paper will predominantly focus on the investigative phase. In this phase, the primary goal is the retrieval of specific information. Initially the shape of the object is the most important, in order to be able to put it in a general typology. A second priority is the retrieval of hidden shapes and properties such as the internal structure and cross sections. Finally, the materials and construction techniques are of interest, as well as possible associated organic materials.

X-RAY RADIOGRAPHY

The use of X-ray imaging for cultural heritage has received extensive attention from researchers.[13] It is a technique that is commonly used to gain a great deal of information about highly corroded objects. X-ray is a 2D imaging method that works by sending radiation through an object onto a film or detector. Different densities produce different shades of grey. This process allows for the preliminary identification of objects and an assessment of their state of degradation. An X-ray can be extremely useful during cleaning, but the object is not always clearly identifiable.

The analogue X-ray images of the studied images were obtained at Vinçotte in Wijnegem (Belgium) using an Andrex 225 kV source with a focus of 2.5 x 3 mm and Agfa Structurix D7 film. The digital X-ray images were taken using the facilities of LVR-LandesMuseum Bonn, using a device made by GE Inspection Technologies with a stepless adjustable tube voltage of 5-225 kV, a maximum tube current of 50 mA, and a maximum tube power of 1,600 W.[14]

μCT

μCT refers to micro-computed tomography. It is a non-invasive imaging technique that sends X-rays through a sample, which are then received on a detector. The process is similar to conventional X-ray imaging. The main difference between the two methods is that in μCT, the sample is rotated, and a 3D image can be created with further processing.[15] With μCT, the differences in density can be observed in 3D, which means the method can be used to navigate through the objects and, for example, to investigate construction techniques.[16]

The scans for the research presented here were made in collaboration with Ghent University, using the expertise and equipment of UGCT. The High Energy Computed Tomography Optimized for Research (HECTOR) scanner was used with high voltages between 180 and 220 kV and filtration of low-energy radiation was applied to avoid noise. The exposure times were between 500 and 1000 ms. The obtainable magnification in this setup was approximately 1/1,000 of the object dimensions. The whole scanning process was controlled by scannerGUI, a program that assesses all scanner components. To create the 3D reconstructions, the software package Octopus was used.[17]

RESULTS: INDIVIDUAL OBJECTS

For this part of the research, a spearhead was used. Spearheads are interesting for typological purposes, because, for example, they have more variations than a knife. The X-ray shows most contours relatively well. The contours of the inside of the shaft are clearly visible, and in the shaft, vague lines indicate remains of wood. The tip of the spear is unclear, since it is thinner than the rest and strongly degraded. Therefore, its density is lower than the density of the rest of the spearhead, making it appear darker. This shows that the condition of the objects can be defined based on the X-ray. When comparing measurements from X-rays with the objects placed directly on the film with measurements on the physical objects, the deviation is generally less than 2 mm. This supports the claim that it is possible to determine the contours of an object by using X-ray. This method is only reliable when an object is placed directly on the film. When an object is located somewhat above the X-ray film, deviations will occur. Since the object is not magnified in a uniform manner, adding a scale does not provide a solution. It is important that it is always known whether an object has been placed directly on the film or not. If not, it is more reliable to measure dimensions on the object itself.

With selective cleaning, the most important parts of the object are visible. In those areas, the original surface (that may or may not have moved during the corrosion process) is exposed, and the shape and cross-section can be determined. If there is decoration in another location, it is possible that this will be missed. Selective cleaning does not provide the contours of the inside of the shaft. Based on the results of the selective cleaning and the X-ray, an archaeological drawing could be made that shows the basic properties of the spearhead.

Full cleaning exposes the original surface of most of the object, except for the inside of the shaft. Decorations that might be missed with selective cleaning will become visible, but organic remains that might have been preserved in the corrosion

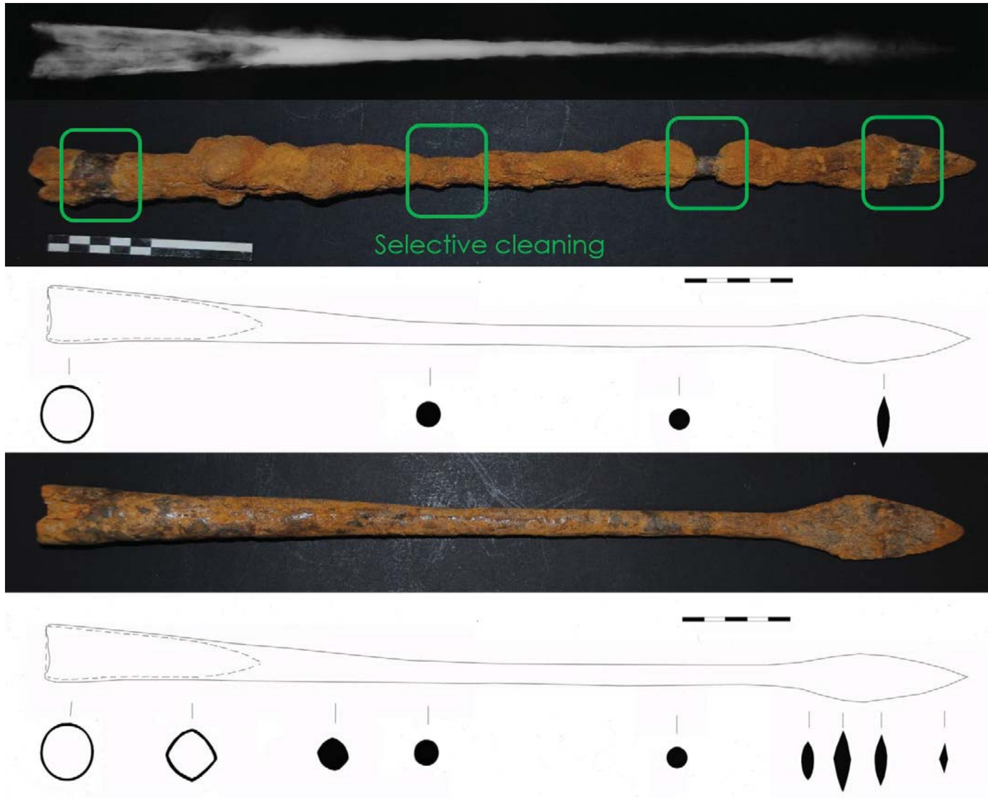

FIG. 1 *Merovingian spearhead (NLA14-1145), from top to bottom: analogue X-ray (Vinçotte, 120kV, 25 sec, 4 mA); after selective cleaning; drawing based on X-ray and selective cleaning; after full cleaning; drawing with all relevant areas,* Manuel J. H. Peters

layers could be lost. Full cleaning allows for exposing all cross-sections and nuances, but in the present case, this process was aided by the cross-sections that the μCT scan produced. Usually, it is not possible to obtain such accurate results with highly degraded objects. Even an experienced conservator can have trouble with exposing the right shapes of such objects.

In these cases, the images of a μCT scan can be of added value. The cross-section of the spearhead developed from lenticular to rhombic. Without the μCT scan, cleaning would result in the appearance of one of those shapes, instead of a transition.

Based on the results of all methods, it was possible to construct an archaeological drawing that represents several relevant properties of the spearhead. However, there is a difference in the information value of these shapes and cross-sections. The size deviation between an X-ray and cleaning makes a relatively small difference for placing the object in a typology. Generally, typologies follow object contours, although some have more detailed criteria, such as the typologies of Petersen and Wheeler.[18] The typology of Siegmund, which is often used in north-western Europe, also applies the cross-sections,[19] as does Jessop for Medieval arrowheads.[20] Others use clear shape features; for example, the dome of shield knobs or the shape of a sword pommel.[21] µCT scans could be relevant when an object is being used for further investigation that might lead to the refinement or adaptation of existing typologies.

RESULTS: BLOCK EXCAVATIONS

For several objects, X-ray and µCT scans were made, using one or multiple parts of the block. A comparison between the different results was made in order to show the differences in the obtained information. In order to assess the usability of the techniques for the various research interests, the results obtained by µCT are organised as such.

Object Outlines, Internal Structures, and Cross-sections

The soil and corrosion layers can obscure 'hidden shapes', such as the object outlines, the internal construction, or cross-sections. In order to create an archaeological drawing and assess the typology of an object, the contours of the object can be obtained by a 2D X-ray. In order to obtain cross-sections, selective cleaning or a µCT scan is required. The latter has more precision, since the full range and variation of shapes can be observed, whereas the results of selective cleaning depend on the skill of the conservator and the selection of the area.

In order to gain more detailed information about objects such as swords that are still in their scabbards, the cross-section is an important feature. Because the sword is covered with corrosion and soil, and, most importantly, there are organic remains on the scabbard, part of that scabbard would have to be removed to obtain a cross-section. This is undesirable, because these organic remains are extremely rare in archaeological sites like this.[22] Although there is no metallic iron present anymore, it is possible to use µCT to identify the outlines of the object (abandonment surface), in the various corrosion layers, and to observe the cross-section of the sword. X-rays show differences in density related to the different materials. µCT takes this a step further, since it is possible to apply filtration to the various materials and densities, which can make those materials appear transparent. This allows for the visualisation of a sword that is still inside its scabbard. This is a great improvement in the level of obtainable information, since this 3D view is otherwise unobtainable. Although µCT provides impressive results, organic structures such as mineralised leather are more clearly visible with investigative cleaning. Other features that can be made visible with these imaging techniques include pattern welding.

Related Objects and Associated Materials

The other benefit of µCT is the possibility of identifying related objects and materials that are normally obscured by corrosion layers, and are difficult to identify on an X-ray. In one of the block excavations, there was a copper alloy buckle that was relatively hard to identify on the X-ray, whereas on the µCT even the decoration is visible.

FIG. 2 *Sword tip inside scabbard (NLA14-111). From left to right: digital X-ray (LVR-LandesMuseum Bonn, 67,7 kV, 9,9 mA); µCT scan; µCT scan with transparent scabbard; cross-section of mineralised blade with fullers (NLA14-1147)(UGCT, 220 kV, 85 W, 1000 ms, voxel size: 180 µm),*
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FIG. 3 *Sword ensemble with buckle (NLA14-940), digital X-ray (LVR-LandesMuseum Bonn, 76,8 kV, 8,7 mA). Insert: µCT scan (UGCT, 175 kV, 50 W, 1000 ms, voxel size: 50 µm) and copper alloy buckle covered by iron corrosion (author),*
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FIG. 4 *Handle of a short sword (NLA14-1754), left to right: analogue X-ray (Vinçotte, 120 kV, 30 sec, 4mA); digital X-ray ((LVR-LandesMuseum Bonn, 70 kV, 9,6 mA); µCT scan (UGCT, 175 kV, 50 W, 1000 ms, voxel size: 50 µm); handle after cleaning (author),*
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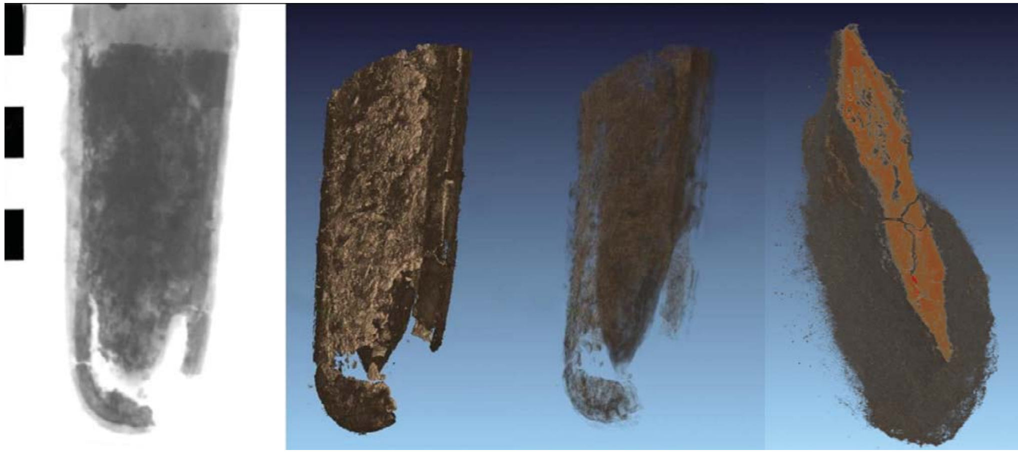

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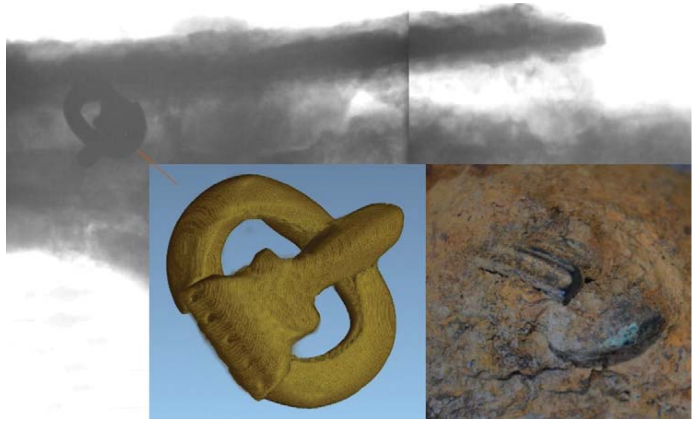

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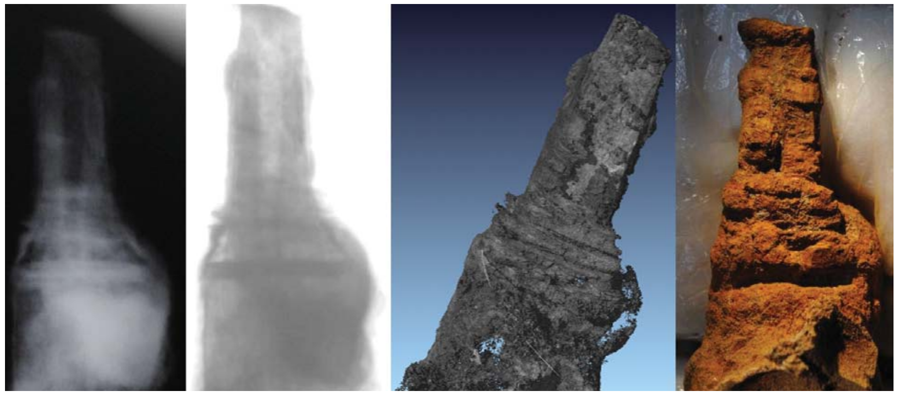

Excellent results with organic materials were obtained on the handle of a short sword. On the X-ray, some lines are visible, because iron corrosion has taken the shape of the original organic material and mineralised it. On the µCT, the organic rings are a lot clearer, which was an advantage during the conservation treatment of the object. It is extremely complicated to make organic structures like this visible by mechanical cleaning without damaging them, since the difference between the mineralised organic material and the other corrosion products is hard to observe, and the concretions that are present are harder than the organic material. The µCT scan allows for the localisation of these organic materials, significantly improving the speed of the conservation process. Unfortunately, the resolution with block excavations is not high enough to identify textile or wood. In order to do so, a sample should be taken, and a more detailed scan should be carried out.[23] Additionally, when organic materials are not strongly mineralised, they are not sufficiently discernible.

DISCUSSION

Compared to the traditional, straightforward process, there are many benefits that come with the application of a range of cleaning and imaging techniques when working with fragile or complex archaeological iron objects. Selective and investigative cleaning are much faster than full cleaning, and only the relevant parts are exposed, which means that the most important information will still be revealed. When an object has undergone full cleaning, all surface details and decorations are visible. If there are organic remains present, these can be investigated. However, in that case, there is also a chance of information being lost.

An X-ray provides a relatively accurate 2D image of the outline, possible decorations, and condition of the objects. For the identification of individual objects, a combination of X-ray and selective cleaning is usually enough. In the investigative phase, a combination of µCT and selective and investigative cleaning is the best option for optimal data collection: It offers a better result and is faster than the full cleaning of an object based on a 2D X-ray image. The µCT scans made things visible that would most probably have been missed during mechanical cleaning, such as mineralised organic remains.

However, µCT does have some disadvantages. Access to the necessary equipment is not always possible, since it is predominantly available at universities. A complication was the upright positioning of the objects, which makes it difficult to scan swords. In most examples presented here, a support had to be created using polyurethane foam and a separation layer of plastic. Another challenge is the post-processing: To get a clear result (without noise), the density parameters needed to be manipulated. This means that archaeologists, conservators, and technicians need to collaborate, since an experienced eye is required to virtually excavate the object until recognisable shapes appear.

Because it is possible to look through the soil and the corrosion, the organic materials can be preserved for future research. A downside of this is that it is difficult to interpret the objects. A possible solution is to use the µCT scans to clarify such objects. This is still a better option than removing corrosion and associated materials to obtain a uniform result with a significant loss of information. Since it is not possible to carry out stabilisation treatments on objects that remain in blocks, they will need to be stored at a low humidity and temperature, according to their specific material properties. While this could be used as an argument against this methodology, these environmental factors should be controlled for all archaeological objects, including those that have received treatment, therefore this point is neglectable.

CONCLUSION

Iron objects are of significant value in dating and interpreting archaeological sites. Due to the corrosion process of iron and the decay of organic materials in the ground, the information contained in these objects is often inaccessible. Using different levels of processing that apply various imaging methods in combination with a range of cleaning methodologies can provide a solution to this problem. For individual objects, an X-ray and selective cleaning are usually sufficient, while µCT and investigative cleaning are more interesting for complex block excavations with a variety of materials. The results largely depend on the skills of the specialist who is doing the µCT scan and image manipulation as well as on the communication between the conservator/archaeologist and the µCT specialist.

The case study presented in this paper shows the prime advantages of µCT compared with 2D X-ray imaging: the possibility of viewing objects in 3D and thereby assessing both their external and internal structure. The advantage compared with full cleaning is the possibility of visualising mineralised organic structures. Additionally, objects are being documented in their current state, original position, and context. Highly degraded and fragmented objects can therefore still be documented and virtually reconstructed in order to answer archaeological questions about typology and stratigraphy within a block. The method remains relatively expensive; therefore, the desired level of information needs to be clear.

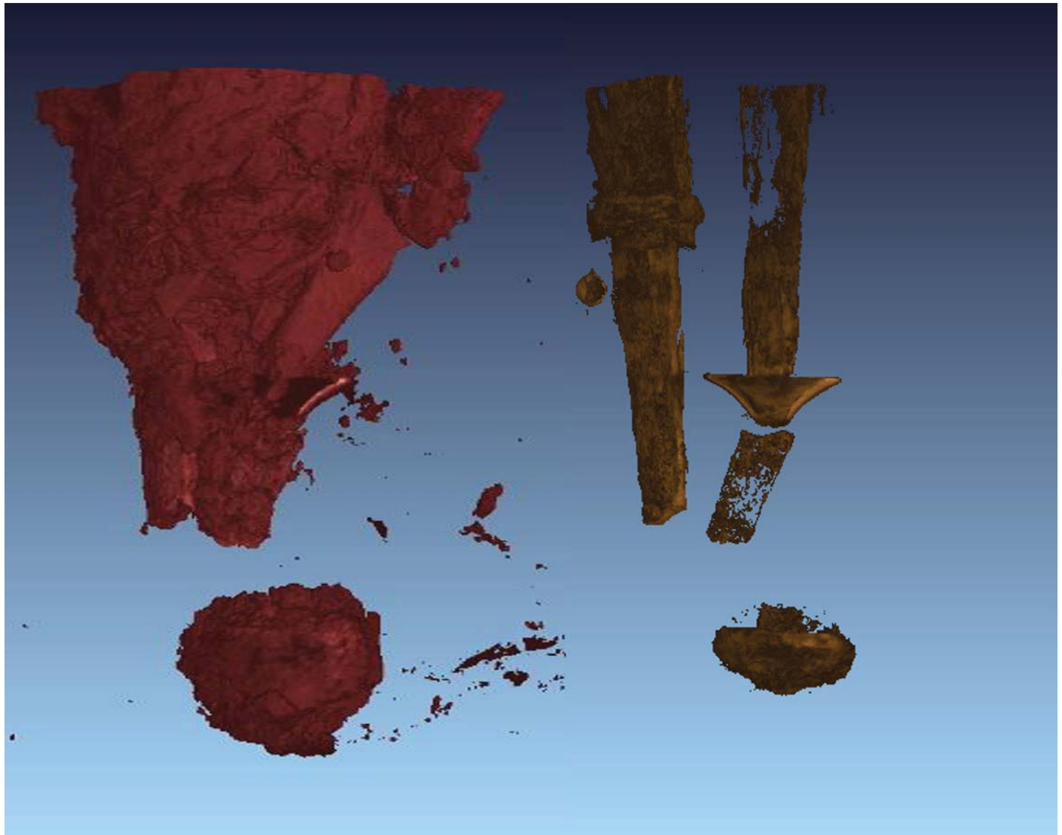

FIG. 5 *Post-processing of µCT scan to reveal hilt area of swords in a block excavation (UGCT, 175 kV, 50 W, 1000 ms, voxel size: 50 µm)*

ENDNOTES

[1] This research was carried out as part of a master's thesis at Artesis University College Antwerp (now University of Antwerp), supervised by Natalie Cleeren. The author is grateful for the collaboration with the Ghent University Centre of Computed Tomography (UGCT), Bureau Archeologie & Monumenten Nijmegen (BAMN), LVR-LandesMuseum Bonn, Vinçotte Wijnegem, and the department of Metallurgy and Materials Engineering at KU Leuven.

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