Ancient Basketry on the Inside: X-ray Computed Tomography for the Non-destructive Assessment of Small Archaeological Monocotyledonous Fragments. Examples from South-east Europe

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Abstract

This study proposes non-destructive assessment instrumentation, being the X-ray CT scanning, for the evaluation of archaeological basketry remains prior to any destructive analysis. There are three case studies, originating from two archaeological sites in South-east Europe, with three different stages of preservation (poor, sufficient and very good). In addition, there are two preservation modes – charring and desiccation – along with two conservation situations: treated and untreated with conservation agent fragments. The three different scenarios were chosen to explore the potential range of CT scanning technology when applied to monocotyledonous small-sized archaeological remains. It was proved that this non-invasive X-ray method is particularly suitable in the case of the often-disadvantaged ancient basketry remains.

1. Introduction

The very small-sized vegetal remains, such as the ones from basketry and other perishable material are often determined as unidentifiable. This is mostly due to their perishability and limited sample size. This article challenges these extremely fragile archaeobotanical remains by the application of the non-invasive and non-destructive assessment technology, which is the application of computed tomography (CT) scanning.

1.1. X-ray CT scanning in the study of archaeological woody remains

Initially designed for medical diagnostics, X-ray computed tomography scanning has been also applied for research purposes of different materials (Tuniz & Zanini, 2018). Since the current study focusses on basketry, and baskets are traditionally made with woody material and “grasses” (monocotyledonous), here a brief overview of the existing applications of CT to archaeological woody and non-woody material will be summarised (Beailieu & Dutilleul, 2019). It should be mentioned that very few previous applications of CT technology to non-carpological archaeological monocotyledonous remains were encountered in the existing scholarship.

Recently, the method was used for the study of heritage wooden objects of all sizes, varying from large Japanese wooden statues (Morigi et al., 2007), Italian or Flemish Medieval musical instruments (Sodini et al. 2012, Bulcke et al. 2009) to Renaissance miniature paintings (Morigi et al. 2007). This tool for non-invasive assessment and analysis revealed a great range of “hidden” details of the inner construction and structure of the observed objects, such as the application of “invisible” adhesive, micro pins, or micro wooden wedges. Apart from the technological analysis, CT scanning was applied to the study of wood anatomy of archaeological objects too.

However, a major obstacle proved to be the achieved image resolution of the scanned wood fragments, where some of the finer anatomical features remained obscured. Almost unavoidably, there was an additional method of analysis to-be-applied, to confirm/improve the CT scan for anatomical identification of ancient wood, such as Reflected Light microscopy and further 3-D reconstruction of the obtained images (Table 1). Nevertheless, if CT scanning needs to be brought further in terms of botanical identification of archaeological wood, there is a niche where it seems to be particularly suitable – the non-destructive assessment of perishable and small in size archaeological plant remains, preceding any destructive analytical process.

Table 1
Recent applications of X-ray Computed tomography to wood and charcoal concerning archaeology.

ARCHAEOLOGICAL	FRESH	SAMPLE	SAMPLE SIZE	RESOLUTION	ANATOMICAL STRUCTURES RECORDED	CT METHODOLOGY APPLIED	VERIFICATION METHOD APPLIED	PROBLEM ENCOUNTERED
	X*retted	Retted fibers of female hop stem	1.5cm	n/a	Fibre bundles in sclerenchyma and xylem of <i>Humulus lupulus</i>	Micro-CT	White-light microscopy	n/a
X		Block-lifted	-30x10x4mm -130x90x14mm -13x8x 1.5mm	-115µm -125µm -25µm-2µm	Large-luminal early wood vessels, their lumen diameter, 2–3 visible ring boundaries, medullary rays; <i>Quercus</i> sp.; <i>Fagus sylvatica</i>	µ-XCT/Sub-µ-XCT	RL microscopy	Resolution
X		Cross section of midden deposit	< 0.5 mm	0.9 µm	Wavy bundles of thin stems in an irregular pattern	Micro-CT	SEM	Resolution
X	X	Preserved in weaponry corrosion	1mm ³	100µm scale	Scalariform perforation plates in both <i>Illex aquifolium</i> and <i>Prunus avium</i> ; spiral thickness in modern wood	Sub-µ-XCT	Optical and RL microscopy	Resolution
X	X	Medieval mask	5x3x7mm	0.5 µm/pixel	Vessel ray pitting of <i>Salix</i> sp.	synchrotron x-ray µ-CT	Optical microscopy	
X	X	Fresh wood	-1mm ³ -1.6x1.8x1.1mm	< 25µm	Scalariform perforation plates, ray pitting and prismatic crystals of <i>Pinus sylvestris</i>	Microtomed at 1mm ³ + Sub-µ-XCT	None	None
X	X	Lab-produced charcoal; Archaeological charcoal	0.7cm ³	>21 µm,	Porosity of fresh <i>Pinus sylvestris</i> ; mineralisation of archaeological <i>P. sylvestris</i>	CT and X-ray density imaging	3D reconstruction	Resolution

1.2. Research questions

Archaeological basketry remains of vegetal origin are a peculiar type of archaeobotanical material characteristic with their extreme perishability, especially in the vast majority of taphonomic scenarios in South-east Europe. Their unstable condition is mostly due to the pathways of preservation typical for the region – predominantly they are charred, rarely desiccated and very rarely – waterlogged. This makes the archaeological basketry remains not-suited for undergoing the necessary manual fragmentation for achieving planes of observation (transversal, tangential and radial in the case of wood) because fragmenting them often means losing them. However, the application of a non-invasive assessment technique could at least partially solve that problem. And this was the main rationale that directed this study: could a non-invasive methodology, such as CT scanning, assess the level of preservation of small-sized and brittle archaeological basketry fragments and later aid their botanical identification?

2. Materials And Methods

This study presents three different archaeological basketry fragments, but all part of objects made with the technique of diagonal twilling (confirmed by the presence of the endings of selvages of the twilled surface), which consists of plaiting several strands to create an even twilled surface. The three basketry fragments are in different stages and modes of preservation. They were selected to represent poor, sufficient and very good preservation of their plant tissues, so the potential of the CT-scanning could be tested for different taphonomic environments. The first two fragments, subject to CT-scanning, came from a

single object – a twin-handled woven sack (zembil) from the Late Minoan (*circa* 1450 BC) settlement of Akrotiri (Santorini, Greece), while the third one consists of a woven mat fragment from the Roman burial mound Kitova (1st c. BC – 2nd c. AD), located in South-east Bulgaria (Fig. 1).

The sack from Akrotiri (Inventory numbers 035, later 8860, 8862) is a published item, which comes from Pillar Shaft 68A (Beloyanni, 2007). It is made in diagonal twill, while the handles are coiled. The size of the item is 0.175 cm in height and 0.275 cm in diameter (*ibid.*). Another smaller basketry item was discovered inside vessel 035 together with its content – carbonised barley grains (*ibid.*; Sarpaki, 1992; Fig. 2.a). Object 035 is preserved in a charred mode, and its vegetal tissue is infiltrated with the fine particles of the volcanic tephra, following the Santorini eruption. Besides, at the time of its discovery, the item has been treated with a 10% solution of thermo-plastic resin (Paraloid B-72®), to preserve its structure as a whole. The two analysed fragments were sampled from the body weave of the object and near the base (Fig. 2.a, red arrow). Both fragments were initially evaluated with the application of Reflected Light optical microscopy (BF-DF, Olympus BX 51) and the first one consists of agglomerated plant parts of a monocotyledonous plant(s) and was considered poorly preserved (*SCAN 1*), while the second one was considered sufficiently preserved single plant part of a monocotyledonous plant (*SCAN 2*).

The mat from Kitova mound is an unpublished item, originating from the central burial of the mound (Grave 6), where a young female individual was covered with a woven mat, perhaps placed as a shroud. The mat was in contact with several large bronze vessels and a wooden box amongst the grave offerings. Based on the inventory the burial was dated between 1 century BC and 2nd century AD. The mat is preserved in desiccated mode and as an assemblage of numerous fragments with an approximate surface coverage *in situ* 0.5m x 0.7m. In terms of conservation, the mat was treated with a 10% solution of the acrylic resin Paraloid B-72®, but prior to its application, a fragment (2.4 cm x 1.2 cm) was sampled for the purposes of the archaeobotanical analysis (Fig. 2.b, red arrow). This fragment was also examined under Reflected Light microscopy and its preservation was evaluated as very good (*SCAN 3*).

The micro-CT scans were conducted with Phoenix v/tome/x M® industrial scanner and were performed at the Hounsfield Facility of the University of Nottingham, UK. The achieved resolution came to 8µ due to the relatively large sample sizes (*circa* 4mm in diameter), which determined the FOD (focus-to-object distance) of 818.6(7) µ and 32.74(9) µ, operating in magnification x24.9. The scans were analysed with Phoenix datos/x 2.0 CT® software, where three-dimensional images and videos were produced (Supplement). The imaging was oriented along the X and Y-axis of the specimen, where the horizontal view (X) consists of a virtual transversal plane (Fig. 3.a), while the vertical (Y) shows the virtual longitudinal plane (Fig. 3.b). The density of the scanned material is what the radiograph reflects: areas with low X-ray absorption and hence with lower material density are visualised with dark voxels (the volumetric pixel unit used in X-ray CT), while the areas with high X-ray absorption and denser material are visualised with brighter voxels (Beailieu & Dutilleul, 2019; Kozatsas et al. 2018; Mansbridge 2015). In addition, the standard radiograph view was combined with “Surface determination mode” (hereafter: SDM) in order to enhance the visibility of the density of the anatomical features of the observed vegetal tissues (as in Fig. 3 and Fig. 5). The anatomical descriptions of the monocotyledons followed Cuttler (1969), Evert (2006), Metcalfe (1960; 1971).

3. Results

3.1. Preparation for CT scanning: Light microscopy

The samples were pre-examined with optical microscopy, including initial evaluation with a stereoscope and Reflected Light microscopy (BF-DF). The fragment which is described below as *SCAN 1*, appeared as an amorphous vegetal mass, consisting of agglomerated plant tissue. Going deeper into RL microscopy did not reveal any anatomical features, except the outline of the parallel venation, characteristic for the monocotyledonous plants. However, under less magnification, the stereoscope image displayed several disintegrated plant parts interwoven together, as part of the body weave of the studied sack. So, it may be suggested there were leaves and/or stems chosen to create the basketry item. It should be pointed out, that this fragment was extremely brittle and even during the careful manipulation for optical examination, it was fragmenting further. Here, the main rationale behind the following application of CT scanning was to avoid any manual treatment and still – to assess the level of preservation of the available plant tissues.

Regarding the fragment, which later will be subject to *SCAN 2*, it became clear that it consisted of two to three stems/leaves of a circular and acute overall outline. When examined under PPL light, the treated with conservation agent surface was polarising the light ejected from the microscope, making any anatomical analysis a difficult task. Only the longitudinal plane, being the epidermal tissue, was observed because obtaining a good transversal section would mean fragmenting the (already very) small fragment. Here the dense concentration of stomatal apertures (*circa* 2 per 50µm; Fig. 4. b) leads to the assumption that the observed plant part is a leaf. Anatomically wise, some of the morphology of the stomatal cells could be also detected: they appeared as non-paracytic and *cf.* superficial with open apertures (Fig. 4.b). The better preservation of this fragment (when compared to the previous one) stands out, but yet its limited size lead to the application of CT scanning, aiming at the evaluation of the preservation stage and that way taking a decision of further manual fragmentation for the purposes of botanical determination, because if the last was to-be-applied perhaps a single try would be possible (given the minimal size of the fragment).

Regarding *SCAN 3*, the preserved plant part consists of a culm or cylindrical leaf with a diameter of *circa* 2.5 mm of a monocotyledonous plant, as seen by the parallel arrangements of stomata, distributed along with the preserved epidermal tissue (Fig. 4.c). The high density of preserved stomatal cells (*circa* 3–4/ 1 mm²) points in support of both the abaxial epidermis being present (as the adaxial is often absent in cylindrical leaves) and the plant part being determined as a leaf, not a culm. It should be noted that this fragment performed quite well during the manual treatment when adjusted for optical examination. The desiccated stage of preservation ensured a great level of elasticity of the specimen under observation, which was not treated with any conservation agent. However, the transversal view was still quite unclear, because of the shrinkage of the anatomical structures due to the deposition process. Here, it was obvious that good preservation of the epidermal tissue is observed, but yet it was uncertain that the ground tissue is still present, which was the question to-be-answered when CT-scanning was performed.

3.2. Micro-CT scanning results

3.2.1. SCAN 1 (Poor preservation of fragment from object 035 of LM Akrotiri)

The first fragment which underwent the CT scanning was evaluated as not very promising when examined with optical microscopy, and this was the reason for testing a CT scanning of a small section of this fragment (*circa* 4 x 6 mm). Since the grey-tone images (X-ray view) was not sufficiently informative, here an SDM was applied, so the structures appear enhanced, but we lose the density determination, available in the X-ray view. At the overview image (5.a), it was possible to see the twilling elements, even in a quite distorted stage. However, separate cylindrical plant parts (stems and/or leaves) appeared pronounced (5.b), perhaps following the general plaiting direction of the item (5.c, red arrows). In addition, undulated structures of the epidermal tissue of these cylindrical vegetative parts were also recorded and it is assumed they represent the long epidermal cells of the observed monocotyledonous specimen (5.b, marked). All the above-mentioned characteristics were not distinguishable in X-ray view and SDM was applied in order to enhance the visibility of the scanned fragment (see the visual 3-D model at Supplement). When an animated 3-D model was created, it became clear that multiple epidermal tissues are “spiking” from this deformed fragment. Nevertheless, their overall structure was also detectable: the majority of the recorded plant parts are cylindrical and this is a result that would definitely aid the botanical determination of this fragment (Supplement). It should be noted, that the animation also illustrated very well the voids between the separate plant parts: firstly because of the poor preservation mode and secondly – due to the twilling technique, which shaped this basketry object.

3.2.2. SCAN 2 (Sufficient preservation of fragment from object 035 of LM Akrotiri)

A fresh cut was produced, in order to obtain a surface, suitable for observation (*circa* 1.5 x 2 mm). The sharp light voxels, which outline the cut of the observed fragment, are an artefact, created by the force applied when performing the cut, hence – compressing the anatomical structure. Nevertheless, the achieved model provides good visibility of darker and lighter voxels, even if the scanned carbonised fragment does not display excellent density. The overview of the fragment showed the presence of the epidermal tissue (6.a), but also its compact cover with tephra particles and the conservation agent layer (the granular appearances on 6.c). The transversal view illustrated the plant part(s) under observation was deformed – this is particularly visible in the compressed aerenchymatic cavities outlining the cross-section on the outer part (6.b). Moving towards the inside, it was detected that the mesophyll is partially preserved and that there are indications for the presence of vascular bundles (6.b, marked). However, the transversal view also shows that the sampled fragment consists of at least two plant parts because a second layer of aerenchymatic cavities is detected, being attached to the first plant part; in addition, at the very bottom of the image there may be a third plant part too (6.b, red arrows). This may be the case when twilling the actual basket – a bundle of plant parts (i.e. three stems) may have been applied in each strand of the plaits, for adding additional strength. The epidermal view (6.c) does not reveal the anatomical features of the tissue in great detail, but it should be pointed out that the outline of the stomatal apertures is detected and even more – their appearance as sunken stomata could be suggested (6. c, marked).

3.2.3. SCAN 3 (Good preservation of a mat fragment from the Roman Kitova mound)

The uncharred desiccated fragment from the Roman burial mat was reduced to *circa* 6 x 3 mm in size and it did provide a very clear X-ray view with the light voxels illustrating the dense preserved vegetal tissues and (excluding the super-light voxels – artefacts from the cut, during the sample preparation), darker ones showing the less compact tissue and the black – displaying the air voids. The overview of the fragment (7.a) proved that the porous tissues are almost completely decomposed, which is particularly visible at virtual transversal section (7.b). The organs, contained in the ground tissue, as the vascular bundles, together with the highly porous aerenchymatic and parenchymatic tissues seem to have decomposed (7.b, c). On the other hand, the epidermal tissue, shown on the virtual longitudinal plain is preserved in much better condition, making even possible the identification of the individual leaves forming the weave of the fragment (Fig. 7.b., c, marked). It seems that the specimen had preserved its cuticular layer, because of its stage of desiccation (and not charring), which appears as? smoothly ridges by the parallel venation. In addition, the X-axis shows elongated structures with identical tissue density, as the already identified epidermis: these are fibres of the sclerified sheaths surrounding the vascular bundles (which remained from the phloem in the vascular bundles, Fig. 7.a, c, red arrows).

4. Discussion

4.1. Is it worth braking? Non-destructive assessment prior to destructive analysis

X-ray CT scanning technology allows a non-destructive way for the evaluation of the plant tissues' stage of preservation, the tissues' location (articulated or disarticulated of their anatomical sequence) and a partial overview of the organs they contain, their shape, size and order. This non-invasive assessment proves to play a key role when proceeding to further destructive analysis. By the application of a CT scan, one can evaluate the readiness and suitability of a certain archaeobotanical fragment for further manual fragmentation for the purposes of botanical identification. For example, if the CT scan concludes that there is no tissue preserved under the epidermis, for the case of monocots, no further fragmentation would be needed, but only analytical observation of the epidermal tissue. On the contrary, if the CT scan confirms the ground tissue preservation, again in the case of monocots, further fragmentation could be attempted.

However, there are scenarios where manual fragmentation would not be applicable, even if sufficient preservation status is confirmed by CT scan. These could be the cases where the sample size is extremely small and/or the sample itself is very brittle. This is very likely the case with carbonised basketry remains and precisely monocotyledonous remains. There are numerous factors that make charred monocotyledonous stems and leaves much more unstable than wood charcoal, including their different mechanical properties, the chemical composition of tissues etc. (Beailieu & Dutilleul, 2019). However, conducting a non-invasive observation, such as CT scanning, could obtain the maximum information if we are about to lose the fragment under-examination when breaking it for obtaining planes of observation.

In addition, given the rarity of archaeological basketry remains in South-east Europe, often these objects are difficult to sample for the purposes of archaeobotanical analysis. One reason behind this, is that sampling involves physical breakage of the preserved objects' surface. And even more – if we would like to obtain a good dataset on the chosen raw plant material, we should sample from multiple areas of the basketry item. This brings forward another issue – the disturbance of the archaeological object as a whole for exhibiting purposes. Perhaps this is the scenario when the financial cost of CT scanning should be brought into discussion: yes, this type of analysis is relatively expensive, but not more than conducting Scanning Electron Microscopy, for example (if we take into account a single session per each method). Nevertheless, CT scanning could be applied to extremely small vegetal fragments, below the accepted sample size for standard charcoal study (Asouti & Austin, 2005), which would require an almost invisible breakage from the archaeological object. In addition, the sample-preparation for CT does not include any treatment of the surface (as the coating necessary for SEM), which renders the method as completely non-invasive. Hence, if we are aiming at obtaining an evaluation and assessment information with a minimal physical harm to the original perishable archaeological object (thus sampling a fragment of minimal size) and at the application of a non-invasive technique (so we preserve the fragments to later apply an invasive method, if this is necessary), the cost of conducting CT scanning seems rational and judicious.

4.2. Too small, too brittle: challenging the minimal sample size

Unfortunately, the sample size and the level of preservation do not ultimately go together – for example not always a small sample size means insufficient preservation and vice versa, the optimal preservation does not promise a sufficient sample size. Here the term “sufficient” is used for the stage of preservation that ensures manual fragmentation for conducting analysis for botanical determination of charred monocotyledonous fragments. This is where the assessment proves useful and informative – the interim stage between the initial examination and the destructive analysis for identifying the plant species. This is also where the general idea of what is a minimal sample size could be questioned. If for wood charcoal the recommended minimal fragments' size is 2mm³ (Asouti & Austin, 2005), then for grassy plant remains it could possibly be brought lower because the diagnostic anatomical structures for monocots are smaller in size. A good example is the registered *circa* 3–4 stomatal apertures per 1 mm² at the fragment subject to SCAN 3. This means that there should be long and/or short cells in the interim areas too, which all contribute to the features at a cell-level, necessary for obtaining a botanical identification. Nevertheless, here comes the challenge of the attained resolution when conducting a CT scan, which until now, proves to be insufficient for species determination. But perhaps in a time-perspective, this will change and the non-invasive CT technology could be applied for identification purposes too, producing virtual planes of observation and replacing the manual fragmentation.

4.3. Testing of different preservation types

The first fragment, which underwent CT scanning (SCAN 1) was charred and in a particularly poor stage of preservation: its whole surface was impregnated with volcanic tephra particles, and its outer tissues were sealed with a conservation agent. However, even at this level of preservation, the conducted CT scanning yet revealed details, preventing the fragmentation of this very unstable sample. The second sample analysed in this paper (SCAN 2) was in quite stable preservation mode – charred and not heavily impacted by volcanic particles. Even if the optical examination of this sample was informative, still the CT scan allowed for the recording of further details, such as the status of plant tissues. The last fragment (SCAN 3) was desiccated and presented great elasticity when treated for analysis, along with very well-preserved plant anatomy. Yet, in this best-case scenario, the CT scan showed the deformation of the inner vegetal tissues, even if the outer ones had good preservation state. The three case studies showcase the potential of the method and its applicability to wider taphonomic environments. Even if the botanical determination approach could differ depending on whether the sample is charred, desiccated, mineralised or waterlogged, the CT scanning assessment would be valid for all described contexts.

5. Conclusion

There are several advantages and disadvantages in the application of CT scanning. Amongst the pros are: CT scanning is a non-invasive technique and this is its greater advantage – the ability to show an internal structure in a non-destructive way. It eliminates the interference with the object, while conventional microscopy requires destructive methods, sectioning and achieving planes of observation, which are time-consuming and harm the object, which renders the technique unsuitable for several types of material culture. CT scanning also represents the object's original structure and features, creating a three-dimensional examination, without any damage to the cells and without creating 'artefacts' during the sample preparation (Bulcke et al., 2009). On the other hand, the major restriction of the method is the achieved resolution that does not allow for detailed anatomical observation. Regardless of the disadvantages of the method, CT scanning is a very promising non-invasive tool for the evaluation and assessment of archaeobotanical objects of small sizes, such as basketry items, but not limited to it, and unstable preservation mode.

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None

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Data will be uploaded as A Supplement to this paper, in a data repository (Mendeley Data or other)

Code availability:

Not applicable

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Figures

Figure 1

Map displaying the location of the two sites, discussed in this paper.

Figure 2

The two basketry objects, subject to this study, at their stage after the application of a conservation agent: a. twilled basket from LM Akrotiri, b. twilled mat from Roman Kitova mound and the area of sampling (red arrows).

Figure 3

Snapshot from the Phoenix datos/x 2.0 CT® software: a. cutting a virtual transversal plane, b. virtual longitudinal plane.

Figure 4

Examination of the studied fragments with optical microscopy prior to conducting the CT scans: a. fragment subject to SCAN 1, under a stereoscope, b. sample subject to SCAN 2 under PPL , c. sample subject to SCAN 3 under BF environment.

Figure 5

SCAN 1: a. an overview, b. details on tilted transversal view, c. details on tangential view

Figure 6

SCAN 2: a. overview, b. virtual transversal view, c. virtual epidermal view.

Figure 7

SCAN 3: a. overview, b. virtual transversal view, c. tilted virtual longitudinal view.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SCAN1XaxisANDONOVA.wmv](#)
- [SCAN1YaxisANDONOVA.wmv](#)
- [SCAN3XaxisANDONOVA.wmv](#)
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