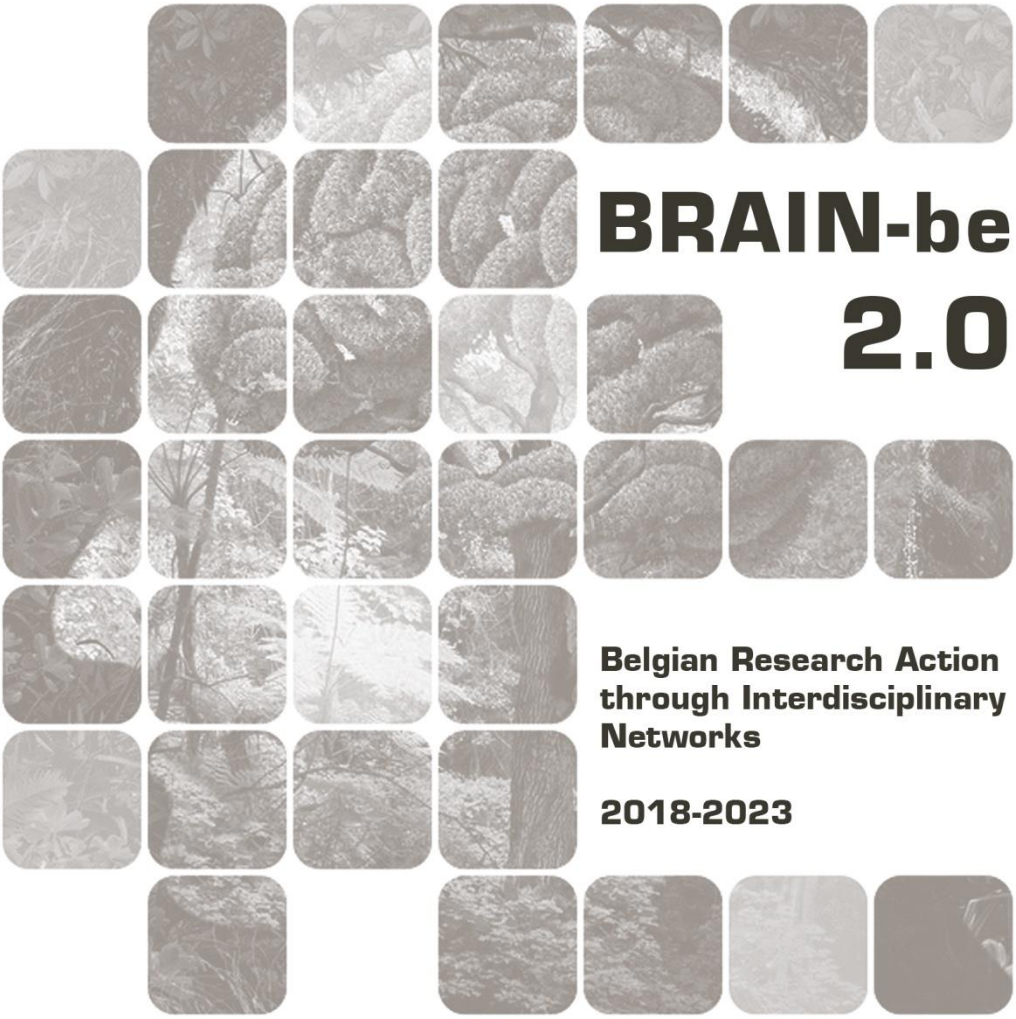

TOCOWO (TOmography of COngolese Wooden Objects)

In support of the international travel of ethnographic collections: Identification of wood on Congolese objects using micro- and sub micron Tomography

Siska Genbrugge (RMCA) – Jan Van den Bulcke (UGent) – Hans Beeckman (RMCA) – Wannes Hubau (RMCA/UGent) - Sofie Dierickx (RMCA/UGent)

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WTCIII
Simon Bolivarlaan 30 bus 7
Boulevard Simon Bolivar 30 bte 7
B-1000 Brussels
Belgium
Tel: +32 (0)2 238 34 11
http://www.belspo.be
http://www.belspo.be/brain-be

Contact person: Helena Calvo Del Castillo
Tel: +32 (0)2 238 36 15

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ABSTRACT

Context

The Royal Museum for Central Africa (RMCA) hosts a large collection of Congolese heritage objects. Of this vast collection, more than 55.000 sculptures, musical instruments, equipment, furniture, and alike are made of wood or contain wooden elements. For less than 7% of these wooden objects has the tropical species ever been determined. Yet a wood identification of the collection objects enable the museum to share its unique collection more widely, sending objects abroad on traveling exhibitions or loans conform to the international laws of endangered species. Discovering more about the wood species represented in the collection can also provide insight into their construction or their region of origin. In addition, knowledge of the wood species of an object can also aid the conservators of the museum in determining the best treatment course, considering the specific characteristics of the wood species and its ageing properties.

Objectives

To date, the practice for identifying African wood species requires a sample of wood from the object. By processing the sample and studying it microscopically, the anatomical features of the wood species can be described and matched to a possible wood species. Such an invasive method permanently removes a part of the object, ranging from 2 mm^3 to 2 cm^3. The TOCOWO project, which started in September 2020, aimed to explore the possibility of micron and sub-micron X-ray computed tomography (µCT) as a non-invasive alternative for the identification of wood species. At the time, the technique had already shown much promise in the field of wood biology, as it can capture high-resolution information of its internal wood structure. A second objective of the project was to formulate a protocol for the µCT scanning of heritage objects, specifically fragile African objects such as held by the museum. Lastly, the project aimed to set up a reference database from the scanned tropical wood species present in the collection.

Conclusions

At the conclusion of the two-year project, 109 objects from the collection of the RMCA have been scanned, creating a unique dataset. The TOCOWO project was able to confirm the technique can lead to positive wood identifications and has also documented the technique's limits regarding the analysis of African heritage objects. The high-resolution scans of the wood structure inside the object show many anatomical features, allowing a description of the wood to be made. The acquired resolution - and chance of a successful identification – depended on the object's dimensions, shape, included materials and wood species. A protocol was drafted to provide a guide through the intricacies of scanning museum objects, and specifically the specific delicacies of analysing African heritage objects. CONteXT, a follow-up project to TOCOWO, will further explore the vast dataset of scanned objects, focusing on the material evidence inside the objects pertaining to their construction, history, and original context. All results will be disclosed by the end of the project in an exhaustive image database and an exhibition in the RMCA.

Keywords

Wood anatomy, African heritage, Conservation, Travelling exhibitions, Micro-CT and sub-micron CT, CITES

1. INTRODUCTION

The Royal Museum for Central Africa (RMCA) in Tervuren holds a large and unique collection of heritage objects from the Democratic Republic of Congo. Over 55.000 of the sculptures, musical instruments, equipment, furniture, and power objects that reside in the museum's reserves are made of wood or contain wooden elements. A wealth of diverse tropical wood species is contained within these objects, yet the majority of them has never been analyzed. Since the 1960s, researchers in the museum have succeeded in establishing the wood species of about 3800 objects from this vast collection, amounting to almost 7% of the wooden heritage collection.

Obtaining a positive identification for the wood contained within the collection objects is vital for the operation of the museum, however. First and foremost, knowing the wood species of an object enables the museum to send it abroad while conforming to the international regulations surrounding endangered species, such as the Convention on International Trade in Endangered Species (CITES) or the IUCN Red List of Threatened Species. Whether it is for an international loan, or a traveling exhibition, the RMCA is bound to first acquire information about the wood species incorporated in the objects before it can share its collection internationally. Secondly, uncovering more of the wood species present in the museum's collection may provide additional insight into the history and provenance of the collection. By identifying more objects in the museum, a link may be found between wood species selection and the types of objects made or the region they originated from. As such, it can provide much needed information to a severely under-documented collection. In addition, an improved understanding of the materials the heritage objects are made of may assist curators in answering questions from customs and other legal instances on confiscated objects. Lastly, knowing the wood species present in the museum's collection will aid the conservation department in better understanding, preserving, and treating the objects in their care.

Unfortunately, the most frequently used method to obtain a wood species identification remains to this day a destructive one: it requires a sample being taken from the object. The sample can range in size between 2 mm^3 and 2 cm^3, with a larger sample improving the chances of an identification. It is then prepared into sections, so the wood anatomical features can be viewed microscopically. Since the sample is irretrievably lost after concluding the analysis, it is impossible to re-incorporate the sample into the object. Consequently, as still evidenced by the eye-catching lacunae in the majority of the objects that make up 7% of the collection objects that were identified since the 1960s, the damaging analysis permanently changes the integrity of the heritage objects.

There was an increasing need for more wood analysis on the collection in the museum, but preferentially a non-destructive alternative. The TOCOWO project (Tomography of Congolese Wooden Objects) started in September 2020, a bottom-up BRAIN project, funded by BELSPO for two years. It aimed to explore the possibilities of X-ray micro and sub-micron computed tomography (µCT) as a non-invasive alternative for wood identification in heritage objects, develop a protocol for scanning collection objects based on the acquired experience and set up a reference database of scanned tropical wood species.

2. STATE OF THE ART AND OBJECTIVES

2.1 Non-destructive wood identification methods

At present, multiple techniques for the analysis of wood are being developed and/or refined, focusing on obtaining a wood species identification non-destructively. There is a large demand, not only from the heritage field, but also from the industrial wood timber trade, to find a sure and minimally destructive technique to combat illegal trade of protected species. A brief discussion of these techniques follows below, as well as why they were or were not considered for the purposes of the TOCOWO project.

Macroscopic and microscopic surface study | A visual inspection of the surface of the wooden object can sometimes reveal wood sufficient features to enable an identification. Many publications and websites aimed at the timber trade offer a guide to the macroscopic study of wood (Ruffinatto and Crivellaro, 2019) (Meier, 2023). Similarly, mobile applications are appearing with the same target audience, facilitating species identification based on the features visible on the wood surface (Tang, et al. 2019) (Koch, 2020). Focusing on heritage objects, Haag et al. proved with their 2017 study of wooden musical instruments that with 3D light-reflected microscopy, high quality images of the surface of the wood could provide enough information on the wood features to identify the wood (Haag, et al., 2017). In this study, as in the timber trade, the visual identification of the surface of wood is relying on a clear view of said surface; a rough exterior or coating obscures the view of the necessary wood features. In the field of timber trade, a small area of the wood can be ‘cleared’, cutting away some of the rough or covered wood to obtain a smooth surface ideal for observation of the features. As such, this technique is only applicable in the heritage field if the studied objects have a smoothly finished and clear coating, as was the case for the guitars in the 2017 study. Unfortunately, the vast majority of wooden objects in the RMCA’s collection have a rough finish, a carved relief or a finishing layer of pigments or patina obscuring the structure of the wood. The macroscopic and microscopic study of the wood surface was therefore not viable as a non-destructive technique for the systematic identification of the collection.

DART-TOFMS | A technique that uses chemical profiling of wood species to enable an identification, DART-TOFMS collects metabolome profiles using mass spectrometry. Direct analysis in real time (DART©) ionization is used in combination with time-of-flight mass spectrometry (TOFMS) to analyze and classify wood species and allows them to be compared and identified based on their unique chemical fingerprints (Deklerck, et al., 2019). Despite some very promising results, for example the 2020 study profiling and comparing 18 stem disks from the DRC and the Côte d’Ivoire (Deklerck, et al., 2020), the technique is still experimental. It relies heavily on a broad spectra database, which is still in development (Prince et al., 2022). In addition, the various coating products commonly found on the surface of the RMCA’s collection objects are likely to skew the results of the DART-TOFMS analysis. As such, the technique was not considered for the purposes of the TOCOWO project.

FTIR-ATR | Relying on Attenuated total reflectance-Fourier transform infrared (FTIR-ATR) spectroscopy, the infrared spectrum of absorption or emission of a wood species can be registered and used to discern between species (Sharma, et al., 2020). The technique shows very promising results in recent years, used in one 2018 study to differentiate between four oak species in Iberian shipwrecks (Traoré, et al., 2018) and, more recently, to identify nine Mexican pine species (Quinones, et al. 2022). Despite these successful case-studies, however, a more developed technique was preferred for the large scale and systematic approach aspired by the TOCOWO project.

X-ray µCT | Around the turn of the 21st century, X-ray micro computed tomography (µCT) became increasingly popular for the study of plant tissue (Steppe et al., 2004) (Gabner, 2009) (Broderson et al., 2013). As it generates a high resolution, three-dimensional view of the exterior and interior of the scanned sample, it can offer an unrivalled visualization of the anatomical structure of wood. In addition, the constant development of higher quality images and faster acquisition time has made µCT an increasingly popular technique for non-destructive analysis. Over the past decades, promising experiments and case studies have proven the viability of the technique for descriptive and quantitative wood identification. Examples include a 2009 study, which successfully visualized the features of four wood samples, covering both temperate and tropical species (Van den Bulcke, et al., 2009). In 2011 the wood of an archaeological artefact was identified. Using X-ray sub-micron CT, a small sample (1 mm³) of wood preserved in a corrosion layer was scanned at a high resolution, enabling a wood species identification (Haneca et al., 2011). Two larger samples of archaeological wood (up to 20 cm in diameter) were scanned using µCT in 2015, allowing one of the two samples to be identified as oak (Stelzner and Millon, 2015). In 2016 a study scanned eight bows of historical musical instruments in their entirety and was able to identify the wood species of three of them. (Fioravanti et al., 2016). More recently, Rankin et al. scanned two archaeological objects from a shipwreck, and were able to scan the small artefacts, a pipe and a tuning peg, at 1 µm voxel resolution, obtaining an identification for both to genus level (Rankin et al., 2021).

In addition to the promise for wood identification shown in the above-mentioned case-studies, X-ray µCT has the added benefit of being unhindered by any finishing layers on the surface of the objects. Unlike the visual analysis or chemical profiling relied upon by the other non-destructive techniques described in this section, X-rays will travel through any patinas, pigments, carvings, or rough surfaces on the object, and still provide a view of the internal wood structure. While highly attenuating materials, such as certain pigments, metals or ceramics, may cause image artefacts due to for example diffraction of the X-rays, the underlying wood may still be visualized to a certain extent. Since µCT was the furthest developed and best suited technique for the study of the varied collection the RMCA, the TOCOWO project set out to fully explore its possibilities and limitations with regards to the systematic implementation of museum objects.

2.2 Project objectives

Systematic analysis of the collection through X-ray µCT | The primary objective of the TOCOWO project was to explore the possibilities and limitations of X-ray µCT for the non-destructive wood identification of heritage objects in the Royal Museum for Central Africa. To fully examine the applicability of the technique for a systematic analysis of museum objects, a large and varied selection of collection objects was scanned, to answer the following questions: at what resolution is it possible to see which anatomical features, and is it possible to obtain a species identification of the tropical wood species inside the scanned heritage objects? Which dimensions and shapes of the objects allow a scan of high enough resolution to be attained, and which materials can deteriorate the quality the acquired scans? The results of the project would both inform future museum professionals of the possibilities of X-ray CT for wood identification and supplement the museum's heritage database with additional wood species identifications.

Draft an optimized scanning protocol | In addition to scanning and identifying the objects from the RMCA's collection, the project also aimed to collate the experiences, both successes and failures, gained during the scan process into a protocol. This optimized protocol would serve as a guide for conservation professionals both inside the FSI and in other museums, who were contemplating using the same techniques for the study of (African) heritage objects.

Set up a reference database | A last objective was to collect the generated high-resolution scans of the heritage objects and their internal wood structure and share them in an online reference database, to facilitate any future comparative studies based on CT scans of tropical wood or wooden heritage objects.

3. METHODOLOGY

3.1 Sample selection

3.1.1 wood sample selection

In the early stages of the TOCOWO project, in order to provide a framework for the upcoming µCT scanning of collection objects for wood identification purposes, a selection of samples of 20 wood species was scanned at different resolutions. By scanning the different species at 1 µm, 3 µm, 8 µm and 15 µm reconstructed voxel size (here used as an indicator of resolution), a first overview could be established as to which anatomical features could be visualized and/or measured at which resolutions. The wood samples were provided by the museum's wood biology department, which manages a large xylarium of reference samples from wood species. Each species was chosen for their prevalence in the object collection, based on the (albeit small) database of already identified wooden objects. Table I shows all 20 scanned species studied in this preliminary experiment, as well as their sample number in the FSI's xylarium, and how often the species was recorded in the museum objects that were already analyzed in the past.

Table i: list of 20 Congolese wood species most often found in the museum's heritage collection.

Wood species	Sample number	Prevalence in the identified collection
RUBIACEAE Crossopteryx sp.		21,37%
Crossopteryx febrifuga Afzel. Ex G. Don	Tw1225	21,37%
EUPHORBIACEAE Ricinodendron sp.		10,01%
Ricinodendron heudelotii (Baill.) Pierre ex Heckel	Tw2603	6,69%
VERBENACEAE Vitex sp.		8,90%
Vitex congolensis A. Chev.	Tw7733	1,01%
Vitex ferruginea Schumach. & Thonn.	Tw59654	0,02%
Vitex madiensis Oliv.	Tw2033	1,72%
APOCYNACEAE Alstonia sp.		8,54%
Alstonia congensis Engl.	Tw422	5,65%
EUPHORBIACEAE Crotonogyne sp.		3,93%
Crotonogyne poggei Pax.	Tw38280	3,93%
RUIACEAE Nauclea sp.		2,69%
Nauclea latifolia Sm.	Tw32703	0,89%
Nauclea pobeguinii (Pobeg.) Merr.	Tw1961	1,80%
FABACEAE Pterocarpus sp.		2,43%
Pterocarpus angolensis DC.	Tw325	0,53%
Pterocarpus tinctorius	Tw5157	0,68%
BURSERACEAE Canarium sp.		2,13%
Canarium schweinfurthii Engl.	Tw801	2,13%
MORACEAE Ficus sp.		1,85 %
Ficus bubu Warb.	Tw2020	0,56%
Ficus mucuso Welw. ex Ficalho	Tw8260	0,13%
Ficus variifolia Warb.	Tw8140	0,35%
BORAGINACEAE Cordia sp.		1,55%
Cordia millenii Baker	Tw8110	1,52%
MORACEAE Milicia sp.		1,24%
Milicia excelsa (Welw.) C.C. Berg	Tw54831	1,24%
APOCYNACEAE Funtumia sp.		1,17%
Funtumia Africana (Benth.) Stapf	Tw476	0,46%
FABACEAE Albizia sp.		0,89%
Albizia zygia (DC.) J.F. Macbr.	Tw64582	0,71%
BIGNONIACEAE Markhamia sp.		0,84%
Markhamia tomentosa (Benth.) K. Schum. Ex Engl.	Tw28543	0,84%

3.1.2 Object selection

The primary goal when selecting museum objects to be scanned, was to make the resulting dataset as representative as possible of the FSI's vast and varied collection. Attention was paid to selecting objects from a wide range of both typology and the culture of origin.

Typology | As shown in figure 1, the 109 selected objects include wooden sculptures, masks and musical instruments, but also power objects and objects of use. The umbrella term 'power objects' covers any object that was ascribed a power by its source community. Either by inclusions of charged ingredients within the objects, or additions of status symbols to signify the power the object wielded, the object could serve as a link between this world and the spirit world and serve the community it was made for. The last category, objects of use, is the broadest. It includes objects like wood working tools, furniture, toys, cutlery and more. A full list of the 109 objects scanned in the course of this project can be found in annex 1, ordered by their typology.

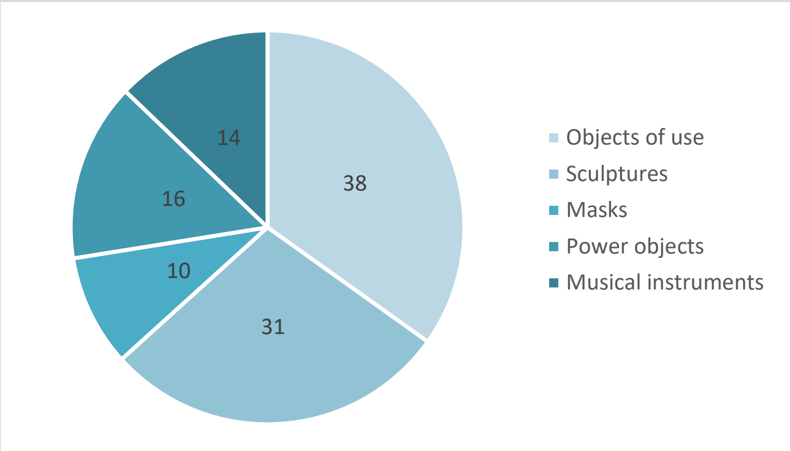

Figure 1: overview of the different types of objects scanned in the TOCOWO project

Geography | Figure 2 shows the geographical distribution of the objects on a map of the Democratic Republic of Congo. There are clearly more objects selected from cultures in the south of the country, with less objects from the northern cultures, and distinctly less objects from the middle of the country. This discrepancy mirrors the geographical provenance of the museum's collection, which is in its turn reflective of the (Belgian) collector's presence in the DRC in the past 150 years. The object fiches shown in annex 1 also include the objects' source cultures.

Dimensions and shape | In addition to their typology and geographical provenance, objects were further assessed with regards to their physical features. The dimensions of the object are an important indicator for the eventual success of the scan, as the width of an object determines how close the object can be placed to the X-ray source inside the scanner, which in turn influences the highest attainable resolution. The objects included in this research ranged between 88 and 5 cm in height, 104 and 1 cm in width. This large range in dimensions was targeted to fully explore the possibilities of the technique; by including both more promising and more challenging parameters. While the maximum width was considered, equally important during the selection process was the shape of the object. Most objects in the RMCA's collection are not homogenous in diameter, with a shape including narrower parts, or protrusions. By positioning the objects to target the narrowest zone of the object, done with the help of custom-made supports for the art objects, the highest possible resolution for each object could still be obtained. The object list in annex 1 also contains dimensions of the object.

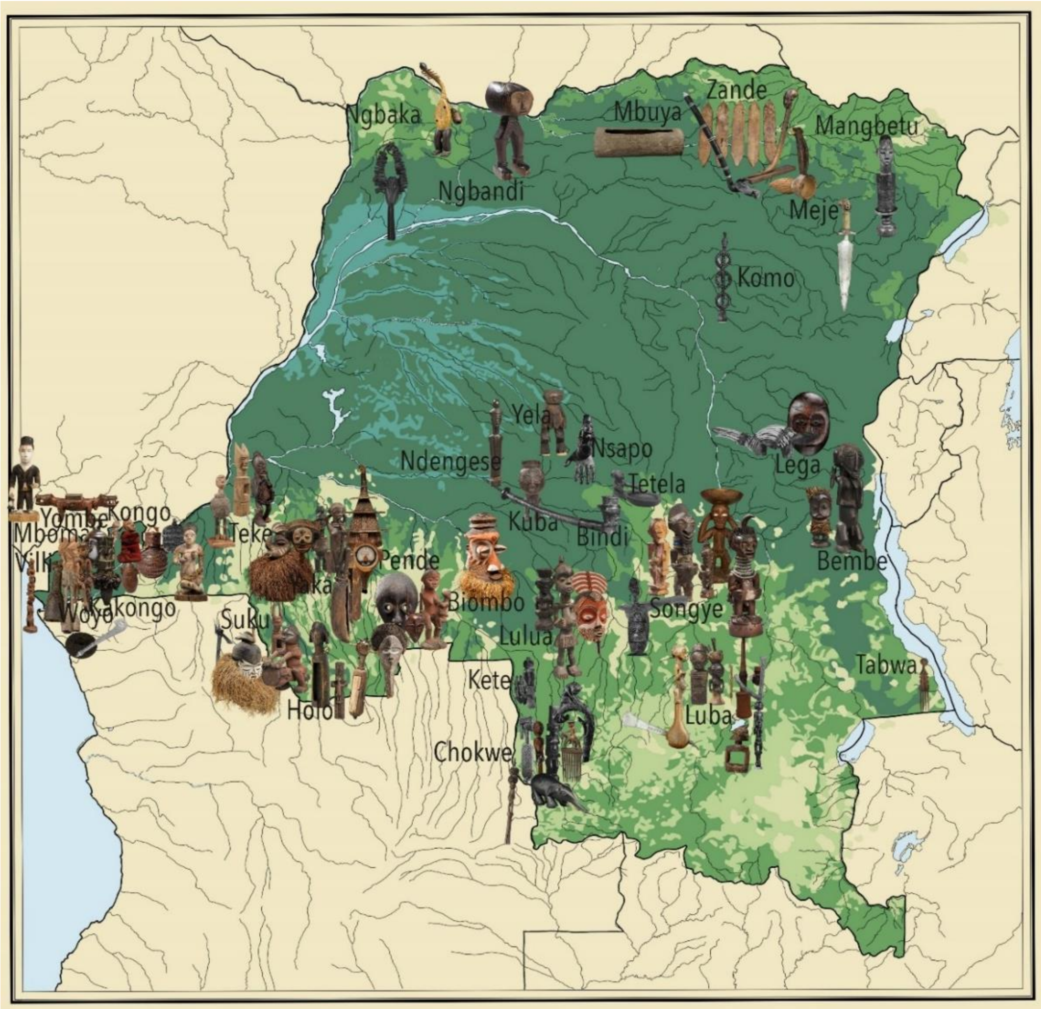

Figure 2: geographical distribution of the 109 collection objects scanned during the TOCOWO project ©RMCA ©UGCT ©UGent-Woodlab

Materials | Further attention was paid to the materials each object is made of. The majority of the 109 scanned objects contain materials other than wood, either organic or inorganic: plant fibers, fur, glass, metal, and teeth to name just a few. As these materials each have a different attenuation coefficient, their reaction when exposed to X-rays will differ. Higher attenuating materials such as metals can cause the X-rays to scatter or diffract, leading to 'image artefacts' or loss of information in the scans. A wide array of materials frequently found in the collection was included in the final selection of objects, to fully evaluate the potential interference any of the materials could have on the resulting scans. A final category in the object information given in annex 1 includes all materials other than wood included in each object.

Fragility | A last, but determining, factor in the selection of the objects was its physical condition. After the preliminary selection was made based on the previously stated factors, a conservator had final say over whether the selected objects were in stable enough condition to be scanned. Foremost because the objects needed to be able to travel from the museum's storage in Tervuren to the scanning facilities in Ghent (and back), with all the risks inherent in art travel. Secondly because, once at the scanner, the objects endured some manipulation to place them in a custom-made support and into the scanner in the desired position. Objects with a risk of loss of material or breakage were therefore removed from the final selection.

3.2 Micron and sub-μT scanning

All scans acquired during the TOCOWO project were made with high resolution X-ray CT scanners located at the facilities of the UGent Center for X-ray tomography (UGCT, www.ugent.be). The department develops state-of-the-art X-ray CT scanners for research, making each scanner modular and optimized for specific research fields. In contrast to medical X-ray scanners, the industrial scanners used in the TOCOWO project have a stationary X-ray source and detector, while the sample is placed on a rotation stage in between both. All the scanners used in the TOCOWO project were micron and submicron scanners, capable of generating high-resolution scans. This high quality is imperative to successfully meet the intended objective of the project: to visualize the internal wood structures inside the objects and enable wood species identification.

Figure 3 shows a schematic of the main components of an X-ray scanner. The X-ray source (A on the schematic) generates X-rays. In the instance of the scanners discussed below, the X-rays were generated in a cone-shape, shown as a blue bundle on the schematic. The 'focal spot' size will influence the resolution of the resulting scan. The detector (B on the schematic) captures the X-rays that travelled through object and registers the energy that remains after passing through the sample. The image captured on the detector is a projection image, or radiograph. Because the object turns a full 360° while it is being scanned, projections of every angle of the object are taken. These 2D projections are subsequently processed through digital reconstruction into 3D information about the scanned volume.

3.2.1 Scanners

Three scanners from the UGCT department were used in the course of the TOCOWO project. They are described more in depth below.

Nanowood | The Nanowood scanner was used to scan the samples of 20 tropical wood species at four resolutions for the preliminary experiment. The scanner was developed specifically for the study of wood samples. It has two sources and two detectors, enabling high-resolution scans on small and larger scales. The first source and corresponding was capable of scanning the reference samples at 1 μm voxel size. To scan the samples at the three lower resolutions (3 μm, 8 μm and 15 μm), the second X-ray source and detector were used (Dierick, M. et al., 2014).

HECTOR | The main system used to scan the bulk of the collection objects was the High-Energy CT scanner Optimized for Research, or HECTOR. Developed to scan larger objects containing highly absorbing materials at a faster rate, the scanner was ideally suited to scan the wide variety of heritage objects from the museum's collection (Masschaele, B. et al, 2013).

TESCAN CoreTOM | The most recent addition to the scanning facilities of the UGCT, the CoreTOM scanner was developed as a general purpose system, capable of scanning a large range of sample sizes and materials. Some of the smaller collection objects were scanned using this scanner, in tandem with scans being made in HECTOR, to optimize the use of scan time. (https://www.ugent.be/we/ugct/en/research/ctscanners)

3.2.2 Sample preparation

Wood samples | The wood samples of 20 different tropical species, scanned for the preliminary experiment, were subdivided into small cubes. The samples that were scanned at the highest resolution, 1 µm voxel size, were cut into needle-shaped specimen of 1 x 1 x 10 mm. For the 3 µm scans, cubes of 5 mm^3 were made, and for the 8 µm and 15 µm scans the cubes were cut to 1 cm^3.

Heritage objects | Before each art transport from the reserves in Tervuren to the facilities in Ghent and back, the condition of the collection objects was documented in a condition report. Photographs and a detailed description of each facet of the object were made, to allow a comparison at arrival Ghent facilities. Any changes in the condition could be noted, signed off by the accompanying conservator – in this case the hired researcher on the TOCOWO project. In addition to the labour-intensive process of preparing condition reports, many of the selected objects also required a support: to be able to stand in the scanner, or to position them favourably for a better region of interest scan. Each support was custom-made by a conservator, using polyethylene foam, wood or Styrofoam, depending on the objects' weight and dimensions. A layer of Tyvek© was always used between the object and its structural support, to protect it from any friction or dirt during the scanning process. Figure 3 shows a Bindi pipe positioned vertically to optimize the quality of the scan, by placing it inside a foam block (indicated in orange) and stabilizing it with wooden sticks (indicated in green).

3.2.3 Overview and Region of Interest scan

Each object was scanned twice: first visualizing the entire object in an 'overview' scan, and then targeting only a small part of the object at a higher resolution in a 'region of interest' (ROI) scan. Figure 3 illustrates the configuration of both scans. To capture as much of the object as possible on the detector, the sample is moved further away from the X-ray source, and closer to the detector. The objects that exceeded the dimensions of the detector (40 x 40 cm) had to be scanned several times, after which the scans were stitched together. These overview scans enable an unprecedented view into the object, inside and out. The ROI scans were made by placing the object closer to the X-ray source, and further from the detector, to achieve a larger magnification of the internal wood structure. A lot of time was invested in finding the optimal position of the object for the ROI scan: as close as possible to the X-ray source without any danger of touching the metal casing of the source when the object completed a full rotation during the scan. The Bindi pipe shown in figure 3 was placed at 91 cm

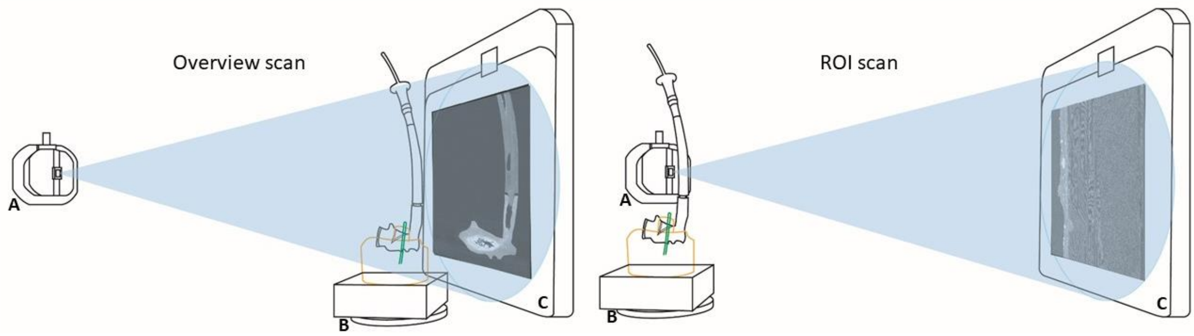

Figure 3: Schematic representation of the configuration inside HECTOR for the overview scan and ROI scan of a Bindi pipe (EO.1957.35.2). A indicates the X-ray source, B the rotation stage and C the detector. The support is made of polyethylene foam (orange) and wooden sticks (green). ©RMCA ©UGCT ©UGent-Woodlab

from the X-ray source for its overview scan. For the ROI scan of the stem of the pipe, it was placed at 3.3 cm form the X-ray source, while the bowl of the pipe moved unhindered underneath the source.

3.3 Wood identification

3.3.1 Wood planes

After the scans are reconstructed, they constitute a digital, three-dimensional volume of information on the sample. Using specific software, it is possible to virtually cut through this volume in any direction. This is especially interesting for the analysis of wood anatomy, as it enables the three important planes in the wood to be uncovered with ease: the transverse plane, horizontal inside the tree, the radial plane, along the axis of the tree along the rays of the wood, and the tangential plane, perpendicular to the radial plane. Figure 4 illustrates all three wood planes inside the 3D model of a scanned sculpture. To make the cross sections of the scans, the open-source software ImageJ© was used (Schneider et al., 2012).

Aside from digital cross-sections, the 3D information recorded during scanning could also be rendered into a 3D model. The proprietary software VGStudio MAX© allows these virtual models to be rendered, analyzed, and manipulated (Tkac et al., 2022). The model shown in Figure 4 is set to 50% transparency, to allow the internal structure to be seen.

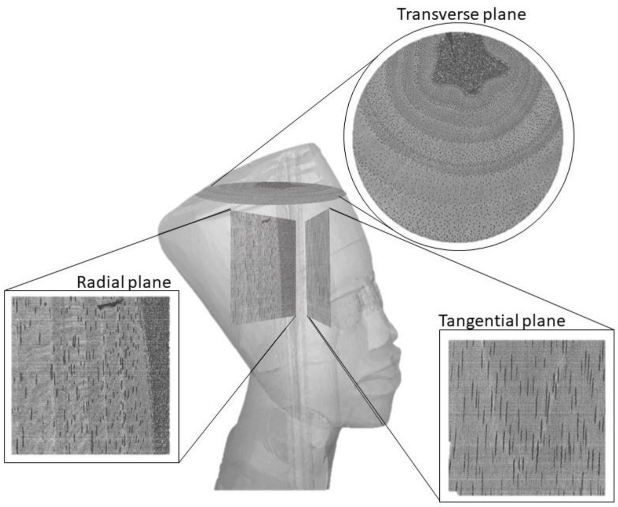

Figure 4: 3D rendering of a Congolese statue (EO.1955.132.1) showing the position of the three wood planes inside the object. Rendering made using VGStudio MAX©. Cross sections of the three wood planes made with ImageJ©. ©RMCA ©UGCT ©UGent-Woodlab

3.3.2. Reference databases

Once all planes were virtually retrieved from the acquired ROI scans, the anatomical features they revealed could be studied. Each of the three wood planes shows a different aspects of the anatomical features of the wood, and thus offers additional information that can narrow down a wood species identification. A first step in the identification of the scanned wood species was to describe the discernible and/or measurable features on the scans. In order to do this, the standardized system listed by the International Association of Wood Anatomists (Wheeler, 2012) was followed, whereby each possible anatomical feature is assigned a numerical code. This coded description can then be compared to the online database Inside Wood (insidewood.lib.ncsu.edu), which contains the anatomical descriptions of over 7.000 modern hardwoods. By entering the observed features, the search engine of the online database will narrow down which species could be a possible match to the scanned wood.

Once a shortened list of possible species was refined from the initial search on the inside wood database, the scans were further subjected to a visual comparison to the micrographs of each wood species included on the website. As a final step, the scans were also compared to the physical microscopical sections stored in the RMCA’s wood department. This vast reference collection of African wood species was used as a final check before committing to an identification of the scan.

4. SCIENTIFIC RESULTS AND RECOMMENDATIONS

4.1 Unique dataset of 109 Congolese heritage objects

Over the course of 2 years, 109 Congolese heritage objects have been scanned using high-resolution X-ray µCT, resulting in a vast dataset of highly qualitative, three-dimensional information about the exterior and interior of these precious cultural objects. This dataset contains scans of a wide variety of objects, including musical instruments, sculptures, objects of use, masks and power objects. Figure 5 shows an extract from the dataset; a slit drum from the Yaka culture, a sculpture from Mboma, a headrest (no ascribed culture or region), a Ndenge cup and a Lulua sculpture. Underneath each object a cross section from their overview scan shows a virtual 'slice' from the interior of the objects.

Figure 5: Five Congolese heritage objects that were scanned during the TOCOWO project: (left to right) a Yaka slit drum (MO.0.0.2504), a sculpture from Mboma (EO.1953.74.3262), a head rest (EO.0.0.22709), a Ngende cup (EO.0.0.26582) and a Lulua sculpture (EO.0.0.43862). Each object is shown above a cross section of their overview scans. Cross sections made with ImageJ©. ©RMCA ©UGCT ©UGent-Woodlab

Thanks to specialized software such as described in 3.1.1, the digital information of each scan can be virtually visualized, manipulated and analyzed, revealing a wealth of information about these, previously severely under-documented, objects. The dataset acquired during the TOCOWO project contains 218 scanned volumes, as each object was scanned twice. The Region of Interest (ROI) scans are exclusively high resolution scans of the internal wood structures of each object. Depending on the dimensions, shape and materials of the objects, the obtained resolution of these ROI scans ranged between 2.5 µm and 19 µm reconstructed voxel size. The overview scans visualize the entire object, and hold clues about the construction of the artefact, the use of the object in its culture of origin, any damage it sustained and treatments it received in the past.

The example shown in Figure 6 is a Congolese ciborium, and both its overview and ROI scan. The object was used in Christian ceremonies to hold the host, and is made up of two parts: a chalice and a lid. The 3D rendering and cross-sections of the overview scan allows the grain of the wood to be traced through the chalice and the lid, confirming the object was carved out of the same piece of wood. The carved cross at the top of the lid was joined using a half-lap joint, reinforced with an adhesive that can be isolated on the scan (indicated with a in Figure 6). Previously undetected insect-damage and internal fractures were also visualised on the scans, indicated with b in Figure 6. The high-resolution ROI scan of the carved cross on top of the lid, revealed distinctive features such as broad axial parenchyma bands. An identification of Wenge wood, *Millettia laurentii*, could be determined.

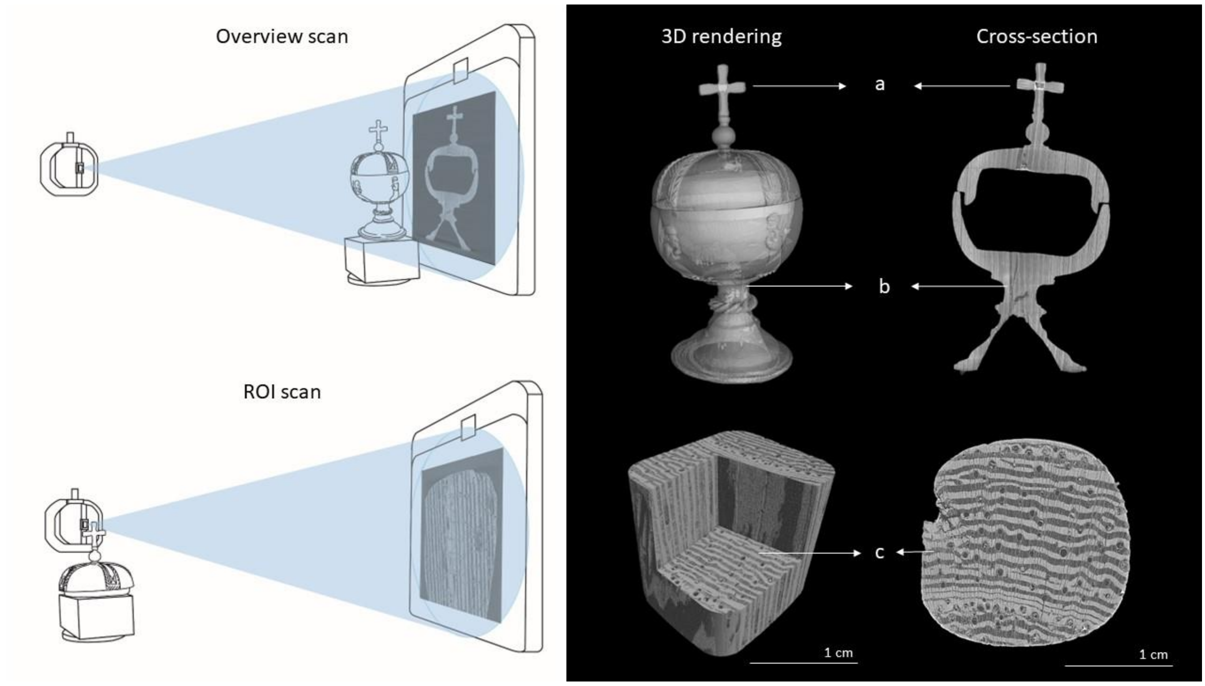

*Figure 6: Schematic representation of the scan set-up (left) of the ciborium (Wood (*Millettia laurentii*), shell); 31.5 x 18 x 19 cm ; sj.1197) in HECTOR. Above the overview scan at 170 µm voxel size, below the ROI scan at 5 µm voxel size. 3D renderings (middle) made with VGStudio MAX©; Cross-sections (left) made with ImageJ©. A: the visualized joinery of the cross on top of the Ciborium lid. B: a fracture line inside the object. C: broad axial parenchyma bands of the Wenge wood ©RMCA ©UGCT ©UGent-Woodlab*

Annex 1 shows a full list of all objects that were scanned, including the obtained resolution for both the overview scan and ROI scan, expressed in µm voxel size. The list was obtained from the temporary Microsof Lists database, set up to keep track of all objects prepared, scanned and studied during the course of the TOCOWO project. All rendered 3D models and cross-sections of the scans, as well as the results of the wood identifications and any other conclusions drawn from the scans, will be added to the main database used by the RMCA: The Museum System (TMS), thus supplementing all retrieved information to each studied object.

The extensive dataset, both raw and reconstructed files, is backed up in two locations: at the RMCA's Long Term Preservation Platform (LTP), funded by BELSPO, and at the UGent network shares. Here the valuable scans are safeguarded and will be available for research in future; as it is probable that new research questions arise that may be answered by this unique resource, or that technological advances will make advanced analysis of the scans possible.

4.2 Optimized protocol for X-ray scanning heritage objects

The experience gained over the past two years of scanning over 100 collection objects – each unique and posing its own challenges for obtaining high-quality scans - were distilled into a protocol. It is a protocol specific to the µCT scanners used at the UGent scanning facilities, but the general principles described can be applied to others. It is the hope that this document can be of use to researchers in future, either in the RMCA or other museums, when considering µCT of collection objects for future projects. It guides the decision making involved in all stages of scanning - object selection, preparation, and scan acquisition- in the form of a decision tree. The document also takes the intended research purpose into account, managing expectations by offering the possibilities for scanning museum objects. The full document is shown in annex 2, and covers the object's condition, dimensions, materials, as well as the type of scan that is most suited for the intended research questions. A final draft of an article introducing the protocol is finished and will be submitted in the near future.

4.3 wood identification

4.3.1 database existing identifications

An important jumping-off point at the start of the TOCOWO project was the database of existing identifications of wood species in the museum's heritage collection. This Excel database covers a little less than 7% of the 55.000 wooden heritage objects in the museum and is almost exclusively made up of objects analyzed and identified by Roger Dechamps. Dechamps was active in the wood biology department of the RMCA from the 1960s until the beginning of the 90s, and single-handedly identified most of the 3814 objects in the existing database. Albeit a small percentage of the larger collection, the database nonetheless offered an invaluable first indication of the wealth of tropical wood species present in the collection. In addition, the database gave a first overview of the most prevalent species and in which types of objects they were most found. At the start of the project, some time was dedicated to reworking the Excel database, removing double entries, updating botanical names of wood species, and unifying the spelling of both geographical regions and cultures from the DRC. Once updated, the database could be more easily and correctly analyzed: it covers 294 different tropical wood species found in 54 different types of objects, originating from 128 different regions and/or cultures in the DRC. Figure 7 illustrates this distribution geographically, indicating the number of objects identified from each culture or region on the map.

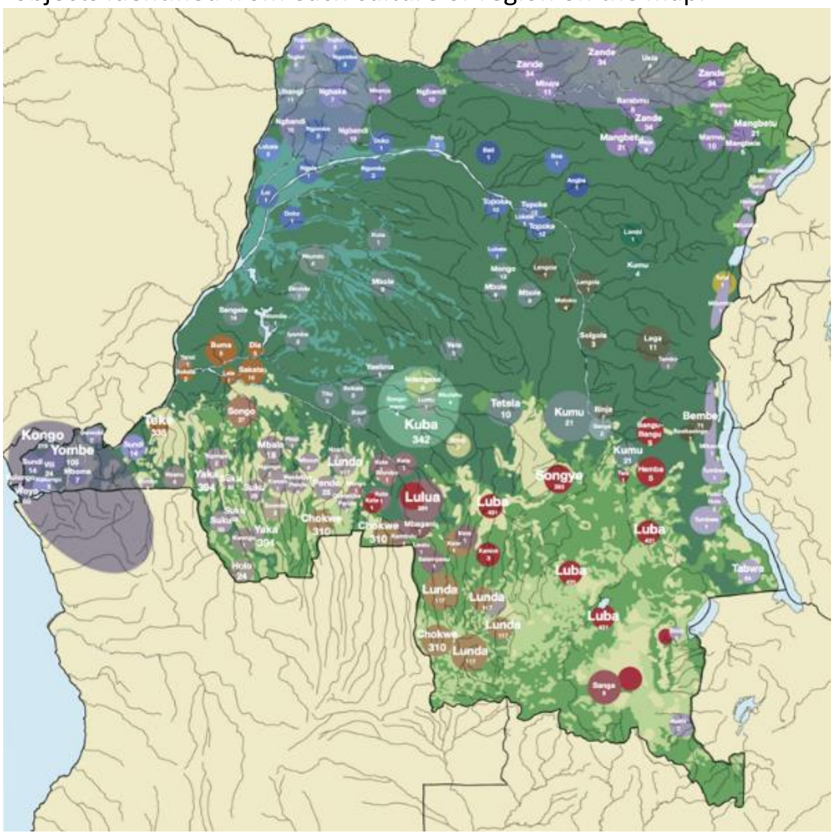

Figure 7: Geographical distribution of the 3814 objects that identified in the second half of the 20th century by Roger Dechamps. For each represented culture, the number of identified objects is given ©RMCA ©UGent-Woodlab

4.3.2 Multiresolution experiment

Early on in the TOCOWO project, a preliminary experiment was set up for the purposes of determining which wood anatomical features were visible and/or measurable at which resolutions. Wood samples from the RMCA's xylarium were sampled and scanned, in order to -independently from the limitations inherent in scanning collection objects (size, shape and added materials)- establish what quality of image was required for a species identification. Thanks to the invaluable information from Dechamps' database, reference samples of the 20 most prevalent tropical wood species in the museum's collection were collected and scanned at 1 µm, 3 µm, 8 µm and 15 µm voxel size. Each scan was virtually cut along the pertinent wood planes (transverse, radial and tangential), to allow for a comparative study between the different resolution scans of the same species. Figure 8 shows an overview of the scans made of a sample of *Pterocarpus tinctorius*; a 3D volume was rendered of the 1 µm scan using VGStudio MAX©, and cross-sections of all the planes were resliced using ImageJ©.

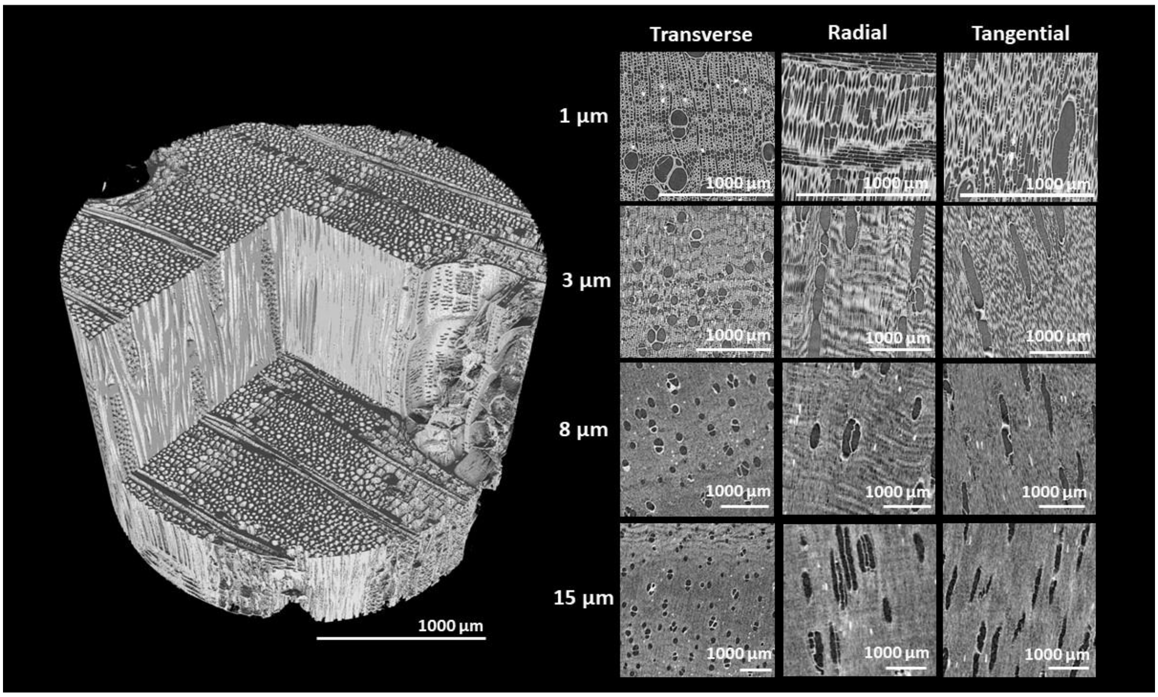

Figure 8: Sample Tw5157 of Pterocarpus tinctorius scanned at 1 µm, 3 µm, 8 µm and 15 µm voxel size. The cross-sections show the transverse, radial and tangential planes at each resolution. 3D volume rendered with VGStudio MAX©. Cross sections made with ImageJ©. ©RMCA ©UGCT ©UGent-Woodlab

Descriptions and measurements of all anatomical features that could be distinguished were recorded per wood species, and per resolution. This resulted in a clear overview of which resolutions are best suited to visualize which features. Unsurprising, the highest resolution of 1 µm voxel size showed the smallest features in the most detail. The top row in cross-sections shown in Figure 8 are 1 µm scans of the *Pterocarpus tinctorius* sample. Between 3 µm and 8 µm voxel size, shown as the middle two rows in Figure 8, most anatomical features could still be seen, if not always measured accurately. The fewest features could be recorded at 15 µm voxel size, the bottom row in Figure 8, although larger scale features, such as vessel distribution or distinct growth ring boundaries, could be described even at the lowest resolution. The exercise to try and match the described features per resolution to the known wood species proved that most samples could be identified between 1 µm and 8 µm voxel size, with the least successful matches at 15 µm. Aside from the resulting overview of visible features and possible identifications, this preliminary experiment had the added benefit of familiarizing the researcher with the species that were found most in the museum's heritage collection and with the inside wood database. The results of this exercise are currently being refined in the third draft of an article, and will be submitted in the next months.

4.3.3 Identification objects

Of the 109 Region of Interest scans made of collection objects in the course of the TOCOWO project, all but two could be scanned at a high enough resolution to reveal the internal structure of the wood to a very qualitative degree. The technique has been successfully proven to produce high quality visualizations to make descriptions of the wood structure. The majority of the dataset has already been virtually processed, retrieving the three wood planes from the digital volumes of the scanned wood, as well as analyzed, providing detailed descriptions of the visible wood features. Partly due to the size of the dataset to be analyzed, and to the challenging nature of many tropical wood species, the identification process went a lot slower than hoped. Figure 6 illustrates one of the first success stories of the project, in identifying the Wenge wood of the Congolese ciborium. As shown both on the 3D rendering and the transverse cross section of the ROI scan (at 6 µm voxel size), the broad parenchyma bands are a very distinctive feature that aided in a quick identification. At the conclusion of the TOCOWO project, the 20 first objects have been positively identified, but a large part of the dataset still awaits confirmation of the wood species analysis. Thanks to the close collaboration with the wood biology department, this process is succesfull ongoing, and is foreseen to be completed by the end of 2023. At this time, the results of the identifications will be reported in a peer reviewed article.

4.4 Prospects and recommendations

The large potential of knowledge held in the unique dataset acquired during the TOCOWO project could not be fully explored in the past two years, and to this end, a follow-up proposal was written and accepted. From March 2023 until February 2025, the CONteXT (CONgolese heritage objects examined and contextualized through X-ray Tomography) project will pursue the further visualization and analysis of the 109 scanned objects. In doing so, it aims to delve deeper into the potential of the obtained overview scans. These complete 3D models show the scanned heritage objects, inside and out, and can reveal much about the object's condition (the extent of damages previously unseen), construction (identification techniques or other materials), historical use and past conservational treatments. In short, to allow the objects to tell their own history and original context, through their material evidence. As shown in Figure 9, the possibilities of manipulating, visualizing, and studying the scanned objects with specialized software like VGStudio MAX© are barely explored yet in the TOCOWO project. Adjusting transparency of the 3D renderings can offer a look inside the structure of the objects, as shown in the middle model in Figure 9. Here, adjusting the transparency shows the center of the tree, or the pith, in the middle of the object, revealing how the object was extracted from tree it originated from. The last two renderings show how higher-attenuating materials can be increasingly isolated using the program, filtering out the wood structure and highlighting the presence of pigments in the object's face, and the rope around its neck. Describing and researching the wealth of conservational and contextual insights contained inside the large dataset will result in adding much-needed information on the objects in the collection.

Figure 4: From left to right a Yaka mask (EO.), its 3D rendering. The middle rendering is shown at 50 % transparency. The last two renderings increasingly filter out the less attenuating materials, isolating only the pigment and rope used in the mask. Rendering made using VGStudio MAX©. ©RMCA ©UGCT ©UGent-Woodlab

A second objective of the CONteXT project is to engage in the ethical questions that arose while scanning the objects during the TOCOWO project. Visualizing these Congolese heritage objects fully, inside and out, unavoidably has the potential of revealing sensitive information, kept guarded inside the objects for centuries. At least 16 of the 109 scanned collection objects are labeled as 'power objects', and it is possible others that also played a spiritual role in their source communities have been mislabeled in the museum database. These mankisi, or power objects, are typically imbued with a power by addition of either a 'package' of ingredients only known to the Nganga, or spiritual leader, or of nails driven into the wood of the object, or power attributes such as necklaces with pouches containing similarly secret ingredients. These additions activate the object as a spokesperson to the spirit world, and it acts as both protector and judge for the community it serves as long as it holds power. By scanning the objects in the museum's collection, the interior of a number of these mankisi are easily revealed. In order to study and disseminate the scanned dataset with the respect due to the cultures it originated from, the CONteXT project aims to enter into conversation with the object's source communities, and exchange knowledge and perspectives on the objects that were scanned. By asking to what extent the scanned objects are allowed to be viewed, inside and out, as well as if and how the scans should be shared with public and academic audiences, the project hopes to conclude the results of both the TOCOWO and CONteXT projects in an inclusive, respectful and meaningful way.

5. DISSEMINATION AND VALORISATION

5.1 Presentations

Over the past two years, many opportunities presented themselves to share the TOCOWO project and its intermediate results at international conferences. During the covid period, these events were organized online, but from spring 2022 in-person conferences could be attended. All the presentations listed below represented enriching experiences, offering a chance to build and expand a network and to collectively reflect on the presented topics.

Tervuren (online) | November 20th 2020
Internal presentations for the RMCA - "TOCOWO: tomography of Congolese wooden objects"

Antwerp (online) | May 3rd 2021
ConNext: Conservation by the next Generation - "Poster presentation TOCOWO: tomography of Congolese wooden objects"

Turin (online) | November 18-20 2021
Knocking on Wood – "Through & through: a conservational look at scanned Congolese wooden objects"

Amsterdam | April 19-21 2022
From forest to heritage– "Micro- and subµ X-ray CT scanning of Congolese heritage objects for wood identification"

Los Angeles | May 13 – 17 2022
American Institute for Conservation – "Eyes only? Revealing or preserving secrets of Congolese art objects"

Paris | June 28th – July 1st 2022
InArt – Presentation "Micro- and subµ X-ray CT scanning of Congolese heritage objects for wood identification and conservation"

New York (online) | March 18th 2023
Art Bio Matters – ""Non-invasive" techniques: X-ray tomography of Congolese wooden objects"

5.2 Workshops

New York | April 22 – 24 2021
Art Bio Matters – Poster presentation "TOCOWO: tomography of Congolese Wooden Objects"

Ljubljana | October 13 – 14 2022
Taking Care creative study lab – Presentation "In support of international travel of ethnographic collections: identification of wood on Congolese objects using micro- and sub micron tomography"

Stuttgart | March 29 – 31 2023
Taking Care creative study lab – "Exchanging expertise and experience across continents: towards a sustainable co-stewardship"

Kontich | April 20 -21 2023
St.Rita Campus College – Diversity training with year 1 and 2

5.3 Website

a website was created to share its main objectives and activities. A short background about the project, the Congolese heritage collection studied, and the techniques used are given. The website also briefly addresses the ethical stance of the TOCOWO project, committing to a respectful study and dissemination of the scans taken of more culturally or religiously charged objects (tocowo.ugent.be).

5.4 Follow-up Committee

Throughout the duration of TOCOWO project, the follow-op committee was convened on four occasions. Initially, at the start of the project in the fall of 2020, each member was contacted individually to introduce them to the hired researcher, the project and its main objectives. Roughly every 6 months, all members of the committee were invited to receive an in-depth update of the project's preliminary results, successes, and challenges. Each meeting was then followed by a moment of discussion, where questions, opinions and suggestions were welcomed. The meetings with the members of the follow-up committee provided moments of honest reflection and inspiration for the hired researcher and helped to steer the project where necessary.

Cindy Zalm | Head of delivery and realization at the Stichting Nationaal Museum van Wereldculturen (NMVW) in the Netherlands, Cindy Zalm is very familiar with the challenges and sensibilities of managing and researching ethnographic collections. Her advice and insight into the project often focused on the dissemination of the project's results towards the museum professional community and integration of the scans into the collection database.

Dr. Katarina Čufar | Dr. Čufar is professor at the University of Ljubljana, Slovenia, at the department of wood science and technology. She has a lot of experience with the study and identification of tropical wood anatomy and showed a lot of interest in X-ray µCT as a non-destructive alternative for wood species identification.

Prof. Charles Indekeu | Professor Indekeu taught at the University of Antwerp and is an experienced wood conservator. As such, he had many interesting suggestions concerning the conservational insights made possible by scanning the collection objects. In addition, his experience with the RMCA's previous head of Wood Biology, Roger Dechamps, helped reconstruct some of the questions concerning Dechamps' dataset and methods.

Dr. Victor Deklerck | Dr. Deklerck works as research leader on the World Forest ID project, at the Royal Botanical Gardens, Kew. He specialized in tropical wood identification via analytical techniques. Familiar with different techniques for wood identification, his opinions and suggestions were very valuable and inspiring.

Prof. Tom de Mil | Associate professor in wood science at the University of Liège, and an alumnus of the UGent, Dr. De Mil has experience with both tropical wood anatomy and X-ray µCT. His advice was often indispensable, supplying practical insights and suggestions for the analysis and presentation of the results.

Prof. Corneille Ewango | Professor Ewango teaches at the University of Kisangani, DRC. He was invited to the follow-up committee meetings, but was unfortunately often unresponsive due to his activity in the field in the DRC.

Table ii shows the meetings where the Follow-up committee was convened between the start of the project in 2020 and its conclusion in 2023

Date	Meeting subject	Channel
5-7 October 2020	Individual contact to introduce the project, hired researcher and challenges.	E-mail and Teams meetings
8 April 2021	First meeting convening the full committee. A first update included a discussion of the first 15 scans made and the lessons learned from this experience.	Teams meeting
4 November 2021	Second meeting with the follow-up committee. By now over 50 objects had been scanned, and more specific successes and hurdles could be raised for discussion. The preliminary experiment examining 20 tropical wood species scanned at different resolutions was also presented.	Teams meeting
7 July 2022	Third meeting convening the follow-up committee. The 86 scanned objects were presented, as well as the optimized protocol for X-ray scanning heritage objects.	Teams meeting
21 February 2023	Final follow-up committee meeting, in which the 109 scanned objects were discussed, as well as the attained results and remaining opportunities of the unique dataset of scans.	Zoom meeting

6. PUBLICATIONS

Submitted (November 2021): Dierickx, S., Van Es, M., Genbrugge, S., Beeckman, H., Van den Bulcke, J. and Hubau, W. 2022 “Through and through: A conservational look at scanned Congolese Wooden Objects.” Conference paper CESMAR7 ‘Knocking on Wood’, Turin.

Submitted/rejected (October 2022): Dierickx, S., Genbrugge, S., Beeckman, H., Van den Bulcke, J. and Hubau, W. 2022 “Opportunities and challenges of X-ray scanning of African wooden objects: an optimized protocol” European Physical Journal Plus. Will be resubmitted later on.

3rd draft: Dierickx, S., Genbrugge, S., Beeckman, H., Van den Bulcke, J. and Hubau, W. 2022. “Tropical wood species identification through multiresolution micro-CT scans”

Final paper on TOCOWO project: identification of tropical wood species on 20 Congolese heritage objects

7. ACKNOWLEDGEMENTS

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8. ANNEX

Annex 1: overview of scanned objects, sorted by typology. The list was retrieved form the Microsoft List database set up for the TOCOWO project.

Charged objects

Description : Amulet

Title
EO.1953.74.4983
Culture/Region
Kete
Resolution
Overall: 62µ
ROI: 6,5µ
Object dimension
11,1 x 3,6 x 3,2 cm
Other materials
Plant fiber

Title
EO.0.0.17831
Culture/Region
Ngbandi
Resolution
Overall: 120µ
ROI: hoofd 9µ
Object dimension
22 × 7,8 × 3,5cm
Other materials
Plant fiber,Metal,Leather

Description : Cimpaba

Title
EO.1964.43.1
Culture/Region
Woyo
Resolution
Overall (tiled): 90µ
ROI: 4,5µ
Object dimension
42 cm x 9 cm
Other materials
–

Description : Itombwa

Title
EO.1957.32.21
Culture/Region
Kuba
Resolution
Overall: 105µ
ROI (snuit): 4µ
Object dimension
5 x 2,5 x 29,7 cm
Other materials
Plant fiber

Description : Nkisi

Title
EO.0.0.3659
Culture/Region
/
Resolution
Overall: 150µ
ROI: 135µ
Object dimension
23 cm x 49 cm x 19 cm
Other materials
Metal

Title
EO.0.0.7235
Culture/Region
Teke
Resolution
Overall: 71µ
ROI: 5µ
Object dimension
11,5 cm
Other materials
Textile,Earth

Title
EO.1955.128.4
Culture/Region
/
Resolution
Overall: 80µ
ROI: 25µ
Object dimension
14 cm
Other materials
Glass,Resin

Title
EO.0.0.29054
Culture/Region
Teke
Resolution
Overall scan: 135µ
ROI: head, 8µ
Object dimension
25,6 x 7,4 x 8 cm
Other materials
feathers,Earth

Title
EO.1949.37.1
Culture/Region
Luba
Resolution
Overall scan: 150µ
ROI: shoulders, 8µ
Object dimension
27,2 x 7,2 x 8,3 cm
Other materials
Horn,Textile,Earth

Title
EO.1953.74.1641
Culture/Region
Yaka
Resolution
Overall scan: 145µ
ROI: head, 7µ
Object dimension
27,3 x 7,2 x 5,2 cm
Other materials
Textile,Plant fiber

Title
EO.1967.63.430
Culture/Region
/
Resolution
Overall scan: 167µ
ROI: head, 9µ
Object dimension
31,5 x 12 cm
Other materials
Plant fiber,Beads,Shell,Textile,Pigment

Title
EO.1980.2.501
Culture/Region
Songye
Resolution
ROI: 15µ
Overall: 145µ
Object dimension
46,2 x 12,2 x 15 cm
Other materials
Textile,Beads,Metal

Title
EO.1980.2.2867
Culture/Region
Songye
Resolution
ROI: 8µ
Overall: 125µ
Object dimension
22,5 x 4,8 x 7,2 cm
Other materials
Teeth,Metal

Title
EO.0.0.33952
Culture/Region
Kongo
Resolution
ROI: 6µ (feb 2023 CoreTOM)
Overall: 85µ (Oct 2022)
Object dimension
14,8 x 8,9 x 7 cm
Other materials
Textile

Title
EO.1955.32.1
Culture/Region
Yaka
Resolution
ROI: 7,5µ
Overall: 125µ
Object dimension
32 × 11 × 10cm
Other materials
Metal,Earth

Description : Sceptre

Title
EO.0.0.43677
Culture/Region
Yombe
Resolution
Overall: 130µ
ROI: 7µ
Object dimension
33,3 x 8,2 x 11,2 cm
Other materials
Glass,Resin,Pigment

Description : Katatora - divination instrument

Title
EO.1967.63.269
Culture/Region
Kotschi
Resolution
Overall (tiled): 85µ
ROI: 4µ
Object dimension
10,5 cm x 40 cm x 5,7 cm
Other materials
Textile,Pigment,Resin,Glass

Title
EO.1951.10.1
Culture/Region
Songye
Resolution
ROI: 19 µm (Feb 2023)
Overall: 127 µm (stacked 4x Feb 2023)
Object dimension
88 x 37 x 41 cm 10 kg
Other materials
Pigment,Plant fiber,Beads,Shell,feathe...

Title
EO.1951.12.17
Culture/Region
Komo
Resolution
ROI: 4µm (feb 2023 CoreTOM)
Overall: 135µ (stacked Oct 2022)
Object dimension
44 × 7,9 × 2,4cm
Other materials
Pigment,Metal

Title
EO.1961.31.8
Culture/Region
Luba
Resolution
Overall scan: 71µ
ROI: head, 8µ
Object dimension
12,3 x 6,4 x 2,6 cm
Other materials
–

Masks

Description : Mask

Title
EO.0.0.15003
Culture/Region
Biombo
Resolution
Overall: 160µ
ROI: 85µ
Object dimension
32,8 x 15,3 cm
Other materials
Pigment,Plant fiber

Title
EO.1951.35.5
Culture/Region
Lega
Resolution
Overall scan: 123µ
ROI: forehead, 14µ
Object dimension
22,4 x 14,1 x 3,3 cm
Other materials
–

Title
EO.1980.2.1991
Culture/Region
Pende
Resolution
Overall: 151µ
ROI: 9µ
Object dimension
27,3 x 9 x 5,8 cm
Other materials
–

Title
EO.1953.74.2105
Culture/Region
Yaka
Resolution
Overall: 160µ
ROI: 13µ
Object dimension
30 × 27 × 24cm
Other materials
Plant fiber,Pigment

Title
EO.0.0.23319-1
Culture/Region
Yaka
Resolution
Overall: 121 micron
ROI: 9 micron
Object dimension
22 × 16,4 × 11,8 cm
Other materials
Pigment

Title
EO.1948.40.13
Culture/Region
Pende
Resolution
Overall scan: 173µ
ROI: chin, 12µ
Object dimension
33,4 x 19 x 14,5 cm
Other materials
–

Title
EO.0.0.15404
Culture/Region
Lulua
Resolution
Overall (tiled): 121µ
ROI: 3,5µ
Object dimension
57,9 x 29,7 x 18,5 cm
Other materials
Pigment

Title
EO.0.0.24970
Culture/Region
Yaka
Resolution
Overall: 112µ (Feb 2023, stacked 3x)
ROI: 5µ (Feb 2023)
Object dimension
69 × 30 × 26cm
Other materials
Plant fiber,Pigment,Textile

Title
Sj.1975
Culture/Region
Pende
Resolution
Overall: 108µ
ROI: 6µ
Object dimension
52 x 26 x 16 cm
Other materials
Plant fiber,Pigment

Title
EO.1953.74.4158
Culture/Region
Suku
Resolution
ROI: 3µ
Object dimension
130 × 60 × 38cm
Other materials
Plant fiber,Fur,Pigment

Musical instruments

Description : Bell

Title
MO.1958.16.2
Culture/Region
Yombe
Resolution
Overall: 118µ
ROI: 8µ
Object dimension
20,1 × 12,1 × 11cm
Other materials
Plant fiber

Title
MO.1955.113.17
Culture/Region
Kongo
Resolution
Overall: 62µ
ROI: 4,5µ
Object dimension
10,9 x 3,7 x 2,5 cm
Other materials
Plant fiber

Title
MO.0.0.35047
Culture/Region
Woyo
Resolution
Overall: 150 micron
ROI: 7 micron
Object dimension
22,4 x 8,2 x 6 cm
Other materials
–

Title
MO.0.0.34821
Culture/Region
Woyo
Resolution
Overall: 160µ
ROI: 11µ
Object dimension
28,6 x 9,5 x 8 cm
Other materials
–

Description : Drum

Title
MO.0.0.2493
Culture/Region
Yaka
Resolution
Overall: 145µ (Feb 2021)
ROI: 8µ (Feb 2023, CoreTOM)
Object dimension
46,5 x 10,4 x 14 cm
Other materials
Plant fiber

Title
MO.0.0.2504
Culture/Region
Yaka
Resolution
Overall: 130µ (Feb 2021)
ROI: 6µ (Feb 2023 HECTOR)
Object dimension
41,8 x 6,9 cm
Other materials
Metal,Plant fiber

Title
MO.1953.74.2866
Culture/Region
Holo
Resolution
Overall: 131µ (feb 2021)
ROI: 8µ (feb 2023, coretom)
Object dimension
36,9 x 9 x 10 cm
Other materials
Plant fiber

Description : Xylophone

Title
MO.0.0.13352
Culture/Region
Zande
Resolution
Overall stacked: 167µ
ROI: 8µ
Object dimension
51,8 x 8,7 x 2 cm
Other materials
–

Description : Harp

Title
MO.1980.2.516
Culture/Region
Zande
Resolution
Overall stacked: 155µ
ROI: 4µ
Object dimension
35,4 x 5 x 28 cm
Other materials
Metal

Title
MO.0.0.9458
Culture/Region
Ngbaka
Resolution
Overall: 115µ (Feb 2023, stacked 3x)
ROI: 5µm (Feb 2023)
Object dimension
–
Other materials
Leather,Plant fiber,Beads,Glass

Description : Rattle

Title
MO.1954.27.1
Culture/Region
Yombe
Resolution
Overall: 176µ
ROI: 12,18µ
Object dimension
40,5 × 14,8 × 14,4cm
Other materials
Plant fiber,fruit

Title
MO.1967.63.952
Culture/Region
Chokwe (Angola)
Resolution
Overall (stacked): 145µ
ROI: 5µ
Object dimension
46 x Ø: 5.2
Other materials
fruit,Plant fiber

Description : Violin

Title
MO.0.0.410
Culture/Region
Bas-Congo
Resolution
ROI: 4,5µ (Feb CoreTOM)
Overall: 151µ (Oct 2022 - stacked)
Object dimension
48,5 × 13 × 15,4cm
Other materials
Metal,Plant fiber

Title
MO.1953.74.2711
Culture/Region
Holo
Resolution
Overall: 82µ (Feb 2023, stacked 3x)
ROI: 7µ (Feb 2023)
Object dimension
51 x 9,4 x 8,9 cm
Other materials
Metal,Plant fiber,Textile,Horn,feathers

Objects of use

Description : Arrow holder

Title
EO.0.0.740-4
Culture/Region
Luba
Resolution
Overall (tiled 4x): 110µ
ROI: 6µ
Object dimension
77,6 x 24,5 x 9,3
Other materials
–

Description : Axe

Title
EO.0.0.9415
Culture/Region
Luba
Resolution
Overall (without the metal of the blade): 140µ
Object dimension
39,7 x 6,2 x 31,8 cm
Other materials
Metal

Description : Box

Title
EO.1954.2.5
Culture/Region
Mangbetu
Resolution
Overall tiled: 150µ
ROI: 10µ
Object dimension
48,9 x 9,9 x 11,2 cm
Other materials
–

Description : Calendar

Title
EO.1975.51.37
Culture/Region
Kongo
Resolution
Overall: 63µ
ROI: 8,5µ (tjoep)
Object dimension
10,7 × 7,4 × 1,1cm
Other materials
Plant fiber

Description : Cane

Title
EO.1952.28.2
Culture/Region
/
Resolution
Overall scan: 145µ
ROI: head, 5µ
Object dimension
26,2 x 3,6 x 3,6 cm
Other materials
–

Title
EO.1958.30.36
Culture/Region
Chokwe
Resolution
Overall: 83µ
ROI: 5µ
Object dimension
14,5 x 2,1 x 3,1cm
Other materials
Resin

Title
EO.0.0.43327
Culture/Region
Chokwe
Resolution
Overall: 157µ
ROI: 4µ
Object dimension
33,2 x 5,9 x 5,2 cm
Other materials
Earth,Pigment

Title
EO.1948.20.193
Culture/Region
Chokwe
Resolution
overall (enkel wood carving): 120µ
ROI (enkel staf midden): 3,5
Object dimension
78,8 cm
Other materials
–

Description : Chair

Title
EO.0.0.2104
Culture/Region
Songye
Resolution
Overall scan tiled: 151µ
ROI: head, 18µ
Object dimension
43 x 22,6 x 18,4 cm
Other materials
Shell

Title
EO.1984.34.34
Culture/Region
Chokwe
Resolution
Overall: 145µ
ROI: 7µ
Object dimension
25,4 x 4,8 x 4,5 cm
Other materials
–

Description : Comb

Title
EO.0.0.31952
Culture/Region
Tabwa
Resolution
Overall scan: 105µ
ROI: head, 5µ
Object dimension
18,8 x 4,9 x 2,6 cm
Other materials
–

Description : Ciborium

Title
SJ.1197
Culture/Region
/
Resolution
Overall: 170µ
ROI: 6µ (top kruis)
Object dimension
31,5 × 18 × 19cm, 1,05kg
Other materials
–

Description : Cross

Title
EO.1949.48.14
Culture/Region
Holo
Resolution
Overall: 160µ
ROI: 6,5µ
Object dimension
28,6 x 8,6 x 4,5 cm
Other materials
–

Description : Filter

Title
EO.0.0.4451
Culture/Region
Zande
Resolution
Overall: 150 micron
ROI: 8,5 micron
Object dimension
35,2 × 13,2cm
Other materials
Plant fiber

Description : Fan

Title
EO.0.0.22003
Culture/Region
Punu
Resolution
Overall: 170µ
ROI: 4,5µ
Object dimension
31,8 x 18,2 x 2,9 cm
Other materials
Leather,Plant fiber

Description : Fly chaser

Title
EO.1979.1.63
Culture/Region
Kakongo
Resolution
Overall: 155µ
ROI: 5µ
Object dimension
29,2 × 5,7 × 4,3cm
Other materials
–

Description : Cup

Title
EO.0.0.26582
Culture/Region
Ngende
Resolution
Overall: 175µ
ROI: 14µ
Object dimension
30,5 x 12,5 cm
Other materials
Metal

Title
EO.1948.29.2
Culture/Region
Ngbandi
Resolution
Overall: 166µ
ROI: 55µ
Object dimension
27,8 x 9,5 x 18 cm
Other materials
Metal

Title
EO.1950.24.12
Culture/Region
Kuba
Resolution
Overall: 125µ
ROI: 40µ
Object dimension
21,5 × 13cm
Other materials
–

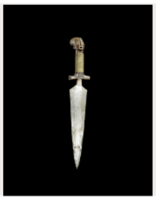
Title
EO.1980.2.426
Culture/Region
/
Resolution
ROI: 5µ (Feb 2023, CoreTOM)
Overall: 80µm (Feb 2023, CoreTOM)
Object dimension
12 x 9 x 8,4 cm
Other materials
–

Description : Head rest

Title
EO.0.0.22709
Culture/Region
/
Resolution
Overall: 90µ
ROI: 14µ
Object dimension
13,8 x 14 cm
Other materials
Metal,Beads

Title
EO.0.0.22717
Culture/Region
/
Resolution
Overall: 95µ
ROI: 15µ
Object dimension
14,3 x 14 cm
Other materials
Metal

Description : Knife



Title
EO.0.0.7538-2
Culture/Region
Meje
Resolution
No overall scan
ROI: headdress, 7µ
Object dimension
30,9 x 4,8 x 6 cm
Other materials
Metal

Description : Lid

Title
EO.1951.50.30
Culture/Region
Woyo
Resolution
overall: 70µ
ROI: 6µ
Object dimension
17,6 cm x 8,6 cm
Other materials
–

Title
EO.1956.88.22
Culture/Region
/
Resolution
Overall: 80µ
ROI: 4µ
Object dimension
9,3 × 19,6cm
Other materials
–

Description : Pipe

Title
EO.1980.2.429
Culture/Region
Nsapo
Resolution
Overall: 135µ
ROI: 9µ
Object dimension
6,7 x 24,7 x 10,2 cm
Other materials
Metal

Title
EO.1957.35.2
Culture/Region
Bindi
Resolution
ROI steel: 5µ
ROI bowl: 20µ
Object dimension
11,3 x 50,5 x 4 cm
Other materials
Metal

Title
EO.0.0.10924
Culture/Region
Zande
Resolution
Overall: 156 micron
ROI kop: 7 micron
Object dimension
11 x 46,5 x 4 cm
Other materials
–

Description : Pestle

Title
EO.1955.80.3
Culture/Region
/
Resolution
Overall: 154 micron
ROI: handle, 6µ
Object dimension
28,8 x 9,2 x 9,4 cm
Other materials
Metal

Description : Pin

Title
EO.1952.53.1
Culture/Region
Luba
Resolution
Overall: 114µ -- moet eigenlijk ook opnie uw
Object dimension
20,4 × 1,4 × 1,1cm
Other materials
–

Description : Powder flask

Title
EO.1954.52.3-1
Culture/Region
Kongo
Resolution
Overall: 69µ
ROI: 4µ
Object dimension
12,2 x 5,3 x 5 cm
Other materials
–

Title
EO.1958.10.4
Culture/Region
Kongo
Resolution
Overall: 80µ
ROI: 8µ (June 2022)
Object dimension
13,9 x 9,8 x 10,2 cm
Other materials
Plant fiber

Description : Shield

Title
EO.1959.23.3
Culture/Region
Songye
Resolution
ROI: 7µ
Overall: 98µ
Object dimension
24,3 × 9,2 × 5,2cm
Other materials
–

Description : Shoe

Title
EO.1971.36.7
Culture/Region
Songye
Resolution
Overall: 150µ
ROI: 4,7µ
Object dimension
27,2 x 9,4 cm
Other materials
Metal

Description : Silence disc

Title
EO.0.0.31454
Culture/Region
/
Resolution
Overall scan: 62µ
ROI: 11µ
Object dimension
10,5 x 10,5 x 0,8 cm
Other materials
Plant fiber,Pigment

Description : Spoon

Title
EO.0.0.673-3
Culture/Region
Lualaba
Resolution
Overall: 115 micron
ROI: 7,7 micron
Object dimension
21,9 × 7,7 × 5,5cm
Other materials
–

Description : Tobacco box

Title
EO.1980.2.1758
Culture/Region
Luba
Resolution
Overall: 175µ (niet getiled, top van punt niet meegescand)
Object dimension
40,4 × 7cm
Other materials
–

Title
EO.1948.20.184
Culture/Region
Chokwe
Resolution
Overall: 78µ
ROI: 4µ
Object dimension
19 × 4,6 × 3,7cm
Other materials
–

Description : Toy

Title
EO.1979.1.887
Culture/Region
/
Resolution
ROI: 4,5µm (HECTOR)
Overall: 90µm (stacked horizontal, Core
Object dimension
8,5 cm x 104 cm x 7,3 cm
Other materials
Plant fiber,Metal

Sculptures

Description : Sculpture

Title
EO.0.0.43336
Culture/Region
/
Resolution
Overall: 164µ
ROI: 12µ
Object dimension
29 x 10,5 x 12,5 cm
Other materials
–

Title
EO.0.0.43896
Culture/Region
Lulua
Resolution
Overall: 101µ
ROI: 35µ
Object dimension
16,5 cm
Other materials
–

Title
EO.1953.74.3262
Culture/Region
Mboma
Resolution
Overall: 90µ
ROI: 35µ
Object dimension
15 cm
Other materials
–

Title
EO.1955.3.170-5
Culture/Region
Bembe
Resolution
Overall: 161µ (tiled)
ROI: 65µ
Object dimension
46 cm
Other materials
Plant fiber

Title
EO.1955.132.1
Culture/Region
/
Resolution
Overall: 121µ
ROI: 10µ
Object dimension
21 cm
Other materials
Glass

Title
EO.0.0.43862
Culture/Region
Lulua
Resolution
Overall scan: 170µ
ROI: neck, 8µ
Object dimension
30,8 x 7 x 7,5 cm
Other materials
–

Title
EO.1949.6.1
Culture/Region
/
Resolution
Overall: 54µ
ROI: 4µ (June 2022)
Object dimension
9,5 x 2,1 x 2,1 cm
Other materials
–

Title
EO.1953.74.1793
Culture/Region
Teke
Resolution
Overall scan: 174µ
ROI: neck, 8µ
Object dimension
31,7 x 6,6 x 8,5 cm
Other materials
–

Title
EO.1960.37.1
Culture/Region
Songye
Resolution
Overall scan: 165µ
ROI: forehead, 10µ
Object dimension
29,9 x 8,3 x 9,3cm
Other materials
–

Title
EO.1980.2.921
Culture/Region
Ndengese
Resolution
Overall: 157µ (tiled)
ROI: 9µ
Object dimension
54 x 9 x 7,6 cm
Other materials
–

Title
EO.1957.53.14
Culture/Region
Luba
Resolution
Overall: 156µ
ROI: torso 10µ
Object dimension
27,3 x 8,3 x 9,1 cm
Other materials
–

Title
EO.1956.55.8
Culture/Region
Yaka
Resolution
Overall: 62µ
Scans: 3,5µ
Object dimension
11,2 x 2,6 x 2,5 cm
Other materials
–

Title
EO.1967.63.568
Culture/Region
Angola
Resolution
Overall: 128µ
ROI: 4µ
Object dimension
22,8 x 5,3 x 6,2 cm
Other materials
–

Title
EO.1967.63.322
Culture/Region
Vili
Resolution
Overall: 100µ
ROI: 4µ (hoofd arend)
Object dimension
18,5 × 3 × 4,8cm
Other materials
–

Title
EO.1951.4.10
Culture/Region
Yela
Resolution
overall: 148 micron
ROI (nek): 10,5 micron
Object dimension
26,3 x 9,5 x 7,5 cm
Other materials
–

Title
EO.1953.74.2849
Culture/Region
Suku
Resolution
Overall: 84 micron
ROI: 6µ
Object dimension
15,2 x 4,5 x 3,4 cm
Other materials
Plant fiber,Pigment

Title
EO.0.0.16665
Culture/Region
Yombe
Resolution
Overall: 140µ
ROI: 9µ
Object dimension
25,5 cm x 9,5 cm x 8 cm
Other materials
Metal,Glass

Title
EO.1980.2.2664
Culture/Region
Pende
Resolution
Overall (tiled): 110µ
ROI: 10µ
Object dimension
50 x 15,7 x 15 cm
Other materials
Pigment

Title
EO.1948.20.200
Culture/Region
Chokwe
Resolution
Overall: 97µ
ROI: 8µ
Object dimension
9,7 x 7,1 x 23,6 cm
Other materials
–

Title
sj.1465
Culture/Region
Suku
Resolution
ROI: 10µ
Overall (tiled 4x): 121µ
Object dimension
Object: 41,5 × 19 × 54,5cm, 2,35kg
Other materials
Plant fiber,Pigment

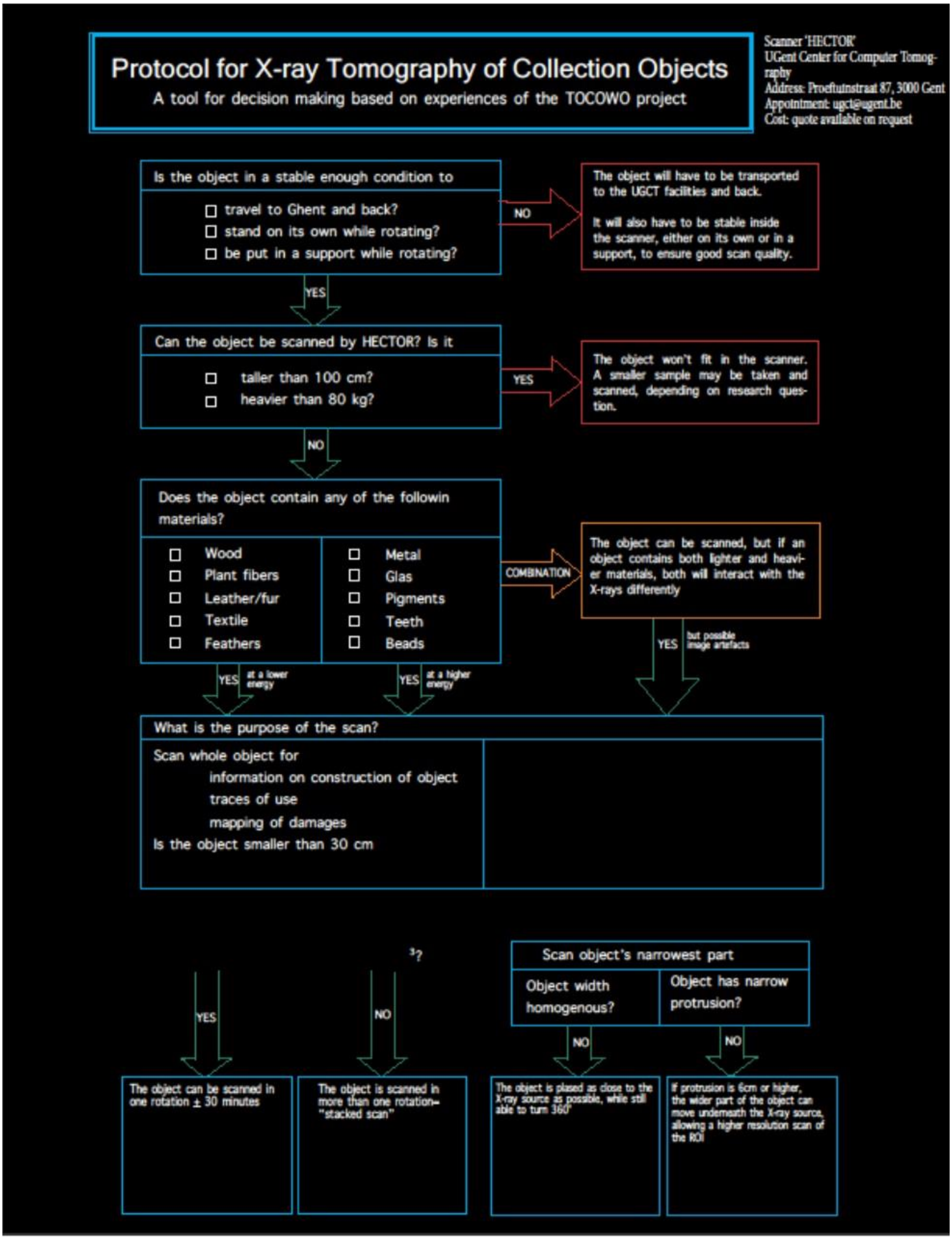
Title
EO.1962.46.4
Culture/Region
Lega
Resolution
ROI: 3,5µ
Overall: 76µ
Object dimension
5,6 × 19,5 × 3,5cm, 0,1kg
Other materials
Bone

Title
EO.0.0.1040-4
Culture/Region
Yombe
Resolution
Overall: 110µ (Feb 2023, stacked 2x)
ROI: 8,5µ (Feb 2023)
Object dimension
48 x 17,5 x 16,5 cm
Other materials
Pigment,Metal

Title
EO.1955.3.170-1
Culture/Region
Bembe
Resolution
Overall: 80µm (Feb 2023, stacked)
ROI: 10µ (Feb 2023)
Object dimension
33 cm
Other materials
Plant fiber

Title
EO.1980.2.2663
Culture/Region
Kongo
Resolution
Overall: 115µ (Feb 2023, 3x stacked)
ROI: 9µ (Feb 2023)
Object dimension
62 x 24 x 23 cm
Other materials
Pigment

Annex 2: Optimized protocol for scanning with HECTOR (High-Energy CT scanner optimized for research)



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