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PROTOCOL

LFA 3D Acquisitions Protocol

Maria Teresa Ferreira[a], Inês Oliveira-Santos[a], Catarina Coelho[a], Eugénia Cunha[a,b]

[a]Laboratory of Forensic Anthropology, Department of Life Sciences, Center for Functional Ecology, University of Coimbra, Calçada Martim de Freitas, 3000-456 Coimbra, Portugal

[b]Instituto Nacional de Medicina Legal e Ciências Forenses, IP., Lisbon, Portugal

Corresponding author: mtsferreira76@gmail.com

ABSTRACT

Bakeng se Afrika is an international project (2019-2022) co-founded by the Erasmus+ Programme of the European Union and had the main goal of developing a digital repository of human skeletal remains. This project was possible due to the association of six higher education institutions (University of Pretoria, Sefako Makgatho Health Science University; Stellenbosch University, University of Coimbra, University of Bordeaux, Katholieke Universiteit Leuven) and the South African Nuclear Energy Corporation (Necsa). Bakeng se Afrika was driven by the growing need of online tools in health sciences and life sciences fields. The project aimed to collect a large digital repository of identified South African osteological collections, to establish standard operating procedures for scanning, storage and analysis of bones, and to reflect and debate on the ethical applications of digital scans of human remains. As part of this project the Laboratory of Forensic Anthropology of the University of Coimbra worked to develop a guide to simplify 3d data collection of bone specimens, made available for teaching and research.

Keywords: Bakeng se Afrika; 3D analysis; Human bones; Teaching; Research.

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RESUMO

Bakeng se Afrika é um projeto internacional (2019-2022) co-fundado pelo Programa Erasmus+ da União Europeia e teve como principal objetivo desenvolver um repositório digital de remanescentes ósseos humanos. Este projeto foi possível devido à colaboração entre seis instituições de ensino superior (Universidade de Pretória, Universidade de Ciências da Saúde Sefako Makgatho; Universidade Stellenbosch, Universidade de Coimbra, Universidade de Bordéus, Katholieke Universiteit Leuven) e a South African Nuclear Energy Corporation (Necsa). O Bakeng se Afrika foi impulsionado pela necessidade crescente de ferramentas online nas áreas das ciências da saúde e da vida. O projeto teve como objetivo estabelecer um repositório digital de coleções osteológicas sul-africanas identificadas, estabelecer procedimentos operacionais padronizados para aquisição de imagens, armazenamento e análise e refletir e debater sobre as aplicações éticas de dados digitais de remanescentes ósseos humanos. No âmbito deste projeto, o Laboratório de Antropologia Forense da Universidade de Coimbra trabalhou no desenvolvimento de um guia para simplificar a recolha de dados 3D de espécimes ósseos, disponibilizado para ensino e investigação.

Palavras-chave: Bakeng se Afrika; análise 3D; Ossos humanos; Ensino; Investigação.

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Maria Teresa Ferreira

Inês Oliveira-Santos

Catarina Coelho

Eugénia Cunha

2022

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1. Introduction

Fundamentally, three-dimensional (3D) digitization allows a three-dimensional object to be recorded by capturing a series of points based on its surface. 3D techniques provide powerful, non-destructive research and development tools for scientific research, allowing a rigorous measurement of features, and geometry, using virtual examination. Imaging methods comprise laser surface scanning, computed tomography (CT) scanning, and 3D photogrammetry. The application of these methods has a comprehensive application across various domains, such as anthropology, primatology, medicine, palaeontology, mathematics, statistics, computer science, and engineering.

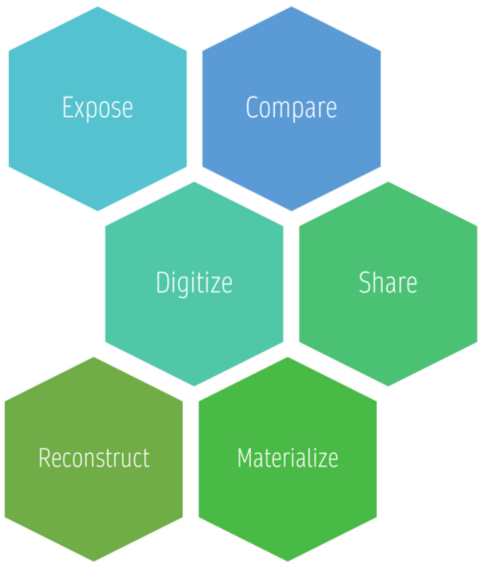


Figure 1 - The six operational areas of Virtual Anthropology for easier application in teaching. Adapted from Weber (2015: 24).

While Virtual Anthropology (Figure 1) originally aimed to study human morphology in space or space-time dimensions (Weber, 2015), its application has become an integral part of Forensic Anthropology research. In fact, its application to the identification process (osteometry; analysis of internal structures such as sinus or trabecular patterns; forensic facial reconstruction) or trauma analysis has become more and more common in both fundamental research and case studies. Other potential applications of these techniques are in teaching environments and curatorship. These approaches have the advantage of being non-invasive, i.e. without the risk of damaging the original sample, a primary concern when dealing with fragile human remains. Moreover, the possibility of a quick image acquisition, which becomes available for analysis whenever and wherever necessary makes them an invaluable resource. Additionally, these techniques also induce the development of new multidisciplinary scientific collaborations, as it allows the swift dissemination of information, even among geographically distant researchers. This benefit becomes even more pressing nowadays. Since 2020, the global Covid-19 pandemic has been affecting the lives of millions, and consequently, influenced and transformed teaching and research habits in all scientific areas.

1.1. Virtual anthropology in the Laboratory of Forensic Anthropology

At the Laboratory of Forensic Anthropology from the University of Coimbra (Portugal), one of the utmost concerns is ensuring the preservation of human skeletal remains the osteological collection. Moreover, improving its accessibility is also crucial both for didactic and research purposes. Virtual anthropology has been an ally in order to accomplishing these goals.

The 21st Century Identified Skeletal Collection (CEI/XXI), housed at the Laboratory of Forensic Anthropology, began to be amassed in 2009, with known information regarding the biographic data and funerary processing of the individuals, specifically: sex, age-at-dead, date-of-death, and dates of inhumation and exhumation (Ferreira et al., 2014). The collection comprises a total of 302 adult individuals, of which 162 are female (28 to 101 years old, mean: 81.19; S.D.: 12.89) and 140 are male (25 to 96 years old, mean: 73.20; S.D.: 15.61) (Ferreira et al, 2021).

Over the course of time, it has been developed research using scanned bones. Altogether, the collection has 513 scanned bones (Figure 2).

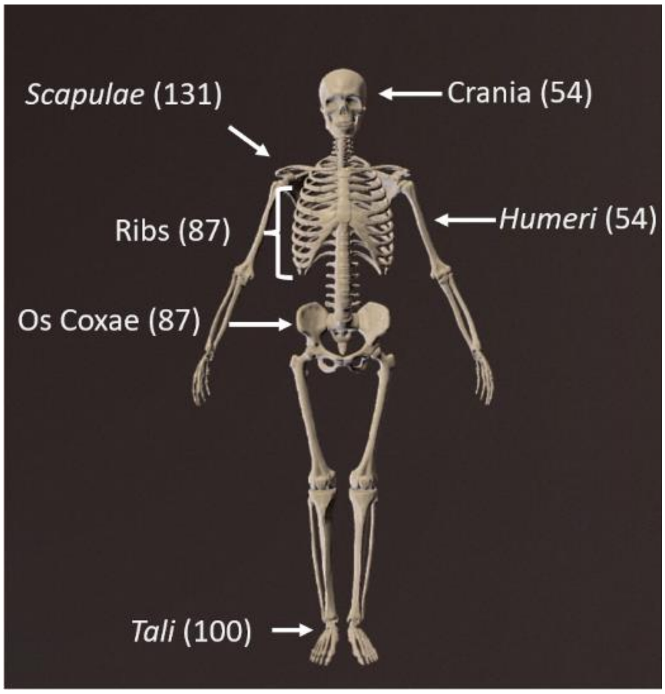


Figure 2 - Type and number of bones already digitized in the CEI/XXI.

In 2015, a method for automated digitizing of landmark coordinates was tested on a sample of 100 left tali (Figure 3), with the aim of creating an automated method for sex diagnosis from 3D scanned bones (d'Oliveira Coelho et al., 2015a, 2015b). In the same year, it was aimed to interpret and compare the size and shape of humeri, after exposure to high temperatures (Figure 4) (d'Oliveira Coelho, 2015).

Figure 3 - 3D acquisition of a left talus (d'Oliveira Coelho et al., 2015b).

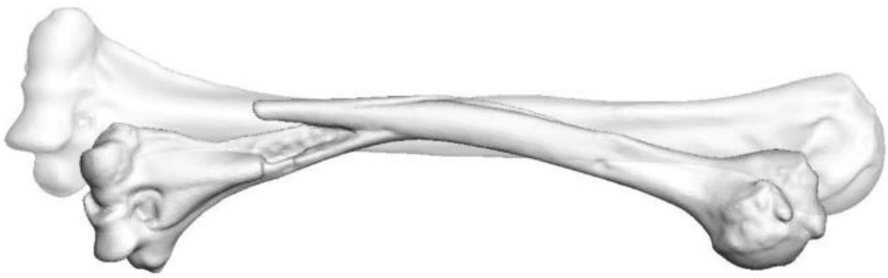
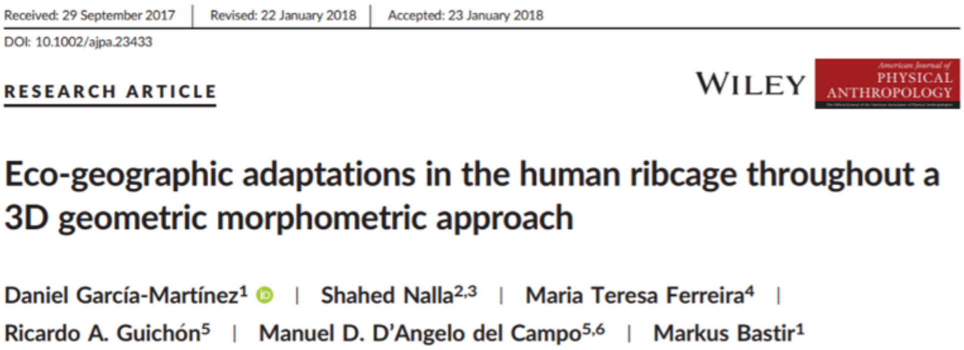


Figure 4 - Right humerus with heat induced wrapping (adapted from d'Oliveira Coelho, 2015: 5).

In another research (Figure 5), García-Martínez and collaborators (2018) used 3D scanned ribs from the CEI/XXI as a comparative framework to test whether ribcage size varies between individuals inhabiting high or low latitudes, and explored the correlation of rib size with latitude.


Received: 29 September 2017 | Revised: 22 January 2018 | Accepted: 23 January 2018

DOI: 10.1002/ajpa.23433

RESEARCH ARTICLE

WILEY American Journal of PHYSICAL ANTHROPOLOGY

Eco-geographic adaptations in the human ribcage throughout a 3D geometric morphometric approach

Daniel García-Martínez[1] | Shahed Nalla[2,3] | Maria Teresa Ferreira[4] | Ricardo A. Guichón[5] | Manuel D. D'Angelo del Campo[5,6] | Markus Bastir[1]

Figure 5 - Research using geometric morphometrics, using 3D scans from CEI/XXI ribs. Please refer 10.1002/ajpa.23433.

During the same year, a MSc student from the Master in Human Evolution and Biology attempted to analyse the accuracy of the software 3d-Id while creating a database with Portuguese crania from the CEI/XXI (Bessa, 2017). Unlike the previous research already mentioned, this method employed data acquisition using MicroScribe® (Figure 6).

Figure 6 - Data collection using MicroScribe® (Bessa, 2017: 19).

In 2018, Andrade and collaborators implemented automatic and semi-automatic methods for morphological analysis of 3D skull models through the extraction and classification of structures aiming to support the estimation of population affinities (Figure 7).

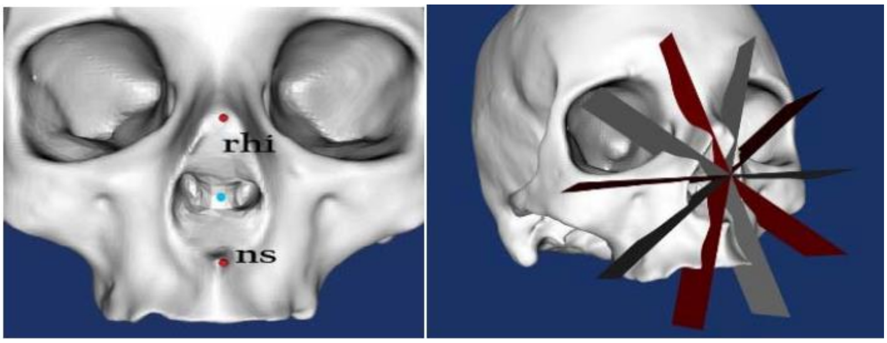


Figure 7 - Point search during a morphological analysis of CEI/XXI 3D skull (Andrade et al., 2018: 570).

In the following year, Kotěrová and colleagues (2019) tested and validated quantitative shape analysis methods for age-at-death estimation using 3D models of pubic symphyses (Figure 8). Simultaneously, Gabriel (2019), during her MSc dissertation in Forensic Anthropology worked to evaluate how experimental burning duration, at a fixed temperature of 700ºC, influences the bones' chemical structure, colour, and deformation (Figure 9).

In the same year, Ammer and colleagues (2019) digitized the trochlear constriction open curves and olecranon fossa closed outlines of 151 humeri from the CEI/XXI to develop a method and an online decision support system for sex estimation (https://osteomics.com/Ammer-Coelho/) (Figure 10).


International Journal of Legal Medicine (2019) 133:603–612
https://doi.org/10.1007/s00414-018-1934-1

ORIGINAL ARTICLE

CrossMark

A validation study of the Stoyanova et al. method (2017) for age-at-death estimation quantifying the 3D pubic symphyseal surface of adult males of European populations

Anežka Kotěrová[1] · Jana Velemínská[1] · Eugénia Cunha[2] · Jaroslav Brůžek[1]

Received: 16 July 2018 / Accepted: 5 September 2018 / Published online: 15 September 2018
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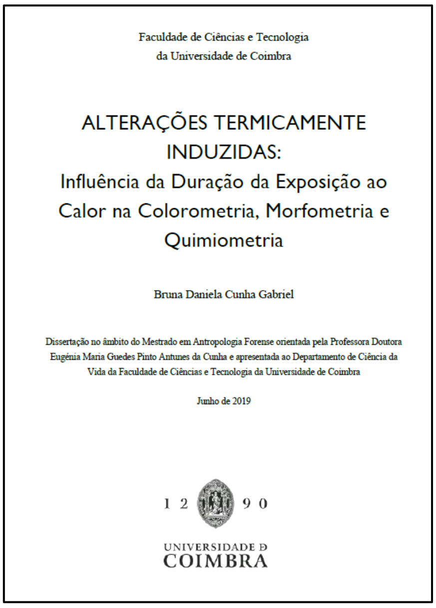
Figure 8 - Research using 3D scans from pubic symphysis from CEI/XXI individuals. Please refer https://doi.org/10.1007/s00414-018-1934-1


Faculdade de Ciências e Tecnologia
da Universidade de Coimbra

ALTERAÇÕES TERMICAMENTE INDUZIDAS:
Influência da Duração da Exposição ao Calor na Colorometria, Morfometria e Quimiometria

Bruna Daniela Cunha Gabriel

Dissertação no âmbito do Mestrado em Antropologia Forense orientada pela Professora Doutora Eugénia Maria Guedes Pinto Antunes da Cunha e apresentada ao Departamento de Ciência da Vida da Faculdade de Ciências e Tecnologia da Universidade de Coimbra

Junho de 2019

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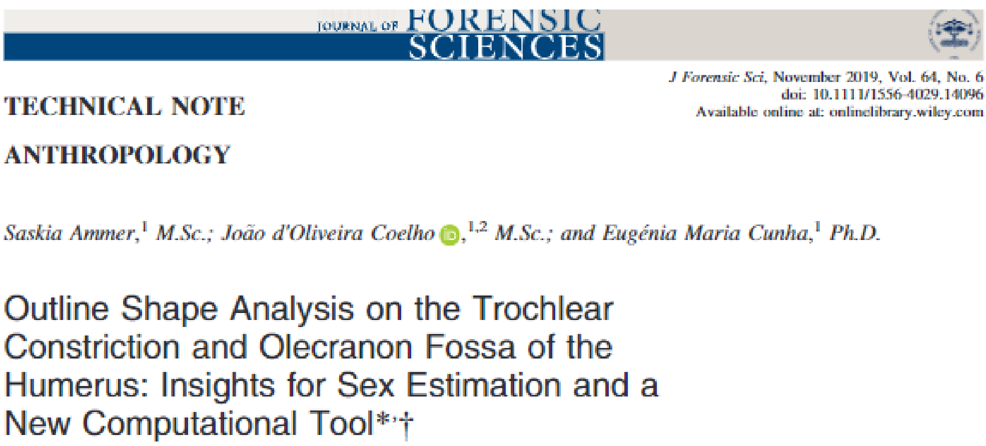
Figure 9 - MSc dissertation where 3D scans from burned humeri were studied.


JOURNAL OF FORENSIC SCIENCES

J Forensic Sci, November 2019, Vol. 64, No. 6
doi: 10.1111/1556-4029.14096
Available online at: onlinelibrary.wiley.com

TECHNICAL NOTE

ANTHROPOLOGY

Saskia Ammer,[1] M.Sc.; João d'Oliveira Coelho,[1,2] M.Sc.; and Eugénia Maria Cunha,[1] Ph.D.

Outline Shape Analysis on the Trochlear Constriction and Olecranon Fossa of the Humerus: Insights for Sex Estimation and a New Computational Tool*,†

Figure 10 - Research using digitized humeri from the CEI/XXI. Please refer https://doi.org/10.1111/1556-4029.14096.

In 2021, Maranho (2021) presented is Master dissertation in Forensic Anthropology on the evaluation of sexual dimorphism of the scapula (Figure 11), applying photogrammetry to the geometric morphometric analysis of its size and shape.

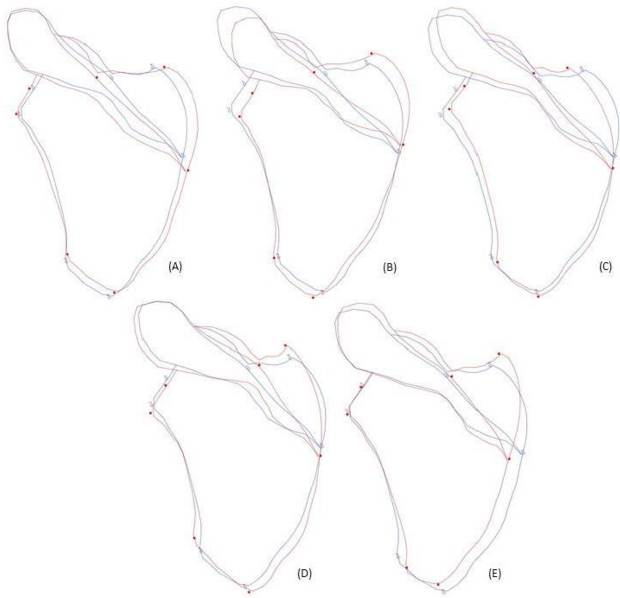


Figure 11 - Shape variation of Portuguese scapulae (Maranho, 2021: 54).

More recently, an ongoing interdisciplinary research is being developed focusing on the identification and analysis of cranial surgical procedures in the CEI/XXI. For this purpose it has been acquired 3D models from CT scans (collaboration with Coimbra University Hospital - CHUC) and surface scans with NextEngine^{TM} (Figure 12).

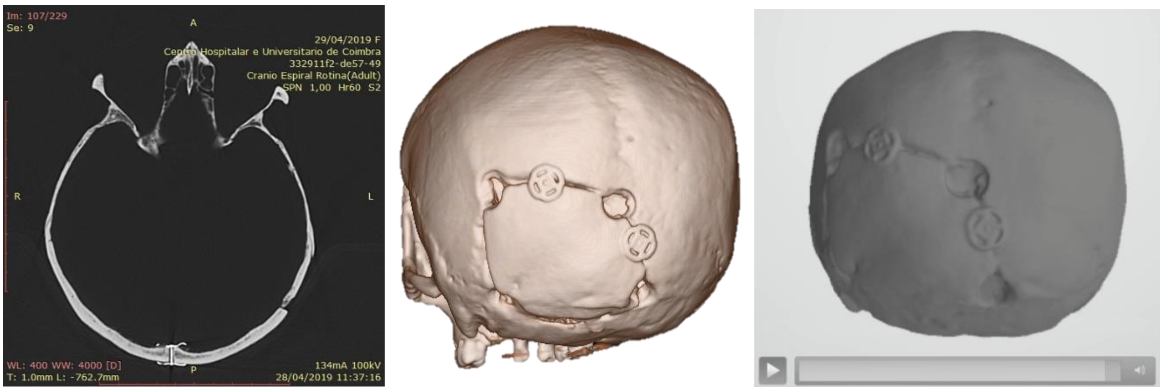


Figure 12 - CEI/XXI craniums digitized using CT scan and NextEngine ™

To summarize, throughout the years, several works have been developed at the Laboratory of Forensic Anthropology by students and researchers (Figure 13). Those investigations have employed diverse techniques such as surface laser scan, MicroScribe®, CT scan, or photogrammetry.

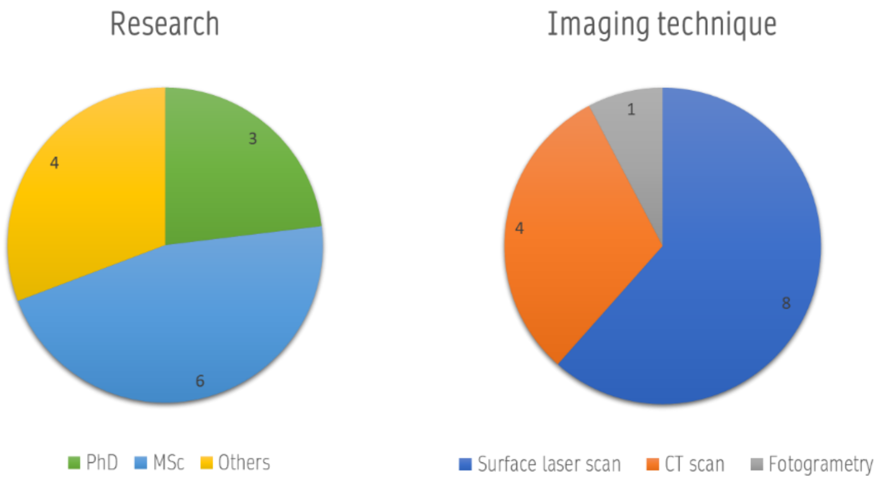


Figure 13 - Overview of research developed at the Laboratory of Forensic Anthropology applying Virtual Anthropology techniques.

1.2. Other activities

Meanwhile, other activities and tools have been developed by the LFA team. Crania of the CEI/XXI are currently being scanned with a NextEngine™ 3D scanner and stored in an online collection. This compilation works as a virtual museum, which allows students and researchers to interact with and explore the crania from CEI/XXI. At present, the expansion of the collection to include other skeletal parts is under work. This will offer a broad range of anatomical regions, improving their use in teaching. Also, this virtual repository works as a step further into guaranteeing the preservation and conservation of this important skeletal assemblage while allowing its use and study.

This virtual repository is available at: http://lfa.uc.pt/the-collection/virtual-repository/ and https://sketchfab.com/lfa.

Additionally, several research tools are available on the LFA website (http://lfa.uc.pt/projects/) (Figure 14). These tools were built by members and collaborators of the laboratory, and aim to be used for student training and to facilitate the analysis of skeletal remains by practitioners.

Figure 14 - Projects developed at the Laboratory of Forensic Anthropology.

Moreover, this knowledge and technology have been added to the work protocols employed by the laboratory team in fieldwork (Figure 15).

Figure 15 - Remains recovers from Torre dos Clérigos Crypt Intervention. Images from National Geographic and Laboratory of Forensic Anthropology.

1.3. The Laboratory of Forensic Anthropology at the Bakeng se Afrika Project

The Laboratory of Forensic Anthropology from the University of Coimbra (Portugal) began its involvement in the Bakeng se Afrika project with the preparation and hosting of workshops. In the summer of 2019, two workshops were held at the Department of Life Sciences, University of Coimbra (Figure 16). The first workshop focused on R statistics environment, taught by Kyra Stull and David Navega, and counted with 29 attendees. The second workshop, on trauma analysis, taught by Steven Symes, Rudolph Venter, and Ericka L'Abbé counted with the participation of 37 researchers and students. This workshop counted also with Calil Makhoul and João Pinheiro, who presented their work on burned human remains and forensic pathology, respectively. Both workshops had a strong practical component, complementing the theoretical lectures, and allowed the participation of researchers and students from nine different countries (Figure 17).

Figure 16 - Workshops held at the Department of Life Sciences, University of Coimbra.

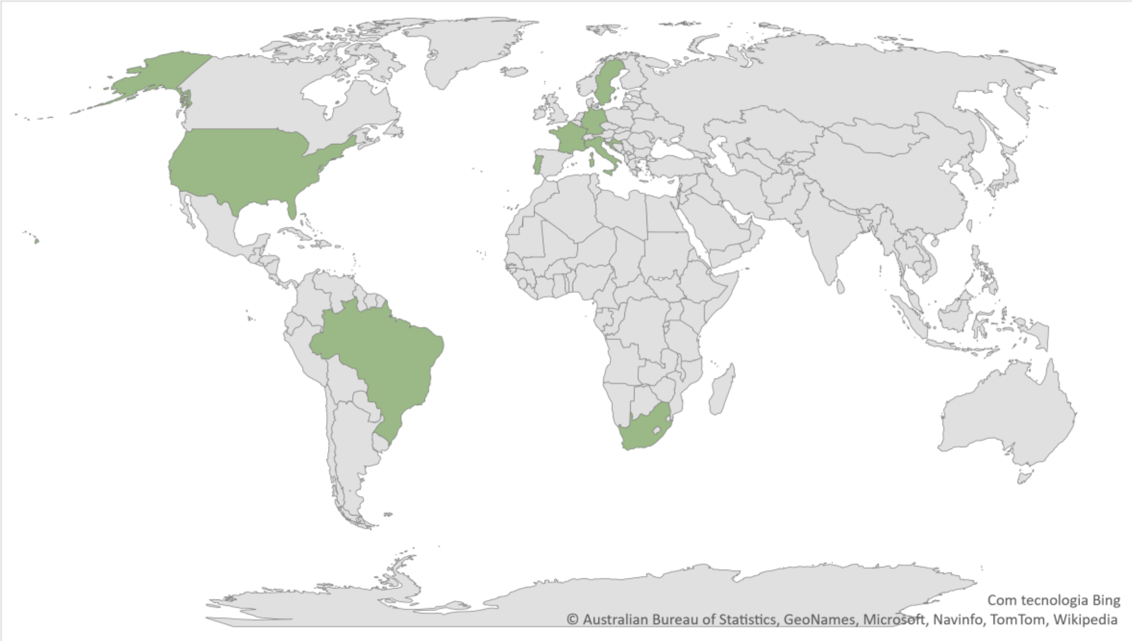


Figure 17 - Geographic distribution of workshop participants (in green)

The participation of the Laboratory of Forensic Anthropology in the Bakeng se Afrika project encompassed, beyond the workshop organization, a flow of students and staff between Portugal and South Africa. However, when facing the restrictions and uncertainties imposed by the Covid-19 pandemic, it was aimed to construct and disseminate a protocol for 3D acquisitions of human skulls, using NextEngine^{TM} 3D Laser Scan. This protocol aspires to be user-friendly for students and junior researchers and contribute to the teaching of Forensic Anthropology.

2. 3D acquisition protocol

2.1. NextEngine™

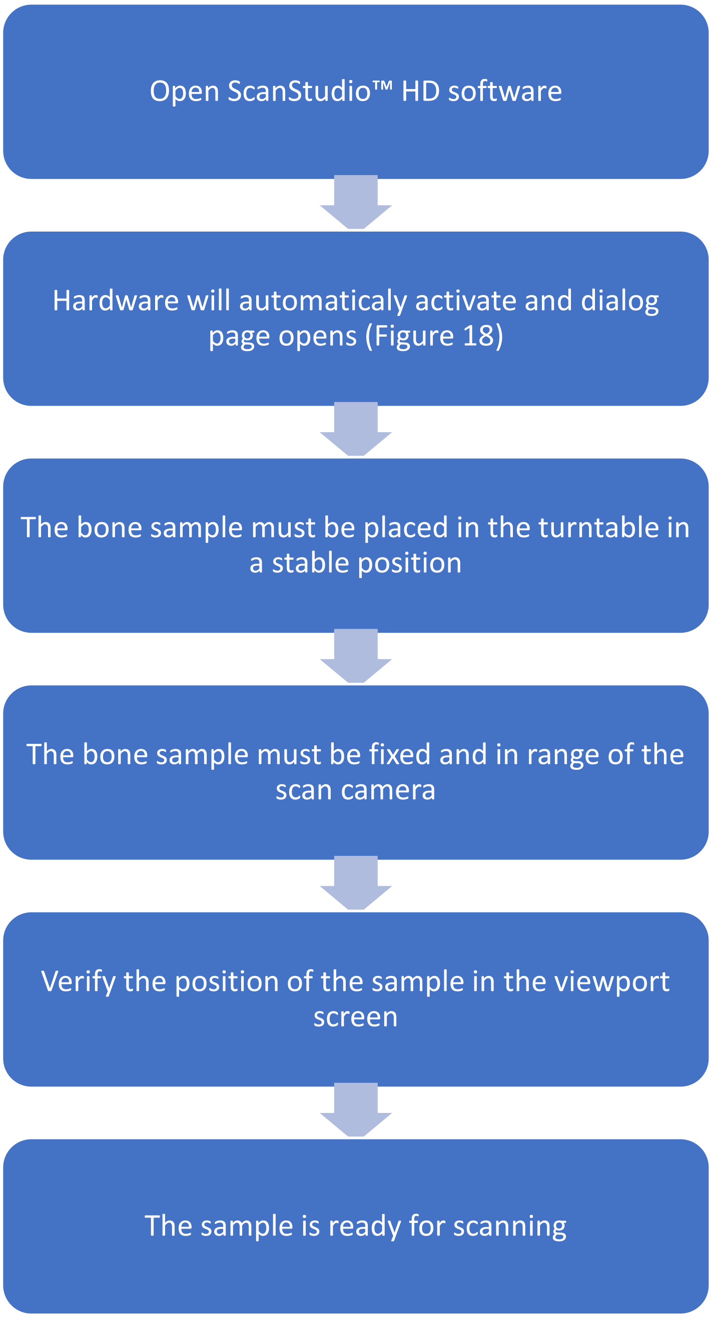
As mentioned by Filiault (2012: 20) "scanning the bones is the first step in exploring the applications of a laser scan in Forensic Anthropology".

NextEngine™ 3D Scanner HD is one of the types of equipment available at the Laboratory of Forensic Anthropology (Figures 3, 15). This laser scan is known for its considerably low price, good resolution, and portability. This scanner, of laser triangulation type, uses an internal digital camera to measure the laser stipes emitted (Filiault, 2012; NextEngine™, 2015). This equipment includes an automated turntable for easier exploration of the specimens. NextEngine™ is associated with the software ScanStudio™ HD to process scan data.

The hardware and software must be correctly installed previously to the beginning of the acquisitions, in a room with constant lighting and on a stable surface. The manufacturer's recommendations (NextEngineTM, 2015) must be followed.

2.1.1. Step-by-step NextEngine™

2.1.1.1. Sample positioning



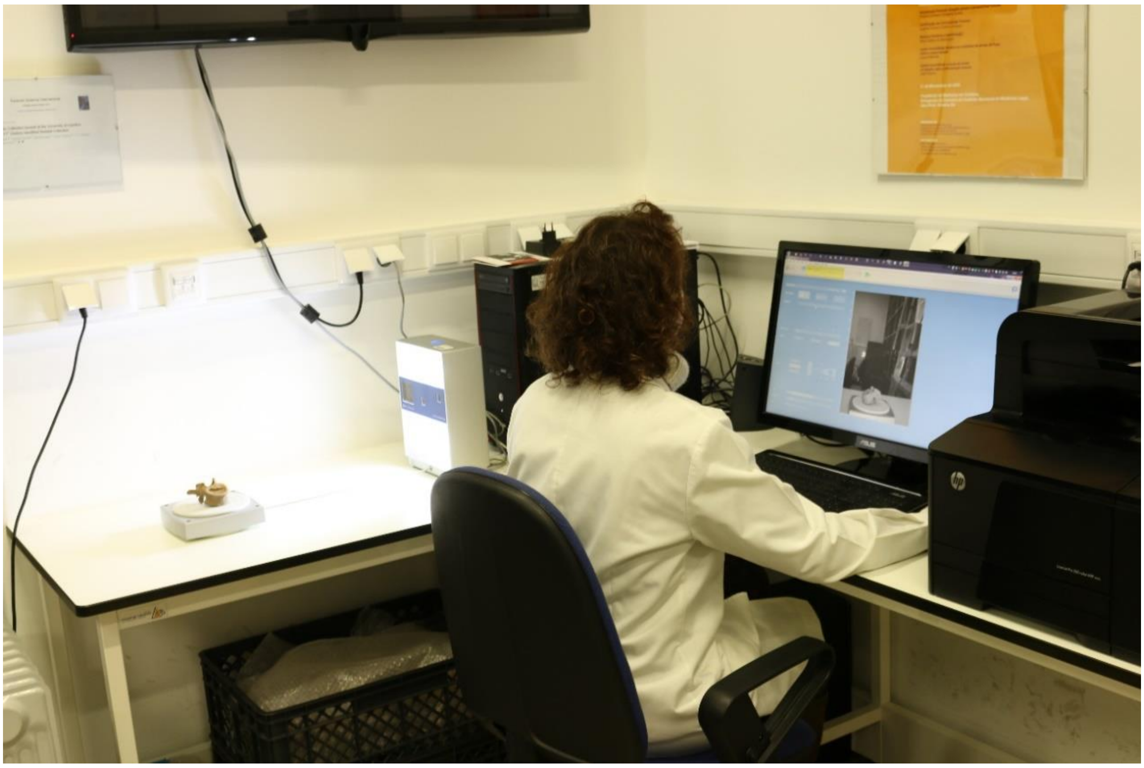


Figure 18 - Beginning of 3D acquisition. The hardware is set on a workbench, with the sample in the turntable. On the computer screen, the scan settings dialog box is visible (the settings are on the left; the camera viewport is on the right).

2.1.1.2. Advice on bone 3D scanning

ScanStudio™ allows the selection of settings as to optimize the acquisition of 3D models. The experience of the Laboratory of Forensic Anthropology teams suggests a series of simple steps to improve the results of the scanning process:

- When digitizing the cranium or mandible, ensure that teeth are fixed on the alveoli.
- Whenever Type 1 landmarks are not available or easily recognizable, it is advisable to mark some auxiliary landmarks on the bone previously to the acquisition. Ensure that the material used for markings is removable and that does not damage the bone.
- Whenever the supporting prongs are not enough for supporting the bone, moulding clay should be used for additional support.
- Selecting range “wide” on settings will allow scanning larger pieces, however, with lower resolution. Selecting “macro”, the bone must be closer to the camera and the scan will have a higher resolution, yet, for bigger samples it will require more scans to attain all of the bone. The option “extended” is not suitable for bones.
- For a good acquisition of cranium 3D models it is needed 3 different positionings: cranium with the inferior surface set on the turntable; cranium with the lateral left surface set on the turntable; cranium with the lateral right surface set on the turntable.
- The higher the resolution wished for the final model, the more time-consuming the scanning process will be. Also, the bigger the file will be. Hence, it needs to be weighted the objective and the final use of the models when selecting the settings.
- For good acquisition of long bones 3D models, it is necessary: a 360° acquisition with the distal surface set on the turntable and the proximal surface fixed on the supporting prong; a single acquisition of each extremity.
- When doing a 360° acquisition it is necessary to adjust the “divisions”. Notice that more divisions equal higher quality, however, it will take more time.

- Target will ensure that the laser intensity is appropriate for lighter or darker samples. Unless the bone piece has very dark or light colouring, it should be kept on neutral during the scanning process.
- It is important to trim and remove the artifacts of the scan obtained, prior to the alignment
- File must be saved in .ply format.
- For aligning the scans, export the files to a processing software, for example, MeshLab (meshlab.net).
- During the aligning of the scans, it is preferable to use Type 1 landmarks.
- With more than two acquisitions, the alignment is made in pairs.

2.2. MicroScribe® G2X

MicroScribe® G2X is a measurement tool developed to capture the geometric characteristics of objects. This equipment is also available in the Laboratory of Forensic Anthropology (Figure 18).

2.2.1. Step-by-step MicroScribe® G2X

2.2.1.1. Sample positioning

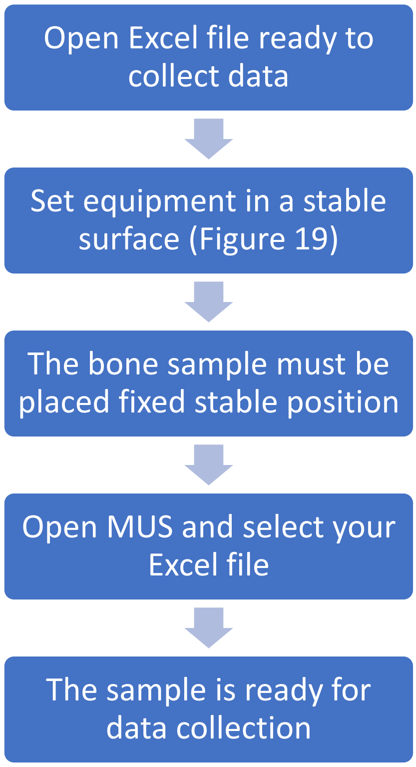


Figure 19 - MicroScribe® G2X data acquisition. Equipment is set on a stable workbench and the specimen fix in a proper support.

2.2.1.2. Advice on bone 3D data acquisition

The experience of the Laboratory of Forensic Anthropology teams suggests some simple actions when using the MicroScribe® G2X equipment:

- When digitizing cranium or mandible ensure that teeth are fixed on the alveoli.
- Various types of supporting techniques may be applied, always adapted to the type of bone under study: metal supporting prongs, support sponge, moulding clay, or others.
- The bone sample must keep its position throughout all the procedure. If moved, the data acquisition must be re-initiated.
- The excel file where the cartesian coordinates are saved must always present the data in the same order: x, y, z.
- It is advised to save the final file in both . xlsx and .csv.
- Before final data acquisition, this technique requires some training as to optimize the procedure and lower inter and intra-observer bias.

3. Final remarks

3D acquisition and consequent geometric morphometric techniques go beyond the traditional approaches by allowing the statistical evaluation of shape by repeatable methods of two- or three-dimensional shape capture.

From an anthropological perspective, if enough data are included, this approach may help in the solution of the problems of subjectivity, witnessed in nonmetric techniques. However, the geometric methods use the same data as the morphological methods, the two approaches will continue to be necessary and should be applied to complement each other.

Moreover, it should be continuously highlighted the relevance of these techniques for the preservation of the specimens' integrity, for scientific dissemination, and also to facilitate the communication and data share between researchers in a global context.

With this guide, we hope to provide a user-friendly tool for those beginning their research careers and also facilitate the teaching process of these young anthropologists.

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Digital Skeletal Repository
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