Research Article

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The Use of 3D Photogrammetry in the Analysis, Visualization, and Dissemination of the Indigenous Archaeological Heritage of the Greater Antilles

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Abstract: The development of digital technologies and the use of advanced photogrammetry programs for modeling archaeological excavations and sites have opened new possibilities for spatial analysis in archaeology and the reconstruction of archaeological contexts. In addition, these tools allow us to visually preserve the features of archaeological sites for future use and facilitate the dissemination of archaeological heritage to local communities and the general public. This paper summarizes 3D photographic visualization of three cave art sites (Los Cayucos and Cueva No. 1 in Punta del Este, Cuba, and José María Cave in the Dominican Republic) and two burial spaces (Canímar Abajo and Playa del Mango, Cuba) using photogrammetry software. The application of these novel methods at the cave art sites allowed us to visualize faint pictographs that were invisible to the naked eye, to better define the shapes of petroglyphs and to reconstruct the position of lost/removed panels. At the burial sites, 3D modeling allowed us to register the

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archaeological context with greater precision. The use of 3D modeling will improve spatial analysis and data safeguarding in Cuban archaeology. Moreover, 3D movies are an effective way to disseminate knowledge and connect local communities with their cultural heritage, while reducing the impact of public visits to remote or endangered sites.

Keywords: photogrammetry, virtual archaeology, Caribbean archaeological heritage, Cuban indigenous heritage

1 Introduction

The research and conservation of cultural heritage, as the testimony of different cultural strategies and cognitive abilities of past human groups, has gained both political and public relevance (Hernández, 2011; International Congress of Architects and Technicians of Historic Monuments, 1931). Internationally, the effects of colonialism and globalization have had a strong negative impact on indigenous cultural heritage. Natural disasters, climate change, and rising sea levels, as well as the uncontrolled pressures of development and tourism, have seriously threatened cultural legacies around the world (Gutiérrez et al., 2012; Hernández, 2012; UNESCO, 2009). This is particularly important in the Caribbean, where the first encounters between Europeans and the indigenous people of the Americas took place, where strong hurricanes are a yearly phenomenon, and where coastal developments, compounded with destruction of protective natural barriers (e.g., mangroves) and the rising sea level, obliterated many archaeological sites. The loss of collective memory of the indigenous groups that inhabited the islands, including their knowledge and their ideational worlds, needs to be prevented or reversed. In the case of the Caribbean region, the study of precolonial indigenous heritage frequently represents the only available evidence for the reconstruction of their identities. The study, conservation, and dissemination of this cultural heritage have the potential to increase the sense of belonging and social identity of indigenous communities. In addition, the study and conservation of cultural heritage is necessary to guarantee balanced and sustainable management of heritage sites for the benefit of current and future generations.

Archaeology reconstructs the way of life and knowledge of past populations based on preserved material remains and their context (Vargas, 1987). Since human cultural heritage is the result of human activity, archaeology contributes to the understanding and revitalization of the identity of past populations by using different techniques and core concepts in the field (Moreno & Sariego, 2017; Pérez, 2006; Renfrew & Bahn, 2011). Archaeology is, on the other hand, a destructive practice, since excavations create knowledge of ancient human societies while destroying the context that provides the information (Vargas, 1987). For this reason, proper, detailed, and relevant documentation is a critical resource that safeguards the archaeological context.

In the case of monuments, the International Charter for the Management of Archaeological Heritage, adopted by the General Assembly of ICOMOS in Lausanne in 1990, emphasizes the value of *in situ* conservation and encourages community participation in creating policies for the protection of their own and/or local cultural heritage. Archaeology can contribute substantially to the engagement of local communities by providing access to research outcomes, by disseminating knowledge, and by promoting the importance of safeguarding community material culture and history. These strategies have been found to engage communities with the protection of cultural heritage (International Committee on Archaeological Heritage Management, 1990). In this respect, the Krakow Charter (De Naeyer, Arroyo, & Blanco, 2000) recognized that the use of modern technologies and virtual presentations should be promoted as a way to protect and disseminate the legacy of past societies. Cultural heritage specialists have endorsed the use of new technologies, such as photogrammetry and topography, along with the use of Geographic Information Systems (GIS) in their workflow. These three techniques are now widely used to record archaeological heritage (Duque & de Francisco, 2015).

Photogrammetry can be used to derive depth information from point clouds generated from two or more overlapping digital photographs of a surface taken at different angles (Williams & Twohig, 2015). Photogrammetry is less expensive than terrestrial laser scanning or structured-light scanning and can facilitate low-cost 3D modeling and analysis without high risk to precision (Simon & Opitz, 2012; Westoby, Brasington, Glasser, Hambrey, & Reynolds, 2012). As a nondestructive technique in which photography is coupled with precise measurements, photogrammetry allows researchers to identify patterns during surveys and remote

documentation (Caro & Hansen, 2015; Duque & de Francisco, 2015; García & Marrero, 2002; Ortiz, 2013; Resco, Espinoza-Figueroa, del Cisne Aguirre Ullauri, Coronel, & Jara, 2018). 3D modeling, which reproduces the volume, texture, and color of objects and features, represents the basis of virtual archaeology, a scientific discipline that applies computer-aided visualization to the integral management of archaeological heritage (Duque & de Francisco, 2015), in accordance with the general guidelines of The London Charter (2009) and the International Principles of Virtual Archaeology: The Seville Principles (2012) (López-Menchero & Grande, 2011).

The preservation and dissemination of Antillean indigenous heritage is of crucial importance for understanding how these cultures and their knowledge contributed to the biocultural development of later Caribbean societies. This is especially important in a region where the colonial narratives portrayed indigenous groups as simple and savages (Almodóvar, 1986; Cowley, 1877; Hernández, 2010), a vision that has largely dominated the general public attitude toward the precolonial Caribbean. Caribbean archaeology has experienced remarkable growth over the last 25 years, leading the debate on critical issues in archaeology such as colonization, migration, identity, subsistence, arts, and human–environment interactions (Curet & Hauser, 2011; Curet & Stringer, 2010; Hofman & Carlin, 2010; Hofman & van Duijvenbode, 2011; Hofman & Antczak, 2019; Keegan, 2010; Reid, 2018; Rodríguez, 2010). Although the understanding of Caribbean indigenous societies has changed significantly within the academic community, general public discourse and textbooks at the primary and secondary levels are still dominated by colonial narratives. In this respect, virtual archaeology has the potential to bring the public closer to new knowledge on the precolonial indigenous legacy in a dynamic and user-friendly way.

At the same time, the use of computer technologies to document excavations and reconstruct cave art increases our technical ability to record, interpret, and protect archaeological heritage (Papagiannakis et al., 2005; Tejerina, Bolufer i Marqués, Esquembre, & Ortega, 2012; Torres, Cano, Melero, España, & Moreno, 2010). In this paper, we summarize the results of the application of 3D modeling techniques in the visualization of five archaeological sites in the Greater Antilles, including two funerary spaces and three sites with cave art. We discuss the advantages of using 3D modeling and share our experience of how photogrammetry can be used to educate and engage people with the precolonial history of the Antilles and the protection of their archaeological heritage.

1.1 3D Modeling in Antillean Precolonial Archaeology

The use of 3D modeling for the study and dissemination of Antillean archaeological heritage is relatively recent. Efforts have been focused in two directions: the preservation of ancient rock art and the 3D modeling of mobiliary objects and human skulls for subsequent studies and museum exhibitions. In March 2012, the General Council of Guadalupe started a program to preserve the island's petroglyphs that were endangered due to rising water levels and erosion. As a result, engravings from ten archaeological sites were digitized using FARO Laser Scanner Focus 3D technology (FARO Technologies, 2012). In Montserrat, drone surveys captured images of four archaeological areas (Valentine Ghaut, Blakes Estate, Potato Hill, and Thatch Valley) in order to create high-definition 3D landscape models (Ryzewski & Cherry, 2017). In 2019, a team of researchers from Indiana University (USA) created orthophotos and 3D models of two pictographic murals (Tributo, Sol y Luna) from José María cave in the Dominican Republic (Hawley & Haskell, 2019). This work was completed by two members of our team in 2019 (Grau, Fernández, & López, 2020).

In Cuba, the first application of precise measurements of 3D burials and terrain features from 2D photographs, and the use of GIS as a method of recording spatial information, took place at the archaeological site of Canímar Abajo in 2007 (Viera, Torres, & Chinique de Armas, 2008). However, the first full 3D modeling of the Canímar Abajo burials, and the reconstruction of other funerary sites and caves, was performed between 2017 and 2020 (results presented here). In 2016, an undergraduate thesis used 3D technology to reconstruct three petroglyphs – two from Maya River Canyon and one from Waldo Mesa cave in Holguín – that are currently located at the Cuban Institute of Anthropology (Hernández, 2016). One of these petroglyphs was printed in resin and is used for teaching purposes. More recently, 13 indigenous skulls from the Montané Anthropological Museum of the University of Havana were scanned using 3D laser and were reproduced for research and public access (Rangel-de Lázaro, Martínez-Fernández,

Figure 1: Location of the archaeological sites included in this study: (1) Cueva No. 1 de Punta del Este, Cuba; (2) Canímar Abajo, Matanzas, Cuba; (3) Playa del Mango, Granma, Cuba; (4) Los Cayucos, Guantánamo, Cuba; and (5) Cueva de José María, Altagracia, the Dominican Republic.

Rangel-Rivero, & Benito-Calvo, 2021). These new methods have provided an additional strategy for the preservation and analysis of Cuban archaeological heritage. They have also provided an excellent means of communicating archaeological knowledge to the general public, an important goal of our research program in precolonial indigenous Antillean societies.

2 Materials and Methods

2.1 Site Descriptions

2.1.1 Cueva No. 1 de Punta del Este, Isla de la Juventud, Cuba

Cueva No. 1 is located in the Punta del Este Ecological Reserve, in the southeast of Isla de la Juventud (Isle of Youth), in Cuba (Figure 1). It is also known as *Cueva del Templo* (Temple Cave), *Cueva de los Indios* (Indian's Cave), *Cueva del Humo* (Smoke Cave), and *Cueva de Isla* (Isla's Cave) (Herrera, 1938; Ortiz, 1943; 2008). The cave is 23 m deep, with a maximum width of 26 m. A 13 m tunnel extends toward the northwest (Núñez, 1975). The cave vault has numerous dissolution holes, seven of which have been turned into skylights that let light pass through its wide openings (Ortiz, 1943). The cave's ceiling and walls exhibit numerous pictographs, mostly in the form of monochromatic and chromatic red and black concentric circles. The central pictogram has 56 circles (28 red and 28 black). The cave was declared a Cuban National Monument in 1981 because of its substantial scientific and cultural value.

This precolonial indigenous cave art was reported in 1922 by the Cuban anthropologist Fernando Ortiz (Herrera, 1938; Ortiz, 1935, 2008). He studied the pictograms, aiming to understand their meaning and the relationships between their positions and the light that projects on them through the skylights. In the 1930s, René Herrera Fritot, Fernando Royo Guardia, and Luis Howel Rivero made a sketch of the cave and located most pictograms (112 drawings) on the topographic plan (Herrera, 1938). Studies continued in the 1960s under the direction of Antonio Núñez Jiménez, who identified an additional 101 pictograms (Núñez, 1975). By this time, many pictograms were fading or were notably damaged by natural and anthropogenic factors, including the smoke from the kitchen of a hermit who lived in the cave for some time (González, 2005; Rodríguez & Guarch, 1980). This was particularly true of one of the pictograms, “the labyrinth,” described by Ortiz (2008). In 1964, some drawings were repainted in an attempt to preserve this heritage for future

generations. In the late 1990s, fungi, algae, and bacteria were detected in the restored areas, which spread to other regions of the cave, affecting both the walls and the ceiling (González, 2005). In 2018, members of our team participated in a research and documentation expedition organized by the Cuban National Monuments Commission, under the leadership of Jorge Garcell. The main goals of the visit were to understand the state of preservation, to identify the natural and anthropic factors affecting the pictograms, to carry out the 3D modeling of the cave, and to plan for future protection.

2.1.2 Los Cayucos, Maisí, Guantánamo, Cuba

Los Cayucos is a cave located between the first and the second emerged marine terrace in Maisí, at the eastern end of Cuba (Figure 1). The cave has a simple 30 m cavity, with an average width of 4.5 m, ranging between 1.5 and 3 m. Toward the center of the room, a set of stalagmites and columns divide the gallery into two sections of similar size, where most of the petroglyphs are located. In 2018, members of our team observed seven petroglyphs, representing anthropomorphic and zoomorphic faces. The cave is within the proposed protected area, Maisí-Caleta Ecological Reserve, where public access is still allowed.

Between 1915 and 1919, the US archaeologist Mark R. Harrington explored the area and took at least one of five missing petroglyphs from this cave to his country. Although there is no reference to the cave or its petroglyphs in his books, in 2012, Daniel Torres located a petroglyph in the Harrington collection at the Cultural Resources Center of the National Museum of the American Indians, USA (Gutiérrez, Torres, González, & Morales, 2020; Harrington, 1935). According to the institution's cataloging card, the cut petroglyph came from a stalagmite in the Los Cayucos Cave in the town of Maisí, Cuba. The actual location of the cave remained unknown until it was found by a team of the Maisí-Caleta Protected Area in 2015. In 2018, members of our team, led by Esteban R. Grau, revisited the site to create 3D models of the cave and its rock art. As the cave is in the process of karst dissolution, it is very important to preserve the archaeological context for future generations.

2.1.3 Cueva de José María, Altagracia, Dominican Republic

The José María cave, also known as Narciso Alberti Bosch's cave (López, 2004, 2007), is located 5 km inland to the south and 6 km southeast of the Guaraguo Ranger Station at the northeast end of the Cotubanamá National Park in Bayahibe, Altagracia, in the Dominican Republic (Figure 1). The cave is 348 m long, with a maximum depth of 15 m. After the cave entrance, a descending ramp leads to a narrow aperture that gives access to a large room with several pictographs. After this first chamber, a narrow corridor covered with pictographs opens on both walls. Toward the right, there is a second level of the cavern with beautiful paintings, including a panel of large pictograms of flying frigate birds and a large female figure.

The José María cave was found in 1979 during an expedition of the Dominican Speleological Society (López, 2004). The study of its cave drawings began in 1993. The team reported 1,125 paintings and petroglyphs (López, 1993). A new investigation was carried out in 2003 to complete the cartography of the cave, identifying 75 more pictographs and petroglyphs (López, 2004). In 2019, a team from the University of Indiana modeled three of the panels using 3D photogrammetry (Hawley & Haskell, 2019). At the end of 2019, two of the authors of this paper (Esteban Grau and Racso Fernández) participated in a research and documentation expedition organized by the Science Academy of the Dominican Republic and used 3D modeling to complete the study (Grau et al., 2020).

2.1.4 Canímar Abajo, Matanzas, Cuba

The Canímar Abajo archaeological site is located on the north coast of the Matanzas province, approximately 40 m from the southwest bank of the Canímar River, at the base of a karst cliff that projects forward in its upper part, forming a rocky shelter (Figure 1). It is designated as both a Protected Natural Landscape and a National Monument.

Since it was first reported in 1984, the site has been excavated by several specialists. Today, it is known as the largest and oldest (1380 BC–950 AD, [2 σ]) “Archaic Age” burial site from the Greater Antilles (Roksandic *et al.*, 2015). In the 1980s, excavations were directed by Dr. Ramón Dacal from the Montané Anthropological Museum at the University of Havana. Early in the 1990s, two excavations were completed by members of the Speleological Committee of Matanzas (Hernández, 2001). From 2004 to 2014, members of our team systematically excavated the site under the direction of Dr. Roberto Rodríguez Suárez (Montané Anthropological Museum, University of Havana) and in collaboration with the University of Winnipeg since 2009. In 2017, our team resumed excavations at the site, under the direction of Dr. Silvia T. Hernández Godoy and Dr. Yadira Chinique de Armas. Given the multidisciplinary perspective that has characterized the study of the site since 2004, results from the site have changed many traditional assumptions about the “Archaic Age” groups from the Antilles (Chinique de Armas *et al.*, 2015, 2017; Nägele *et al.*, 2020; Rodríguez, 2007). We use 3D reconstruction as a regular procedure of our excavation strategy to record site features and their contextual relationships, which has allowed us to preserve and study the original characteristics of the context.

2.1.5 Playa del Mango, Granma, Cuba

The Playa del Mango site is located in the Cauto River basin within Granma province, Cuba (Figure 1). It is situated 14 km inland north of the Guacanayabo Gulf and 3.5 km east of the lagoon system of Las Playas. The site includes three mounds that cover approximately 60,000 m². The chronology of burials from the periphery of Mound 2 suggests that the cemetery was continuously used from at least cal. BC 116 to AD 241 (2 σ). These dates coincide and encompass the use of the domestic area of the mound, dated to cal. BC 55 to AD 435 (2 σ) (Chinique de Armas *et al.*, 2020).

The site was first excavated by Bernardo Utset Masía, a doctor from Manzanillo and a member of the *Junta Nacional de Arqueología*, who exhumed approximately 35 skeletons in Mound 1 (B. Utset, unpublished report). Between 1980 and 1986, two research programs excavated two new areas in Mound 1 and Mound 2, recovering faunal remains (Córdoba & Arredondo, 1988), fragments of human bones, and artifacts characterized by a diverse set of flaked and ground stone tools (Febles & Godo, 1990). In 2014, a joint Cuban–Canadian project, led by the Cuban Institute of Anthropology (Cuba), Casa de la Nacionalidad de Bayamo (Cuba), and the University of Winnipeg (Canada), resumed excavations at the site under the direction of Dr. Ulises M. González Herrera and Dr. Yadira Chinique de Armas (Chinique de Armas *et al.*, 2020). Between 2016 and 2018, a total of 20 primary burials in extended position and dorsal decubitus were exhumed and recorded using 3D modeling.

2.2 Photogrammetry

We organized the workflow in four general phases: (1) taking high-resolution images from different angles, (2) selecting and processing the photos, (3) creating the 3D models and orthophotos for visualization and spatial analysis, and (4) making 3D audiovisual materials (slides and short movies).

2.2.1 Taking High-Resolution Images

We used the image-based modeling technique known as “structure from motion” (Westoby *et al.*, 2012) to reconstruct the cave and funerary site features from high-resolution photos. Caves and excavation layers/profiles were photographed from different angles by following a sequence of parallel photographic transects that covered the cave ceiling, walls and floors, or the excavation surface of interest (i.e., floors, profiles, features). We used a Canon EOS 70D camera with a 24 mm lens to take the images. The number of images at each stop of the transect was determined by the complexity of the morphology of the galleries/excavation layers, with a minimum of nine photos per stop, all at different heights and angles. The shooting angle

covered the entire perspective of the object. A photo overlap of at least 70% with the subsequent area was achieved. We used two synchronized flashes, one on each side of the camera, to ensure the optimal color temperature of 5,600 K, which, along with constant checking of the white balance in the camera, was essential to guarantee color reliability. Photos were taken both as 8-megapixel JPG files and 20-megapixel RAW files. The first facilitated field tests for control of the photo coverage, while with the second one we achieved the highest photo quality.

We placed markers with X, Y, and Z coordinates in caves and excavation levels to scale and orient the images. To obtain reliable measurements, at least six markers per level were used in excavations, including one in the corner of each quadrant. In caves, the control points established during the cartographic survey were chosen as markers. Preferably, we positioned markers on the ground of different sectors of the caves and in the areas of the wall where the original panels would not be compromised. Thus placed, the markers generated a dense and precise network of stations along the topographic polygonal of the galleries. We reinforced measurement controls by using scale rulers with divisions in centimeters and by placing two arbitrary points 1 m apart, allowing for the complementary option of scaling between preset distances.

In the caves, we prioritized digitization of ceilings and walls, covering all the galleries where rock art was present, especially in the form of murals or panels. At Canimar Abajo and Playa del Mango, photos covered all aspects of the context, with a higher density of photos for burials and associated features. We excavated the funerary sites by using artificial 5 cm spits on an open area of at least 9 m². We controlled levels by using a line level and a Leica D810 Disto-compass, for automatic height recording. Multiple sequences were recorded for burials, one for each excavation and bone removal phase.

2.2.2 Selecting and Processing the Photos

The total number of pictures used depended on several factors, including the quality of photos and the complexity and size of the area. We processed photos in Photoshop to increase the readability of details before exporting them to Agisoft Metashape Professional.

2.2.3 Creating the 3D Models and Orthophotos for Visualization and Spatial Analysis

We created 3D models using the commercial software Agisoft Metashape Professional on a PC with a 9th generation I7 processor, 80 GB of RAM, and a Nvidia Geforce 1080 TI graphics card, with 11 GB GDDR 5X. The images were superimposed from the markers identified with X, Y, and Z coordinates.

We obtained an image overlap of 90% for the pictographic murals, while for burial sites the coverage was between 70 and 80%. In the case of the José María cave, the cavity was divided into sectors and subsectors, achieving models of medium to high quality, and a general model of low to medium resolution with a 0.02 cm closure error. In Punta del Este and Los Cayucos, the error was in the order of 0.04 cm.

We used Image J freeware for digital processing of the rock art of the Cueva No. 1 in Punta del Este. The Dstretch plugin (Harman, 2012) was implemented in each pictographic set of the cave to enhance images. We found that different filters were effective for the red (YDS, LAB, RGB, CRGB) and for the black (YBK, LDS) pigments.

We generated a 3D model of the Los Cayucos Idol from images taken by Dr. Daniel Torres in 2012 during his visit to the Smithsonian Museum in order to stitch it back to the wall of the cave in a 3D reconstruction. We defined key points of overlap between the cut stalagmite and the idol as markers and matched the superimposed images.

2.2.4 Making 3D Audiovisual Materials

We generated stereoscopic images using Agisoft Metashape to support the scripted audio narratives. Video clips were completed by combining 3D images and audio files to enhance the public experience. 3D photos

were edited in the Stereo Photo Maker software, which is used to correct the parameters. The final editing process was achieved using commercial software, MagixVdeo Pro, MovieStudio, Platinum, and Mobjet. We created movies in collaboration with the international team, *La Salle*, a nongovernmental organization of speleologists that specializes in 3D photography (www.lasalle3d.com).

We studied the sites in accordance with the heritage laws of Cuba and the Dominican Republic. As such, all 3D models are available to local communities through our public archaeology projects. The files are stored in the official archives of the FANJ, and the information centers of the Academy of Sciences of the Dominican Republic, in the form of CDs and external drives that are renewed regularly to ensure data longevity. They will be incorporated into the online repository of the Caribbean Research Institute. Models and pictures are also available for academics and the general public upon request to the authors. No property issues exist.

3 Results

3.1 Cueva No. 1 de Punta del Este, Isla de la Juventud, Cuba

The entire cave was modeled in 3D (Figures 2 and 3). Importantly, 3D modeling allowed for the observation of a number of pictograms that were fading (Figure 3(1a and b)). The use of the Dstretch plugin allowed us to locate the *El laberinto* (the labyrinth) pictogram that had been missing for the last 77 years (Figure 3(2a and b)).

3.2 Los Cayucos, Maisí, Guantánamo

The 3D modeling of Los Cayucos shows, in greater detail than possible to the naked eye, the original features of the seven petroglyphs that remained in the cave (Figure 4) after five of them were removed. In addition, we were able to virtually relocate one of those removed petroglyphs that has been held in the Smithsonian Institution for the last seven decades. The 3D reconstruction of the petroglyph dimensions,

Figure 2: Partial 3D reconstruction of the Cueva No. 1 de Punta del Este, Isla de la Juventud, Cuba.

Figure 3: Partial 3D reconstruction of the Cueva No. 1 de Punta del Este, Isla de la Juventud, Cuba. (a) The labyrinth pictogram. (b) Visualization of pictograms using Dstretch and digital tracing.

including the shape of the base, allowed us to find their original position at Los Cayucos cave, providing a more balanced appreciation of the existing set of engravings (Figure 5).

Figure 4: Position of petroglyphs in the Los Cayucos cave plan.

3.3 Cueva de José María, Santo Domingo, Dominican Republic

We were able to model 83% of the José María cave using 3D photogrammetry (Figure 6), providing a virtual tour of the cave and its multitude of intricate, overlapping drawings.

3.4 Canímar Abajo (Matanzas) and Playa del Mango (Granma), Cuba

The 3D modeling of the layers at Canímar Abajo and Playa del Mango archaeological sites allowed us to reconstruct five and eight burials, respectively (Figure 7).

The position of each bone/bone fragment was recorded in detail in subsequent layers of excavation for archaeoanthatological analysis (Figure 8).

3.5 Public Outreach

Two preliminary videos (AVI with 4k resolution at $3,840 \times 2,160$; 16×9) have been projected in La Gruta de San Juan, a space for 3D projections of the Antonio Núñez Jiménez Foundation for the study of Nature and Humans (FANJ) in Matanzas, Cuba. The first movie included an exhibition of stereoscopic images from Punta del Este (Figure 9), Los Cayucos, and other Cuban cave art sites, while the other video was devoted to

Figure 5: 3D modeling of the cut stalagmite (a) and the modeled petroglyph, currently at the Smithsonian Institution, USA (b).

the José María cave in the Dominican Republic (Figure 10). In addition, pictures and slides are being created for expositions in La Gruta de San Juan. Movies, pictures, and slides provide varied formats to show the 2D and 3D materials from the sites to members of the community, as the team *La Salle* has successfully done before (Figure 11). Movie scripts will cover topics related to indigenous arts, culinary practices, natural medicine, and fishing gear, among other aspects of indigenous wisdom and knowledge. In addition, we have engaged communities by organizing public talks during excavations and involving local people as strategies of a project on public archaeology that we are developing alongside our archaeological projects.

4 Discussion and Future Directions

There are three main advantages of using 3D visualization for both caves and burial sites: (1) detailed documentation for further analysis of the shape and spatial distribution of features in archaeological context; (2) capturing the state of preservation of rock art; and (3) visualization of archaeological sites

Figure 6: Orthophotos of the José María cave in the Dominican Republic. (a) Panoramic view of the first mural of the final salon. (b) El Sol y la Luna.

for public dissemination. All are equally important and intertwined, as they allow for inclusion of local heritage knowledge in the discussion and for a more involved interpretation.

Virtual archaeology has positively affected the storage, visualization, and analysis of archaeological information recovered during our excavations. The use of orthophotos and digital terrain models from 3D modeling makes it possible to obtain, visualize, and integrate information from the archaeological context with greater accuracy than previous approaches (De Reu *et al.*, 2013). By recording each excavation level, 3D visualization of subsequent bone removal phases allows us to better understand superposition and spatial relationships between bones (Roksandic, 2002), as well as the relationship of burials with other features within the context. Each bone is given a number in the register, allowing later laboratory observations to be incorporated into the burial analysis. Importantly, recording the exact position of bones makes it possible to use predictive models to reconstruct the position of the body at the time of burial (Mickleburgh, Nilsson Stutz, & Fokkens, 2020). 3D reconstructions could also be used for virtual excavations, both as part of the laboratory analysis and as an immersive and interactive teaching module (Morgan & Eve, 2012).

Fieldwork is often associated with strict time constraints. Digital photography allows field crews to increase the speed of documentation without sacrificing its quality. However, the decisions on the number of removal layers per burial context, as well as the optimal amount of photographic detail per unit, still require trained osteologists with experience in archaeoethnatology (Duday, 2006) or dispositional taphonomy (Roksandic, 2002). In particular, we have found that a more detailed sequence is needed for areas of the body such as the neck and shoulders, pelvis and abdominal cavity, and feet. The analyses of the burial context for newly excavated burials from Playa del Mango and Canímar Abajo are underway. We expect that a detailed analysis will reveal whether this type of documentation can be used consistently and under what circumstances, and what kind of supplementary information is needed to maximize its interpretative potential.

In terms of 3D modeling of cave art 3D, our results have demonstrated several instances in which “lost” or removed pictograms and panels were rediscovered using the available 3D techniques. In the Cueva No. 1

Figure 7: Orthophotos of excavation layers at Canimar Abajo (a) and Playa del Mango (b).

at Punta del Este, we have been able to locate the faded image of the “labyrinth” pictograph that was originally recorded by Ortiz (1943) and subsequently lost for 77 years, due to anthropogenic interference (e.g., cooking fires, target practice, and attempts at restoration through repainting), erosion, and the action of microorganisms (González, 2005). The 3D modeling also allowed for the reemergence of a number of original drawings that were lost or incomplete (and poorly visible) because of the fungal infestation. A non-negligible number of drawings that were not previously recorded in the two existing planes of the cave

Figure 8: Details of the 3D reconstruction of burials from Canímar Abajo (a) and Playa del Mango (b) for subsequent archaeo-ethanatomical studies.

Figure 9: Stereoscopic images of the central pictogram of Punta del Este used for 3D short movies (slides).

Figure 10: Stereoscopic images of José María cave used for 3D short movies (slides obtained from the 3D model).

Figure 11: Previous 2D and 3D exhibitions of Cuban natural and historical heritage by the *La Salle* team.

(Herrera, 1938; Núñez, 1975) emerged in the 3D view. With the implementation of 3D techniques, the introduction of subjective elements in the process of restoring rock art in the 1960s was verified, since we could detect the traces of pigment added to the originals. The addition of previously unrecorded images, the correction of misinterpreted and partially destroyed images, and the establishment of their precise location will allow us to better appreciate the sequence in which the images were executed and their spatial relationship, opening new possibilities for interpretation.

Importantly, we documented the looting of the Los Cayucos cave by locating the traces of the cuts from which petroglyphs were removed seven decades ago to form part of the Harrington collection. We virtually rebuilt this petroglyph in its place of origin, restoring the balance of the existing set of engravings and

enabling study of a more complete assemblage. This is relevant since repatriating the petroglyphs to their original location seems unlikely and it is not in exhibition at the Smithsonian Institution. The 3D visualization of the petroglyphs also showed more details of the complexity of engravings (Ortiz, Docampo, Rodríguez, Sanmartín, & Cameselle, 2010) and the identification of some new figures.

The 3D visualization of reconstructed pictograms and petroglyphs from the three caves presented here will allow specialists from different countries to do comparative analyses between caves and regions and to derive a more profound interpretation based on more complete sequence of images from the caves. This work will allow repeated virtual visits to the cave to both local and international specialists, without having to organize difficult and expensive expeditions. This format also allows for a more profound analysis (i.e., of shapes and spatial relationships) than it is possible to obtain in short research visits to archaeological sites. Although we acknowledge that visiting a site directly is a unique experience for researchers and visitors (e.g., natural sounds, lights and shadows, access to the whole context), 3D documentation techniques have the potential to positively affect both accessibility to sites with remote access and preservation efforts (Berquist *et al.*, 2018).

Furthermore, 3D models of the three caves will allow the creation of a virtual tour that will be available to a general audience, including local communities. 3D movies, slides, and photos of Antillean indigenous sites have the potential to facilitate the distribution and socialization of archaeological heritage to general educational centers, research institutions, museums, and visitor centers. The use of 3D movies to promote the knowledge and protection of caves in Cuba, Italy, and France was previously used by the team *La Salle* with excellent results. The 3D modeling allowed the public to get immersed in the experience through images and sounds. We are planning to offer the 3D experience of La Gruta de San Juan to other cities in Cuba and the Dominican Republic and within the local communities in which our archaeological projects are conducted. The process will be informed by the highest ethical standards and respect to other cultural groups' moral principles and perspectives (Ulguim, 2018).

The 3D movies will work toward strengthening the sense of belonging of local populations regarding their heritage in order to promote their active participation in heritage protection initiatives. Instead of talking about Caribbean indigenous history as a long-forgotten past, we promote the vision of it being part of a biological and cultural continuum to which indigenous culture and traditions belong. In addition, 3D movie scripts are aimed at calling public attention to different aspects of indigenous existence, such as art, culinary traditions, natural medicine, ways of sowing, and the survival of some of those cultural traditions, not only among indigenous descendants but also in Caribbean culture more broadly. Future steps will include interactive discussions with the audience and the use of research tools such as surveys and interviews to obtain people's feedback. Collectively, we will work toward decolonizing the precolonial narratives by promoting participation, care, and respect for the indigenous heritage of the region.

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