



SHEDDING LIGHT ON PRE-COLUMBIAN CRANIA COLLECTIONS THROUGH STATE-OF-THE-ART 3D SCANNING TECHNIQUES

DAR LUZ A COLECCIONES DE CRÁNEOS PRECOLOMBINOS A TRAVÉS DE TÉCNICAS DE ESCANEADO 3D DE ÚLTIMA GENERACIÓN

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Highlights:

- A hand-held structured light scanner was used to acquire 3D reality-based models of pre-Columbian crania. The resulting 3D models were used for 3D printing replicas and 3D animations.
- This study provides unprecedented 3D reconstructions of pre-Columbian crania in the Caribbean area, and new 3D reconstructions of artificially deformed crania from South America.
- The 3D resources created will encourage new knowledge through research, and provide broader access to these pre-Columbian crania collection with related learning and outreach activities.

Abstract:

During the 19th and 20th centuries, numerous museums, scientific societies, and royal academies were founded in Europe and America. This is the context in which the Anthropological Museum Montané was founded in Havana, Cuba. Its collection has grown over the years, thanks to researchers, antiquarians, and amateurs. Since its foundation, the Museum Montané has become an essential institution for anthropological and archaeological research in the region. Nowadays, the Museum Montané, like other museums in developing countries, faces a challenge in introducing state-of-the-art technologies for digitizing exhibits and creating innovative projects to attract visitors. The current possibilities of virtualization of cultural heritage using digital technologies have a favorable impact on the preservation, access, and management of museum collections. The use of three-dimensional (3D) models fosters engagement with visitors, stimulates new learning forms, and revalorizes the exhibits. In the current study, we use a hand-held structured light scanner to create 3D reality-based models of pre-Columbian crania from the Caribbean and South American collection of the Anthropological Museum Montané. The resulting 3D models were used for producing 3D printing replicas and animated videos. The 3D resources will encourage new knowledge through research and provide broader access to these pre-Columbian crania collection with related learning and outreach activities. Digitizing these specimens has an importance that goes beyond the creation of 3D models: it protects these fragile and valuable collections for future generations. The methodology and results reported here can be applied in other museums with similar collections to digitally document, study, protect, and disseminate the archaeological heritage. In future projects, we seek to continue exploring the application of novel methods and digital techniques to the study of the pre-Columbian crania collections in Latin American and the Caribbean area.

Keywords: 3D scanning; 3D reality-based models; 3D printing; 3D animations; pre-Columbian crania; museum collections

Resumen:

Durante los siglos XIX y XX numerosos museos, sociedades científicas y academias reales fueron fundados en Europa y América. En este contexto, el Museo Antropológico Montané fue fundado en La Habana, Cuba. Su colección ha crecido con los años, gracias a investigadores, anticuarios y aficionados. Desde su fundación, el Museo Montané se ha convertido

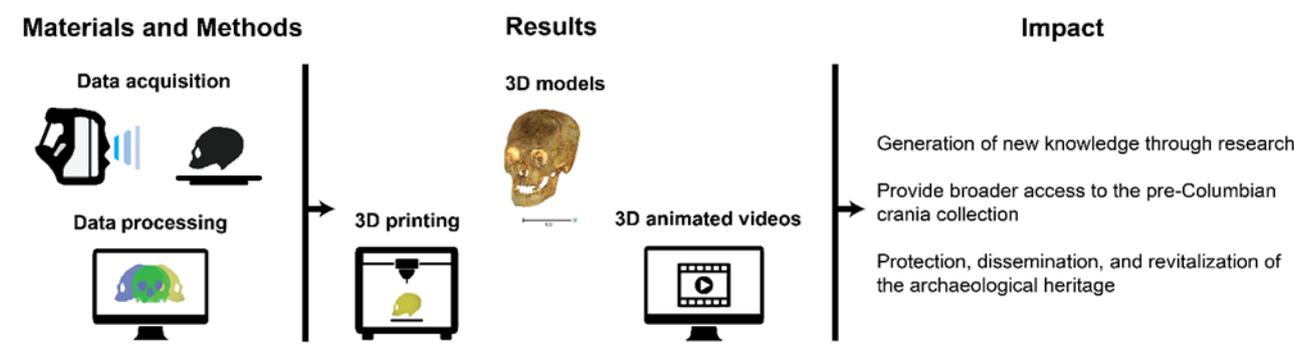
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en una institución esencial para la investigación antropológica y arqueológica de la región. Actualmente, el Museo Montané, como otros museos de países en desarrollo, se enfrenta a un reto en la introducción de tecnologías avanzadas para digitalizar las colecciones y la creación de proyectos innovadores para atraer visitantes. Las posibilidades actuales de virtualización del patrimonio cultural mediante tecnologías digitales repercuten favorablemente en la conservación, el acceso y gestión de las colecciones de los museos. El uso de modelos tridimensionales (3D) fomenta el compromiso con los visitantes, estimula nuevas formas de aprendizaje y revaloriza las exposiciones. En este estudio, se usa un escáner de luz estructurada portátil para crear modelos 3D, basados en la realidad, de cráneos precolombinos de la colección del Caribe y Sudamérica del Museo Montané. Los modelos 3D resultantes se utilizaron para producir réplicas impresas en 3D y videos animados. Los recursos 3D derivados fomentarán nuevos conocimientos mediante la investigación y proporcionarán un acceso más amplio a estas colecciones de cráneos precolombinos mediante actividades de aprendizaje y divulgación. La importancia de la digitalización de estos especímenes va más allá de la creación de modelos 3D: protege estas frágiles y valiosas colecciones para futuras generaciones. La metodología y los resultados reportados pueden aplicarse en otros museos con colecciones similares para documentar, estudiar, proteger y difundir digitalmente el patrimonio arqueológico. En futuros proyectos, continuaremos explorando la aplicación de métodos y técnicas digitales para el estudio de colecciones de cráneos precolombinos en América Latina y el Caribe.

Palabras clave: escaneado 3D; modelos 3D basados en la realidad; impresión 3D; animaciones 3D; cráneos precolombinos; colecciones de museos

Graphical abstract:



1. Introduction

The 19th and the beginning of the 20th century are critical in the study of Archaeology and Anthropology. It is when these disciplines evolved into a more systematic and modern way. Also, it is the period when a large part of museums, scientific societies, and royal academies established (Renfrew & Bahn, 1996; Schultz, 1990; Weber, 1974).

In the Caribbean, first collections were mainly built by antiquarians (professionals and educated people, mostly from high-class families) and historians. In this scenario, museums with anthropological and archaeological collections were founded in Latin America (Curet, 2011; Moore, 2014). One of these institutions was the Anthropological Museum Montané, founded on June 29, 1903, in Havana, Cuba (Rangel Rivero, 2012). Since then, the Museum Montané has become an essential institution for anthropological and archaeological research in the region (Dacal Moure & Rivero de la Calle, 1986; Dacal Moure & Watters, 2005; Rangel-de Lázaro, 2020). The collections held by the Museum Montané are the result of more than a century of continuous work of professionals, antiquarians, and amateurs.

Nowadays, the Museum Montané, like others in developing countries, faces a challenge in terms of technology and innovation adoption (Verona *et al.*, 2018). Limited funding had impacted the introduction of novel technologies to preserve the collections and the creation of innovative projects to attract visitors. In this scenario, digitizing museum exhibits means protecting it for future generations.

The use of three-dimensional (3D) methods for documenting archaeological and anthropological objects has been widely validated in recent years. It has become a needed resource of many institutions to safeguarding cultural heritage and facilitating future reconstructions based on trustworthy datasets (Núñez Andrés *et al.*, 2012; Robson *et al.*, 2012; Stylianidis & Remondino, 2016). The benefits of using techniques such as 3D scanning (Kuzminsky & Gardiner, 2012; Payne, 2019; Rodríguez Miranda *et al.*, 2017), photogrammetry (Liang *et al.*, 2019; Magnani *et al.*, 2018; Pierdicca, 2018) and computed tomography (Charlier *et al.*, 2020; Erolin *et al.*, 2017; Zhang *et al.*, 2012) to digitize museum collections have proved its utility in terms of improving preservation, access, management, exchange of the geometric information, community engagement, research, and learning.

Currently, many museums include multiple forms of digital media, such as video, audio, and 3D animations, providing significant possibilities for viewing the collections without interfering with the physical object itself (Farazis *et al.*, 2019; Fenu & Pittarello, 2018; Gimeno *et al.*, 2017; Santos *et al.*, 2017; Younan & Treadaway, 2015). The use of 3D resources plays an important role in re-establishing connections between museum exhibitions and visitors. Moreover, it helps curators and researchers to maximize time efficiency and knowledge transfer (Kosmopoulos & Styliaras, 2018; Styliani *et al.*, 2009).

The creation of 3D models serves to highlight not only the tangible collection it represents, but also the intangible resources associated with the object such as traditions,

stories, myths, and legends. For example, that is the case of artificially deformed crania. Intentional head-shaping was a widespread practice among the American continent inhabitants at the time of European contact. Spanish chroniclers made first mentions of artificially deformed heads among the native population, including physiognomic descriptions, and the techniques and materials used by the parents or kin to perform the deformation on their newborns (de las Casas, 1875; Portuondo, 1977; Vega, 1826).

1.1. Research aims

In this study, our main goals are: 1) the application of 3D techniques to obtain reality-based models of key pre-Columbian crania from the Anthropological Museum Montané; 2) to use the 3D models generated to produce 3D printing and animated videos. All the 3D resources created will encourage new knowledge through research, as well as to provide broader access to these pre-Columbian crania collection through a variety of learning and outreach activities.

2. Materials and Methods

A representative selection of the 13 unique pre-Columbian crania from the Caribbean and South American osteological collection of the Anthropological Museum Montané was used in the current study (Table 1). The sample selected was collected and donated in the 19th and 20th centuries by Luis Montané Dardé (1849-1936), Carlos de la Torre (1858-1950), Juan Antonio Cosculluela Barrera (1884-1950), Miguel Rodríguez Ferrer (1815-1889), Luis Antonio Barakltr (dates are unknown), and Salvador Massip Valdés (1891-1979). According to the records of the Museum Montané.

Table 1: The sample used in the study

Collector	pre-Columbian crania	No
C. de la Torre (1890)	Tabular oblique deformed crania	1
L. Montané Dardé (1888)	Undeformed crania	1
J. A. Cosculluela Barrera (1913)	Undeformed crania	1
M. Rodríguez Ferrer (1847)	Tabular oblique deformed crania	2
A. Mestre Laboratory (20 th century)	Tabular oblique deformed crania	5
L. A. Barakltr & S. Massip Valdés (20 th century)	Annular deformed crania	3

The sample comprises one cranium with tabular oblique artificial deformation. The cranium was recovered in Maisí, Cuba, during the expedition conducted by Carlos de la Torre in the last decade of the 19th century (de la Torre Huerta, 1890). One cranium discovered by Montané on June 29 of 1888, in the archaeological site Boca del Purial in Sancti Spíritus, Cuba. One cranium retrieved by Juan Antonio Cosculluela Barrera in 1913 at the Guayabo Blanco archaeological site located in the Ciénaga de Zapata, Matanzas, Cuba (Cosculluela, 1918). One cranium and one skull with tabular oblique artificial deformation discovered by Miguel Rodríguez Ferrer in Maisí in 1847 (Michelena Zubieta, 1890). Five crania with tabular oblique artificial deformation recovered in Cuba,

which belongs to Arístedes Mestre Laboratory collection within the Museum Montané. Three Peruvian crania with annular artificial deformation donated to the Museum Montané by Luis Antonio Barakltr and Salvador Massip Valdés at the beginning of the 20th century.

2.1. Data acquisition

All the specimens were scanned using the Artec Space Spider structured blue light scanner and the software Artec Studio 11 (Fig. 1). The equipment can achieve sub-millimetric 3D resolution and point accuracy (i.e., up to 100 µm and 50 µm, respectively) in the final model. All the sample was digitalized following the same procedure. Each specimen was placed on a rotatory platform and scanned on different positions to register the whole geometry and texture of the cranium. This process resulted in almost all cases in three scans per specimen, and the capture of ~900 frames per scan. High-density polyurethane foam support was used to stabilize and immobilize the cranium when the position required it. Each capture was made at a distance of about 20-30 cm. The time of capture for each cranium was between 5 and 15 minutes.



Figure 1: Data acquisition using the Artec Space Spider structured blue light scanner.

2.2. Data processing

The raw scan data was processed using Artec Studio 11. First, a fine registration was run to align the sequential frame pairs on each of the three scans captured on each specimen; also, on this step, the rotatory platform was removed from the scene (Fig. 2a; SV1: frame sequence across one of the scans). Then the *Auto-alignment* tool was used to match the overlapped scans in the same 3D space (Fig. 2b). The aligned scans were registered globally to compare and optimize the frame position across all scans (Fig. 2c). Once the global registration was completed, a maximum registration error of the captured frames of 100 µm was obtained, proving the high quality of the registration. Subsequently, outliers were removed to clean up possible edge noise in the final

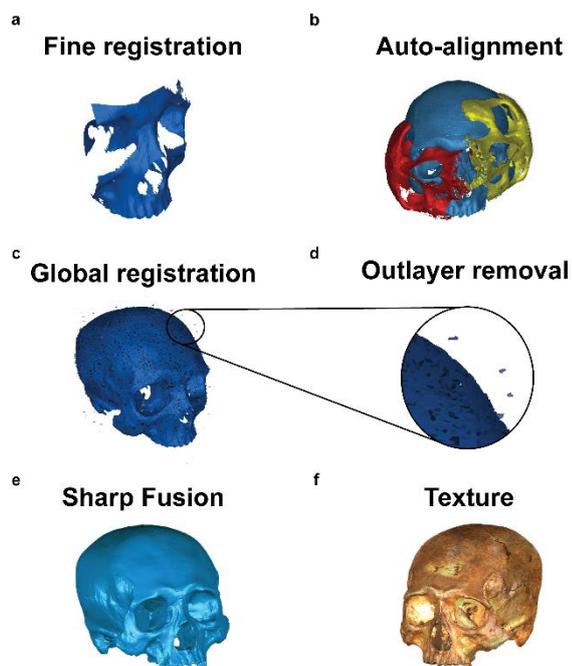


Figure 2: Workflow followed for processing the scan data in Artec Studio.

model (Fig. 2d). For better results, a threshold of 2, recommended for noisier surfaces, and a resolution equal to the maximum registration error (i.e., 100 μm) were applied. Afterward, the *Sharp Fusion* feature was used to fuse all the scans and create a single mesh with a resolution of 100 μm (Fig. 2e). For the fusion, mesh holes were manually filled to avoid filling the craniovascular foramina. Finally, a texture was applied to the models to obtain a realistic appearance (Fig. 2f). *Texture atlas*, in combination with interpolation and normalization of textures, was used for an 8192x8192 output texture size. Texture parameters like brightness, gamma correction, and contrast were adjusted to resemble the actual specimen. The resulting high-quality meshes had an average of 6 million polygons and were exported in .STL (i.e. mesh) and .OBJ (i.e. mesh and texture) formats.

2.3. 3D printing

For the 3D printing, the models were duplicated at a lower polycount, but retaining accuracy, using the *Mesh simplification* algorithm in Artec Studio. The procedure eliminated triangles whose edge length was less than 100 μm , which is related to the maximum resolution/layer thickness of the 3D printer used. In order to avoid gaps in the 3D printed models, the watertight fusion algorithm was applied to fill holes in the mesh without altering the gross morphology of the cranium. 3D models were printed at a 1:1 scale using a bq Witbox printer with fused deposition modeling (FDM) technology and a white polylactide acid (PLA, which is a vegetable, biodegradable plastic) material.

2.4. 3D animated videos

The 3D animations were produced as a high-definition video in After Effects v. 2019. For the first video, we used the full-resolution 3D model of the cranium with tabular oblique artificial deformation recovered by Carlos de la Torre at the end of the 19th century. In the 3D animated video, the 3D model rotates through 360° as the cranium

is viewed from different angles. As the cranium rotates, each bone appears highlighted, first with a color and then with the texture of the 3D model. Then a label appears with the name of the bone. The second video shows one skull with tabular oblique artificial deformation discovered by Miguel Rodríguez Ferrer in Maisí in 1847. The animation shows a 360° view of the 3D model, first revealing the texture applied and then the mesh. On the left side, the superior and inferior views of the skull are displayed.

3. Results and Discussions

Our study provides unprecedented evidence of 3D reconstructions of pre-Columbian crania in the Caribbean area and new 3D reconstructions of artificially deformed crania from South America. Here we present for the first time a study with systematic and reliable results based on the use of digital techniques to reconstruct the valuable specimens of the pre-Hispanic crania collection from the Anthropological Museum Montané. The most remarkable outcome is the implementation of the 3D resources created to raise awareness of the collection, improve research, and promote science dissemination.

The 13 3D models of the pre-Columbian crania are illustrated in Fig. 3. The 3D structured light scanner used was a fast method that allowed us to reach adequate results in terms of both detail and accuracy. The methodology followed during the acquisition and post-processing of the 3D dataset allowed us to create reality-based models reproducing the geometry and textures of the original crania. Specific features such as fractures (Fig. 3b) and foramina (Fig. 3e) were easily identified in the high-resolution models, but also on the simplified meshes. Some structures, such as the orbital part of the frontal bone (Fig. 3a), the lachrymal (Fig. 3k), the inferior nasal conchae (Fig. 3h), and the vomer (Fig. 3m), when present, its acquisition was challenging but possible. On average, we did three scans per specimen, except in one individual, which only presents the neurocranium, and two scans were sufficient to capture the whole surface (Fig. 3d).

No method is without drawbacks. Contrary to expectations, we encountered difficulties during a continuous period of data capturing. The scanner performance was affected by the warm and humidity conditions of the room where we were working. It should be noted that this situation did not affect our results because we stopped between scans to let the equipment (i.e., scanner and laptop) cool down. Apart from the temperature recommendations provided by the hardware developer (Artec3D, 2019), we did not find literature reporting similar issues. Also, the 3D scanner used in this study was more suitable to capture the external surface of the crania. In the future, we may consider using CT scanning to visualize the external and internal morphology of the bones in great detail.

The 3D models created are ready to be examined using free 3D viewers (e.g., Autodesk® FBX® Review, lightweight software that allows viewing 3D models on both laptops and smartphones) and further edited using 3D modeling software (e.g., MeshLab and Blender). Many procedures can be performed using 3D models and software packages, such as computing measurements on the digital surface, viewing and manipulating the specimen from any chosen angle to reveal in detail

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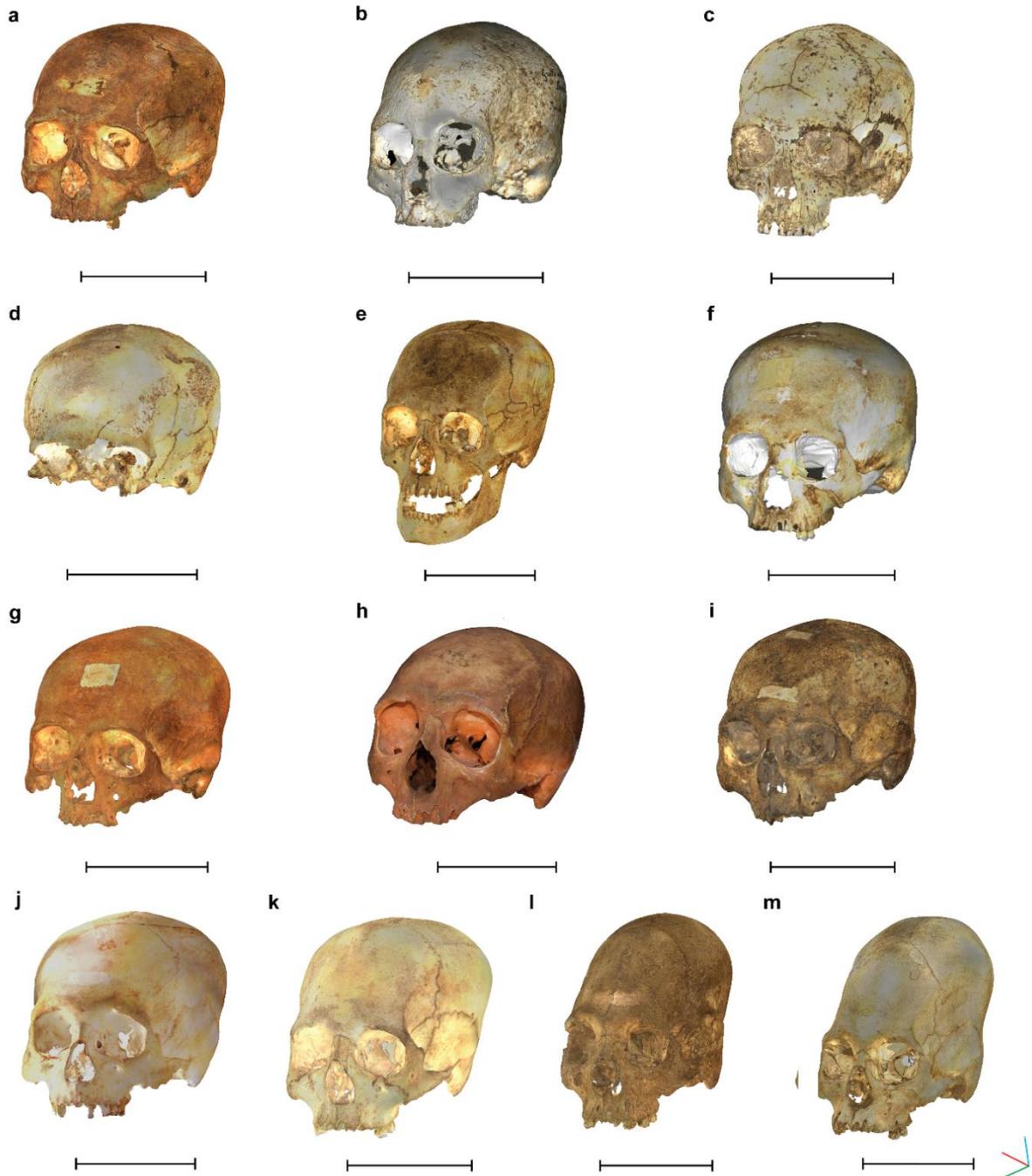


Figure 3: 3D models of the pre-Columbian crania: (a) the cranium recovered by Carlos de la Torre; (b) the cranium discovered by Luis Montané; (c) the cranium retrieved by Juan Antonio Cosculluela; (d) the cranium and (e) the skull discovered by Miguel Rodríguez Ferrer; (f-j) the crania recovered in Cuba and part of the Aristedes Mestre Laboratory collection; (k-m) the Peruvian crania donated to the Museum Montané by Luis Antonio Baraklt and Salvador Massip. Scale bar: 10 cm.

specific features that may be elusive in the physical sample. By simplifying the meshes, we found a tradeoff between producing a satisfactory recognition of the crania structures and decreasing the computation load of the software used, which could be problematic on lower-powered devices. 3D texture rendering in models and videos gives a sensation of reality, allowing researchers, students, and visitors to visualize the different bone structures virtually (Videos 1 and 2 in Figs. 4 and 5, respectively). Moreover, the 3D prints facilitate the manipulation of the reproduced crania, without causing any harm to the valuable original collection displayed in the Museum Montané (Fig. 6).

To date, 3D models, printed copies, and animated videos of the pre-Columbian crania are being used in several research projects. The new 3D resources will be displayed for the visitors of the Museum Montané, creating a virtual and hands-on experience through a variety of learning and teaching initiatives. All this will enhance the information of the physical exhibition, enabling a variety of new interactions, interpretations, and approaches.

Beyond the 3D resources created, these crania contain valuable historical and intangible information associated with them. For example, Fig. 3b shows the cranium

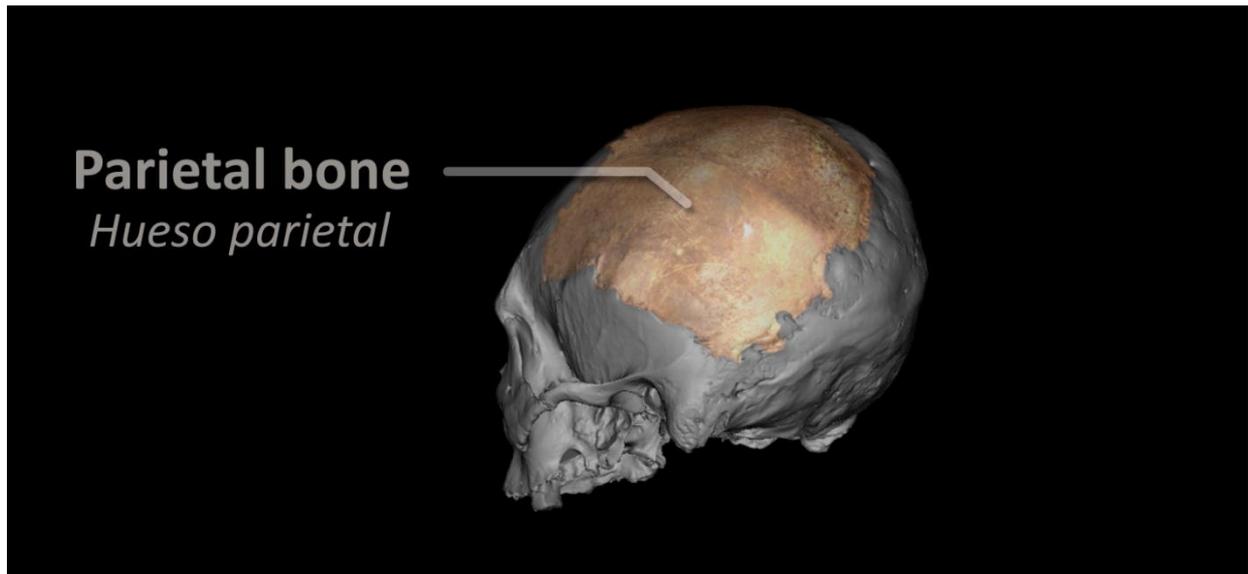


Figure 4: 3D model of the artificially deformed cranium recovered by Carlos de la Torre at the end of the 19th century ([Video 1](#)).



Figure 5: 3D model of the artificially deformed skull discovered by Miguel Rodríguez Ferrer in Maisí in 1847 ([Video 2](#)).

discovered by Luis Montané and misclassified as *Homo cubensis* by the paleontologist Florentino Ameghino (1854-1911), motivating controversy in the academic community at the time ([Montané Dardé, 1907](#)). Figure 3c shows the cranium of Guayabo Blanco. Cosculluela discovered this specimen and other remains in a pre-Hispanic cemetery thanks to the information transmitted by oral tradition among the inhabitants of the

Ciénaga de Zapata ([Rangel Rivero, 2012](#)). Also, Fig. 3d shows the neurocranium with which Juan Santiago Michelena Zubieta (1857-1901) wrote the first anthropological thesis in Cuba ([Michelena Zubieta, 1890](#)). Through the 3D resources produced, we also pretend that all the tangible and intangible information associated with these pre-Columbian crania collection will be promoted.



Figure 6: 3D printed replica of a pre-Columbian cranium from the Museum Montané. Scale bar: 10 cm.

The literature presents numerous examples of the use of 3D techniques for the digitization of cultural heritage. Research on this topic is conducted mainly in developed countries, which translates into a large number of publications (Charlier et al., 2020; Erolin et al., 2017; Fazio & Brutto, 2020; Magnani et al., 2018; Payne, 2019; Rodríguez Miranda et al., 2017; Zhang et al., 2012). In comparison, in Latin American, we could only find a few publications mainly centered on the digitization of monumental structures, archaeological sites, and bioarchaeological remains (Berquist et al., 2018; Gillespie & Volk, 2014; Hixon et al., 2018; Kuzminsky et al., 2016; Novotny, 2019; Pierdicca, 2018). As far as we know, there are no published studies based on the digitization of museum collections from the Caribbean. In developing countries, numerous constraints such as lack of human and economic resources, impact cultural institutions, including museums, limiting the application of new technologies in research and visitor engagement (Boylan, 2004; Morris, 2017; Vermeeren et al., 2018; Verona et al., 2018). In the Museum Montané, like in many museums worldwide, this situation has postponed the digitization of the collections. In this study, it was possible to overcome the funding limitations and digitize part of the valuable pre-Columbian specimens of this institution.

The Anthropological Museum Montané houses one of the most important cultural heritage collections of the region. Prior research used traditional methods involving photographs and drawings (Dacal Moure & Rivero de la Calle, 1986; Rangel Rivero, 2018; Rivero de la Calle, 2002). These are valuable studies either because they are the result of thorough historical research or because they are indispensable literature for understanding anthropological investigation in the region. However, these studies run the risk of falling into repetition and the lack of novelty in methods and results, which may end up taking its toll on the research impact. The digital methods used in this paper aim to fill the gap in current digital research in the region. Moreover, we hope that the methodology and results reported here will be used in other museums with similar characteristics to digitally

document, study, protect, and disseminate their collections. Nowadays, large museums such as the Natural History Museum in London and the Smithsonian are digitizing their vast collections to improve the way of preserving and sharing it. It is equally vital for smaller museums to build a digital database of their samples.

The significance of this research goes beyond the digitization of the samples from the Anthropological Museum Montané. On one side, the results of this study will have a positive impact on research projects based on the collection. All this will promote new studies in areas such as digital analysis and geometric morphometrics, in line with novel research. On the other hand, the use of both virtual and printed versions of museum collections in public engagement and outreach initiatives will improve the ways of communicating science to the public visiting the Museum Montané (Cooper, 2019; Giuseppantonio Di Franco et al., 2015).

Going forward, we seek to upload the 3D models into a digital platform such as Google Arts & Culture, Sketchfab, or Morphosource to increase the visibility of the Museum Montané collection (Champion & Rahaman, 2020). Once the 3D models are uploaded to the chosen online platform, we will include information explaining the intangible resources associated with each cranium. Like previously done in small and large museums worldwide (Erolin et al., 2017; Younan & Treadaway, 2015), the online presence of the 3D collections will significantly increase the visibility of an institution and the cultural heritage which safeguard.

4. Conclusions

The significance of digitizing museum collections goes beyond the creation of a 3D virtual replica. It means preserving for the future the fragile cultural heritage, which one day may disappear. High-quality digital documentation of priceless exhibits becomes essential to protect them and to enhance research, based on consistent datasets.

Our results can be understood as the first steps for the digitization of pre-Columbian crania from the Caribbean area. This may be considered a promising aspect for future research leading to several exchanges with external researchers. The combination of the Museum Montané existing resources with the hands-on 3D data created can satisfy the educational and research needs of the institution. Moreover, with 3D models, printed copies, and animated videos of the pre-Columbian crania, the visitor experience will be enhanced.

As a result of the collaboration built for the development of this project, future research will further explore the application of novel methods and digital techniques to the study of the pre-Columbian crania collections in Latin American and the Caribbean area.

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