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RESEARCH

# Understanding Taphonomy Through 3D and 2D Records: A Case Study from the Tropical Maya Area

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## Abstract
Mortuary archaeology in the Maya region is complicated by both cultural and natural factors. Distinctive funerary depositional and post-depositional secondary activities, in addition to tropical climate, contribute to the complexity of pre-Hispanic Maya funerary practices. This paper proposes to merge 2D and 3D recording data to obtain a comprehensive understanding of the taphonomic phenomena that affect heavily altered burials at the site of Palenque, Mexico. Employing an archaeothanatological approach, we argue that careful 3D imaging, integrated with earlier produced legacy data, provides additional insight into the formation processes of funerary contexts compared to previous methods. Digital photogrammetric analyses improve our capacity to reconstruct joint articulations of the body and its original funerary deposition in situ. The results of this research elucidate the intentional activities that led to the archaeological arrangement of the grave assemblage. By noticing the degree of articulation and clarifying the pace at which bodies decomposed, these results showcase the depositional sequence of one collective mixed burial from Group IV, a domestic compound in Palenque. These results suggest the viability of 3D methodologies in assessing post-depositional disturbances and movements of the body, both for illuminating funerary taphonomic practices and serving as important recording procedures for the future.

**Keywords** 3D taphonomy · Maya · Digital photogrammetry · Palenque · Burials

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## Introduction

Over 50 years ago, Mortimer Wheeler (1954) stressed the importance of three-dimensional (3D) recording in archaeological practice. However, it took several decades before the advent of image-based 3D methods, which allow the creation of 3D models from a series of photographs and subsequently optimized the recording of the third dimension of archaeological contexts (Berggren et al., 2015; Pollefeys et al., 2001). While 3D methods are becoming more commonplace in archaeology, their use in taphonomic analysis is only just beginning. In this paper, we evaluate the advantages and limits that 3D documentation provides to the study of ancient burial taphonomy, a case study from a recently excavated domestic compound, Group IV, at the Maya site of Palenque, southern Mexico. In the Maya area, there are several taphonomic processes that could affect the preservation of bones and funerary contexts. Since Maya burials are situated in tropical contexts, it is often assumed their preservation is low to begin with (Tiesler et al., 2013). Posthumous funerary practices, such as secondary access to burials which commonly involved fire rites, add complexity to understanding pre-Hispanic Maya mortuary contexts (Pereira, 2014; Scherer, 2019; Scherer & Houston, 2018; Tiesler, 2018; Tiesler et al., 2013). Finally, looting and modern construction contribute to burial intrusions and add to the typically poor condition of bones. Consequently, Maya burials are situated in a complex nexus of differing human and environmental taphonomic factors that require innovative and detailed approaches to help elucidate their formation processes. As such, this work builds upon recent advances in 3D visualization techniques utilized by archaeologists and bioarchaeologists in the last decade (Gómez-Olivencia et al., 2018; Leigh Beebe, 2014; Romero Pellitero et al., 2018; Wilhelmson & Dell'Unto, 2015) in order to identify viable ways of addressing the challenges that still affect mortuary and osteological analysis in the Maya area.

In the specific case of Palenque's Group IV, the extensive excavations carried out by the Proyecto Regional Palenque (2016-present) unearthed 41 burials, containing about 80 individuals (Liendo Stuardo, 2016, 2019). All burials were recorded using digital photogrammetry (Campiani, 2016), a 3D image-based modeling technique that uses digital photos to generate 3D virtual geometries (Howland, 2018). This method is also known as closed-range photogrammetry, as it was developed at first for proximal sensing ground-based applications, or Structure from Motion (SfM), from one of the algorithms used to reconstruct the 3D scene. In a nutshell, the digital photogrammetric software analyses the photos of an archaeological context or feature, detecting overlapping feature points in the images, and tracking their movement to reconstruct the scene in 3D (Verhoeven, 2011). In our case study, we utilized Agisoft Metashape, a state-of the-art application to produce our 3D taphonomic record.[1]

In Group IV, the preservation of each burial typically depends on the elaboration of the funerary container. The more elaborate cists, consisting of enclosed stone

[1] An Agisoft Metashape Professional license was made available by the HIVE Lab at the University of California, Merced.

boxes of worked or raw stones and stone slabs, are in relatively good condition. Conversely, rustic cists and simple pits are usually poorly preserved. Although the burials in Group IV are in better condition than funerary contexts in many other Maya sites, overall, the situation is complicated by the continuous cultural intentional reopening of most of the burials by the pre-Hispanic Maya, which results in collective contexts and incomplete and/or disarticulated skeletons. To address this complexity, 3D technology was merged with 2D records to increase the documentation's precision and understand these complex contexts better. We argue that by integrating 3D recording into existing excavation and post-excavation methods (see Freiwald, 2019, p. 15), archaeologists can better comprehend taphonomic processes and gain deeper insights into past cultural funerary practices.

## 3D taphonomy as a Method

### Archaeothanatology

The careful stratigraphic excavation of burials serves to understand the taphonomic phenomena that caused the current arrangement of the bioarcheological elements. Archeologically, "burial" refers to the set of intentional funerary acts (Duday, 2009, pp. 24–25) before during, and after the inhumation of deceased persons. These actions cover these activities (Duday, 1997, p. 92; Tiesler, 2006, pp. 80–84):

1) Pre-depositional practices (pre-burial treatment of the body)
2) Depositional practices (tomb structure, body position, and funerary material)
3) Post-depositional (reopening and re-entering the tomb, reduction, re-inhumation, manipulation of the osseous elements, etc.)

Understanding these actions and their chronological sequences aids in the interpretation of mortuary behavior. The analysis of taphonomy as an archaeological and anthropological field method has been especially developed by the French school of Archaeothanatology (Duday, 1997, 2009; Duday & Guillon, 2006; Duday et al., 2014). These methods merge knowledge about the natural processes of corpse decomposition and the detailed recording and analyses of the archaeological context, to reconstruct the mortuary behavior of ancient populations. Cultural activities, in the form of intentional (either funerary or extrafunerary) and unintentional actions affect the natural decomposition of the body (Duday, 1997, p. 92). In addition, natural factors such activity of animals and plants can also affect decomposition rate and movement of osseous elements (Pinheiro, 2006; White & Folkens, 2005).

Comprehending the biological decomposition of soft tissues is a key aspect of this method. Conventionally, the articulations of the human body are categorized into labile (quicker to decompose) and persistent (slower to decompose) joints (Duday, 2009). By seriating different joint disarticulations chronologically, archaeologists can discern how such connections were maintained or compromised through depositional and post-depositional factors (Mickelburgh et al.,

2022) and subsequently distinguish between natural or cultural alterations of the burials and skeletons. The *in situ* recording of contexts is fundamental to this method because the relation between elements of the skeleton and the volume surrounding the body are the basis for the characterization of the decay environment (Blaizot, 2014; Duday & Guillon, 2006, p. 140; Freiwald, 2019, p. 1). It is hard, in fact, to establish “universal” laws about sequence of disarticulation, since body treatment and position affect decomposition pace (Ortiz et al., 2013) and even preservation of the bones (Bello & Andrews, 2009). The position, location, and condition of the bones and joints depend, then, on all the taphonomic processes affecting the body, including both environmental, climatic, and cultural factors. Consequently, understanding the funerary environment can shed light on ancient funerary practices, especially when posthumous customs and climatic conditions complicate interpretations (Freiwald, 2019, p. 10; Ubelaker, 1989). Field methods were later integrated by post-fieldwork activities (Knüsel & Robb, 2016), specifically by the study of bones’ diagenesis, which bring additional knowledge regarding the formation of the archaeological funerary context (Booth, 2017; Cucina et al., 2004; López-Costas et al., 2016; Ochoa-Lugo et al., 2017; Ross & Cunningham, 2011; Tiesler & Cucina, 2006; Tiesler, 2004a; Wilhelmson & Dell’Unto, 2015). Numerous studies have attested to the capabilities of conducting archaeothanatology *post-hoc* using legacy data to reconstruct burial containers and decomposition sequences (Green, 2022; Harris & Tayles, 2012; Nilsson Stutz, 1998, 2003, 2006; Roksandic, 2002).

In this paper, we emphasize the contribution of archaeothanatology in understanding deposition sequences and the intentional manipulation of human bodies’ post-burial. According to the degree of anatomical articulation, skeletons can be classified as primary (articulated), secondary (disarticulated), or reduced primary (articulated but intentionally altered) individuals (Duday, 2009). These classifications are critical for interpreting ancient funerary practices. Secondary burials occur after the body has decomposed, either as a result of exhumation or *in situ* manipulation, often to accommodate another individual (Hertz, 1960; Pearson, 2000; Pereira, 2017). Reduced primary burials, while still articulated, show clear signs of intentional alteration, indicating that they were not moved after decomposition occurred. As such, these individuals serve as clear indicators of reburial practices.

## Pre-Hispanic Maya Burials and Local Taphonomy

Funerary archaeologists in the Maya region face several challenges. The tropical environment affects the preservation of burials and their content, as humidity, flora, and fauna heavily affect the archaeological funerary context (Schiffer, 1987). Besides, Maya burials are typically exposed to extremely acidic or basic soils and episodic rainfall, which are deleterious for the proper conservation of human bones and perishable materials (Scherer, 2015, p. 93; see also White & Folkens, 2005, p. 52). Individuals deposited in direct contact with soil are usually less preserved than those in indirect contact with soils. Preservation is also heavily affected by the quality of the funerary context, whereby domestic burials are generally worse preserved than royal ones. Additionally, complex cultural practices negatively influence the preservation of pre-Hispanic Maya burials. Maya concepts of death and ancestors included long-lasting relations with the dead, which went beyond the burial of the deceased. As such, the interments were often reopened, and bones and grave goods were manipulated, by the addition or removal of bones and entire skeletons (Chase & Chase, 1996; Eberl, 2005; Fitzsimmons, 2009; Stuart, 1998). Such secondary practices occurred also in domestic compounds, like at Palenque (Núñez, 2011). Finally, ancestors' bodies were often wrapped (McAnany, 1995), a practice which heavily affects the position and orientation and preservation of the skeleton (see below).

## Digital Photogrammetry

Digital photogrammetry generates detailed 3D models of objects and features that range from a few centimeters in size to the landscape scale (Lerma et al., 2010, p. 500). In the 2020s, digital photogrammetry is a relatively cheap technique that only requires a digital camera with reasonable resolution (*e.g.,* 18 megapixels and above) and a medium-quality laptop to produce accurate and well-textured 3D models and precise orthophotos in a matter of hours (Lerma et al., 2010; Pérez García et al., 2011; Pollefeys et al., 2001). Using digital photogrammetry, archaeologists have extensively demonstrated the utility of producing 3D virtual visualization of stratigraphic excavations (Berggren et al., 2015; Charquero Ballester & López Lillo, 2012; De Reu et al., 2013; Howland, 2018; Lercari, 2018; Losier et al., 2007; Nigro et al., 2003). Recently, our team at Palenque proved the viability of merging digital photogrammetric and 3D laser scanning data with "legacy data" (*i.e.,* drawings and maps produced by earlier excavations and topographic surveys), to provide new hypotheses on the construction of the so-called Mausoleum Architectural Project, a constructive effort that involved the building of earlier phases of the Temple of Inscriptions and Temple XIII (Campiani et al., 2021).

Generally speaking, a digital photogrammetric workflow is a relatively standardized and simple process (Bedford, 2017). As a first step, the recorder takes photos of an archaeological feature or object from multiple positions that should be parallel to the surface of the object, preferably shooting in RAW format and using a tripod. The photographer must ensure that these pictures are sharply in focus and that there is an adequate overlapping among them. Notably, the results of this step can be affected by weather conditions and the photographer's skills. Then, using photo processing software (*i.e.,* Rawtherapee or Adobe Lightroom), the photos are automatically renamed according to the archaeological project's data management plan and corrected to obtain neutral exposure and improved color calibration. The third step requires utilizing a digital photogrammetric software to generate a 3D model. In the 2020s, several apps exist for this purpose, with Metashape, 3D Zephyr, and RealityCapture being the most viable and utilized software in archaeological projects. All these apps follow a similar workflow, summarized in Fig. 1 (Verhoeven, 2011).

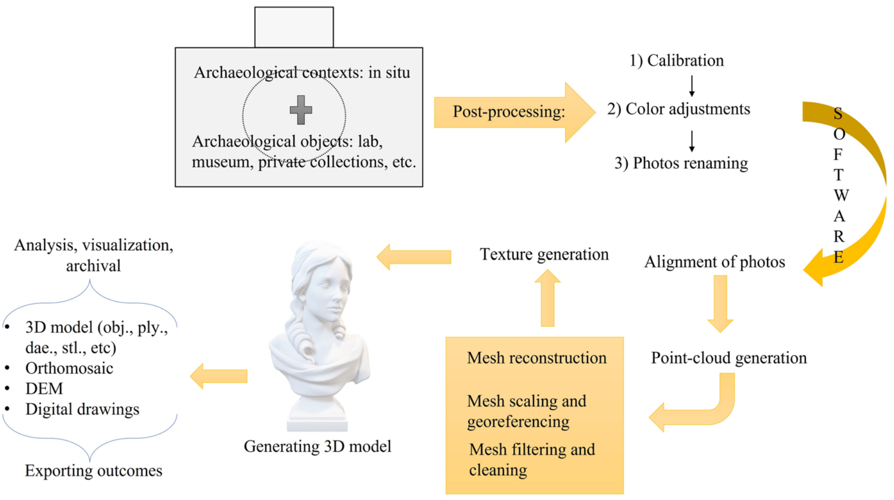


**Fig. 1** Conventional digital photogrammetric workflow according to Bedford (2017): photo recollection, photo processing, and creation of the 3D model

## 3D Taphonomy

The complexity of Maya cultural and environmental context makes this Maya region an interesting study case to apply 3D-informed methodologies. 3D documentation techniques, such as digital photogrammetry, provide an additional set of post-fieldwork analysis of taphonomic processes, which potentially improve *in situ* interpretations. Despite their potential, 3D methods have only recently been applied to the study of burial formation (Haddow et al., 2016; Mickelburgh & Wescott, 2018; Mickelburgh et al., 2021, 2022; Ulguim, 2017; Wilhelmson & Dell'Unto, 2015).

The merging of geographical, topographic, and three-dimensional data provides rich information regarding the interment of archaeological human remains (Randolph-Quinney et al., 2018). In addition to 3D digital documentation, other techniques were used to record and facilitate the interpretation of complex contexts, such as mass graves. Leif Isaksen and L. Saunders (2008) developed a method (XBones) where topographic points of articulations and distal and proximal parts of bones can be used to construct solid stylized polygons of bones forming a virtual three-dimensional sketch of the context. According to the authors, this recording method has the potential of display in a simple manner even extremely complex funerary contexts. Recently, a method involving 3D animation and photogrammetric reproduction was developed in the post-excavation archaeothanatological analysis of a burial from the site Oostwoud-Tuithoorn, in the Netherlands (Mickelburgh et al., 2020, 2021). By supplying further information on the sequence of individual bone movements, the simulation confirmed that the alteration of the context was the consequence a post-depositional, probably unintentional, single event that occurred in the past (Mickelburgh et al., 2020).

Helen Wilhemson and Nicolò Dell'Unto (2015) developed a methodology called "Virtual Taphonomy," which integrates 3D models of burials, archaeological evidence, and osteological data within a 3D geographic information systems (GIS) environment. They argue that a rigorous taphonomic analysis must rely on methods that enhance understanding of the vertical and horizontal relationships between strata and specific elements to better comprehend the diachronic and synchronic burials' formation processes. By creating a precise three-dimensional representation of the spatial relationships between strata and elements, digital photogrammetry provides bioarchaeologists with the tools to enhance the analysis of funerary contexts. In a following work, merging 3D visualizations and geographical information improved understanding of a sequence of intentional secondary disturbances affecting burials at the Neolithic site of Çatalhöyük, Turkey (Haddow et al., 2016).

In the Maya region, the application of digital photogrammetry to the study of taphonomy is still at an early stage. However, this technique has been increasingly used to record burials. For instance, Anna Novotny (2019) tested the effectiveness of 3D recording at the Maya site of Say Kah, Belize, producing successful outcomes. Following this burgeoning approach, this paper attempts to evaluate the advantages provided by such a technique in the context of burials from Palenque's Group IV. This work discusses the 3D funerary taphonomic analysis of one burial, as an explanatory study case. Following Campiani and colleagues (2021), this research also benefits from integrating newly acquired 3D and legacy data, especially drawings and photos from earlier projects documenting funerary archaeology at the site.

## Materials and Methods

### A Domestic Burial at Palenque, Southern *Mexico*

Palenque is in the Northwestern Maya Lowlands, in what is now the state of Chiapas, Southern Mexico (Fig. 2). Although archaeologists found scattered evidence of earlier occupation (San Román Martín, 2005), this Maya city flourished during the so-called Classic Period (*ca* 400–850 AD) (Fig. 3), when the site was the seat of power of a royal dynasty (Martin & Grube, 2000). In the last two centuries of their reign, the rulers of Palenque spread their influence on the surrounding regions, making their city one of the most significant polities of the region (Liendo Stuardo, 2005, 2011). This strength was reflected in the elaborateness of the structures found in the civic-ceremonial center, which included a royal palace, numerous temples, and a ballcourt, besides numerous carved texts, which were broadly excavated and analyzed during the last century (*e.g.,* Acosta, 1973; Bernal Romero, 2012; González Cruz & Balcells González, 2015; Marken, 2007; Ruz Lhuillier, 2013; Stuart & Stuart, 2008). These structures were also the foci of sumptuous funerary practices, such as the royal individuals buried in elaborate sarcophagi, especially ruler *K'inich Janaab Pakal* and queen *Tz'ak-bu Ajaw* (González Cruz, 2011; Ruz Lhuillier, 2013; see also Scherer, 2012).

Since the mid-twentieth century, intensive excavations extended to the domestic compounds surrounding Palenque's civic-ceremonial center, including Group IV to the Northwest (López Bravo, 1995, 2000; Ruz Lhuillier, 1952). Due to the Maya

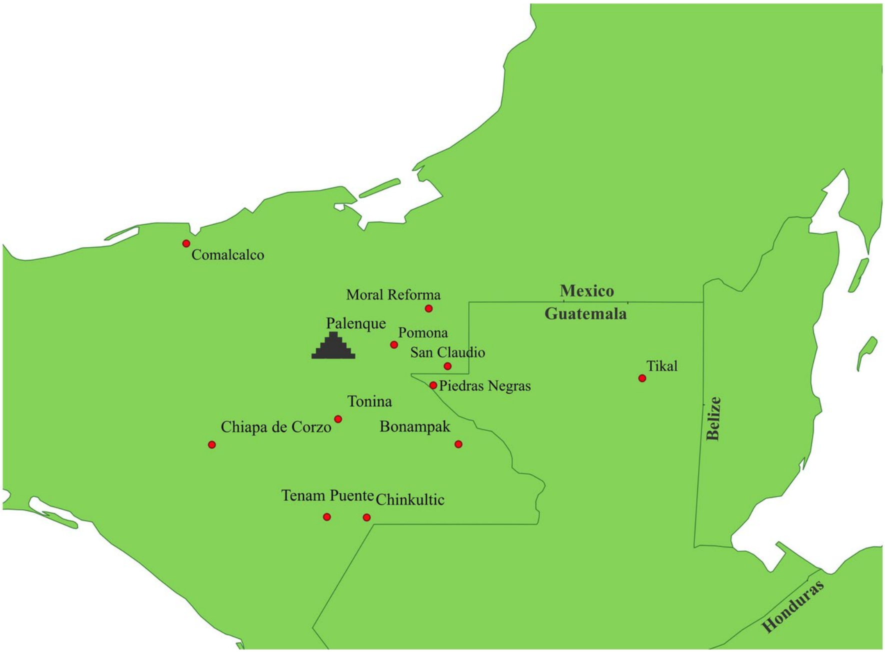


Fig. 2 Location of Palenque in the broader Maya area. Data from INEGI

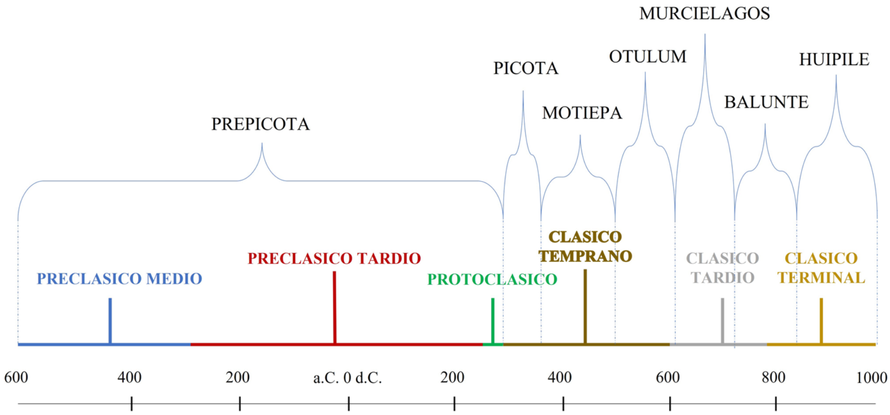


Fig. 3 Chronology of Palenque

habit of burying the dead within their houses, these explorations identified several burials (Chávez Salazar, 2015; Gómez Ortiz, 2001; Rands & Rands, 1961). According to Edwin Barnhart's (Barnhart, 2001) map, Group IV is the main patio of Group J, which is one of the most extensive neighborhoods in Palenque (Fig. 4). Group IV's size and elaborate architecture suggest it was inhabited by a household that acquired exceptional power within the city (Fig. 5). Accordingly, during earlier explorations of the patio,

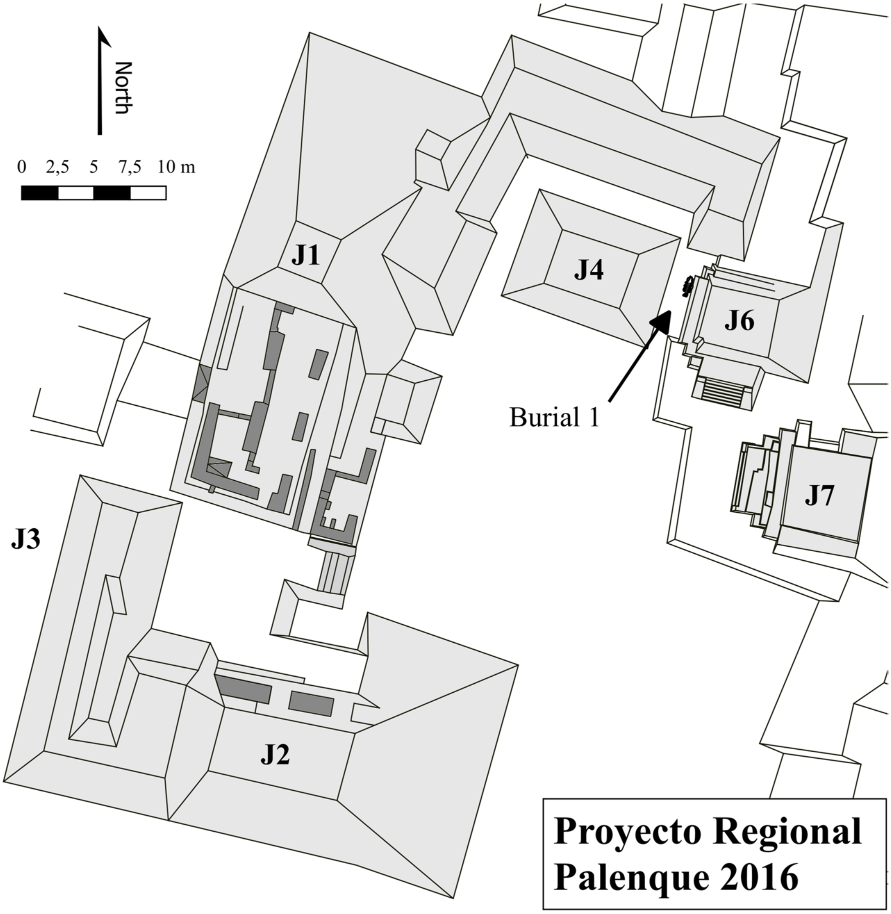


**Fig. 4** Group IV and location of Burial 1. Data from Arianna Campiani, Atasta Flores Esquivel, and the archive of the PREP

Alberto Ruz Lhuiller (1952) found the *Tablero de los Esclavos*, whose glyphic evidence of written texts narrates the relationships of this family with the royal dynasty (Stuart & Stuart, 2008, pp. 223–224). Later, an additional text found on a stone censer enriched the knowledge about this household's historical dynamics (Jackson, 2013; López Bravo, 2000). The architectural layout of Group IV reflects pan-Maya customs and beliefs, with several structures arranged around the central open plaza (Becker, 2003). The buildings on the West (J1, J2, and J3) served mostly residential and administrative function, while ritual and funerary functions were assigned to J6 and J7, on the North-eastern side of the patio (Johnson, 2018a, 2018b; López Bravo, 1995; Fig. 5).

Since 2016, the Proyecto Regional Palenque (PREP), led by Dr. Rodrigo Liendo Stuardo, have been excavating Group IV. Forty-three burials were identified, containing 65 individuals (Liendo Stuardo, 2016, 2019), which complement the 16 burials earlier explorations found in Group IV (López Bravo, 1995; Rands & Rands,

**Fig. 5** Picture of J6 (left) and J7 (right)

1961). Burial's containers are diverse, although cists (stone boxes) are the most common. Most individuals are in an extended supine position, with the head pointing roughly to the north, which is the typical orientation observed at Palenque. However, there are four flexed individuals and a considerable number of disarticulated skeletons. In certain occasions, the original skeletal content was altered either by the removal of specific bones or the deposition of additional individuals (see Núñez, 2011). Therefore, it is not unusual to find mixed collective contexts with both primary and secondary individuals. The complexity of such contexts needs meticulous methodology to excavate and interpret them.

## Methodology

Every burial was carefully excavated and, when possible, the position and orientation of the skeletal elements was recorded (Liendo Stuardo, 2019). The PREP team produced several 3D models documenting each burial according to the number of strata and individuals found (Online Resources 2 and 3).[2] Using the digital photogrammetric workflow described above, we have generated the following items for each layer of Burial 1:

[2] The photographs were taken by distinct members of the PREP. The high-resolution 3D models were produced by the first author of the paper.

1) Georeferenced 3D model: we georeferenced this model to precisely locate the burial in Group IV in the site's map and conduct elevation analysis.
2) Orthophoto: an orthorectified photograph derived from the burial's 3D model, which is perpendicular to its X and Y planes. Afterward, we uploaded it into a GIS environment for spatial analysis purposes.
3) Digital drawing: elaborating the orthophoto in the GIS environment, we produced georeferenced digital drawings of the burial.

Additionally, we created the 3D models of the lumbar vertebrae of one of the individuals interred in Burial 1 (Online Resource 4). We then imported these 3D models into Blender 4.0.1, an open-source 3D modeling software capable of handling large mesh models and used it for analytical purposes. Making use of Individual 1E as our reference, we rearranged our 3D models of each spinal element in the shape we encountered in the field (Fig. 6). The goal of this procedure was to answer the research questions, as discussed in detail in the "Burial 1: Discussion and Results," "Individual 1D: The Presence of a Wrapping Shroud?", and "Individual E: Secondary Reopening and Original Position" sections. The metadata associated to each 3D model are described in Online Resource 5. All these steps played a crucial role in our analysis of Group IV's 43 burials. Methodologically, basic knowledge of taphonomy and archaeothanatology helped inform analysis of decomposition, gravity's effect on the decomposing body, necrodynamics, and preservation at a nuanced level. However, with few exceptions (see Harris & Tayles, 2012; Willis & Tayles, 2009), these methods were previously only developed for temperate climates. As such, we were aware that extreme caution must be exercised for applying them to tropical environments like that of the Maya area.

## Burial 1: Discussion and Results

We focus on Burial 1, as a case study in this article, which is a heavily altered mixed context that contained skeletal remains from a minimum number of five individuals. It is located between Structure J6 and Structure J4, closer to the east wall of the latter (Fig. 4). Burial 1 is a complex context, which is formed of three overlapping cists. The first and most superficial cist contains one primary child (B1A), the second one, another primary child (B1B) with the secondary bones of an adult (B1C), while the third cist contains a primary child (B1D) and an additional secondary adult (B1E).[3] Here, the focus will be on the third one (Table 1; Figs. 7 and 8), since the complexity of this context raised the following questions:

1) Was B1D wrapped in a funerary dress or shroud? The individual presents sign of constriction that may suggest the existence of a constraining textile.

[3] The osteological analyses have been carried out at the Laboratorio de Bioarqueología del Posgrado en Antropología Física, Escuela Nacional de Antropología e Historia.

**Fig. 6** 3D model of the vertebral column of Individual 1E: *in situ* (right) and reconstruction from 3D models of each vertebra (left)

**Table 1** Individuals B1D and B1E

| Burial | Individual | Secondary/primary | Position | Orientation | Sex | Age at death |
|---|---|---|---|---|---|---|
| B1 | D | Primary | Extended supine | North | ? | Child (5–6 years) |
| B1 | E | Reduced primary | Flexed | North | M | 20 years |

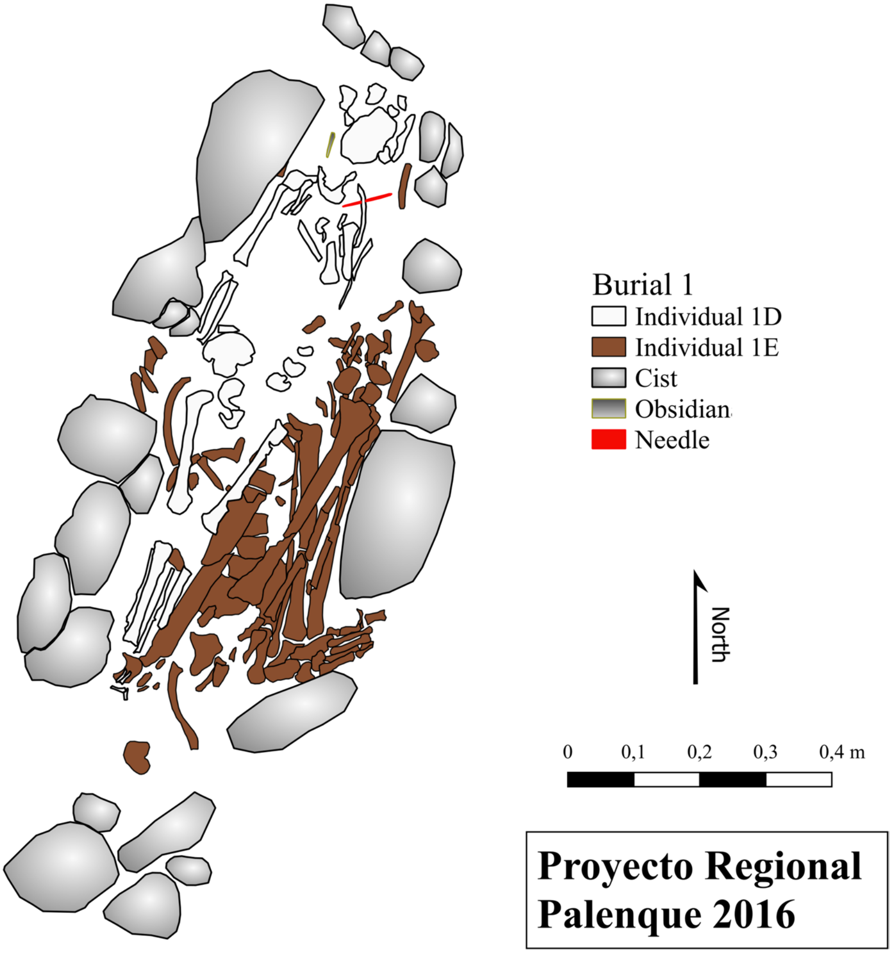


**Fig. 7** Digital drawing of Burial 1

2) Was the burial reopened? The burial is highly altered.
3) What was the original position of B1E? The complexity of the upper torso's alteration made it difficult to determine the original position of the body during excavation. Especially, we aimed to discern whether the torso was positioned supine or on its left side.
4) What was the overall deposition sequence of the burial?

What was the depositional and post-depositional (*e.g.,* reopening) sequence, and how did that affect the position of the remains found during excavation? Since the cist was originally sealed by two burials in antiquity and remained undisturbed except for the PREP excavation, it provides an excellent case study

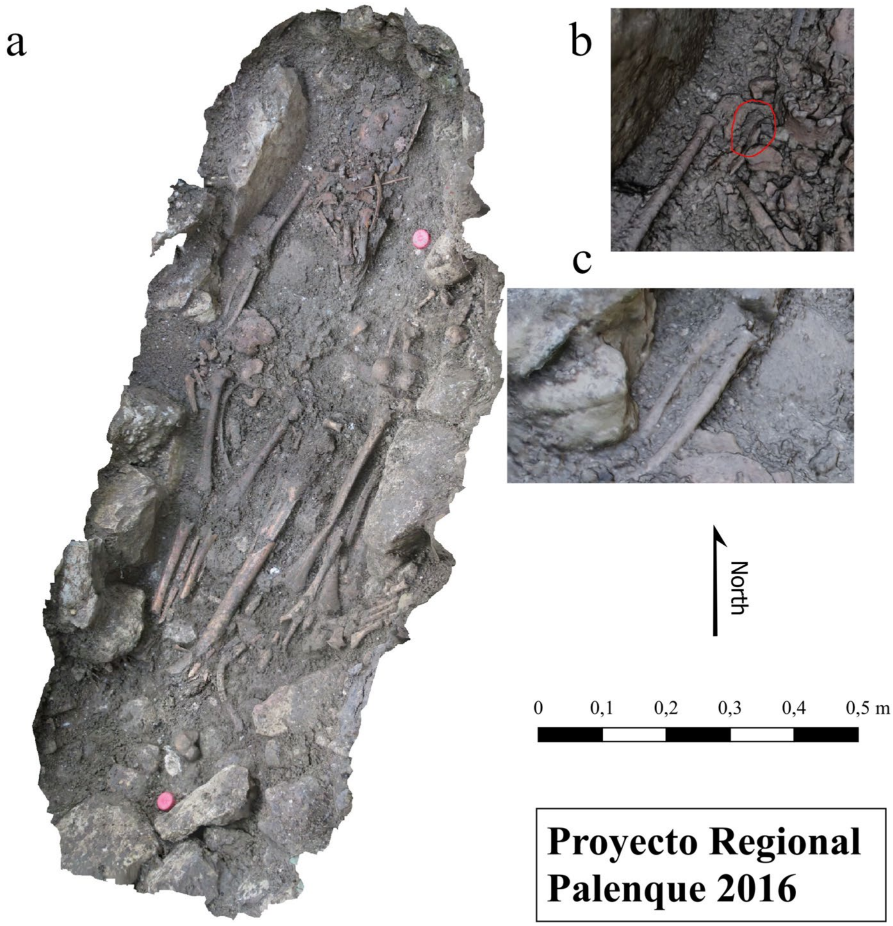


**Fig. 8** **a** Orthophoto of Burial 1 with detail of B1D: **b** verticalized clavicle; and **c** alternated radius (medial) and ulna (lateral). See also the tightness of knees and lower legs

for our analysis. Burial 1's third cist is comprised of an irregular stone enclosure, whose walls are made of worked and semi-worked limestones and arranged in a seemingly haphazard manner. The northern part of the cist is covered with two slabs, while the southern part is left uncovered, revealing loose sediment and the lower sections of the skeletons (Fig. 9). The ancient Mayas deposited grave goods with these individuals. B1D (Table 1) had a bone needle in the neck area and three obsidian blades. B1E was deposited with a quartz crystal among their bones (Fig. 10).

We believe that answering the above questions through the proposed 3D approach allowed us to evaluate its overall viability for taphonomic and mortuary analysis. Table 1 presents the data derived from our analysis of Burial 1.

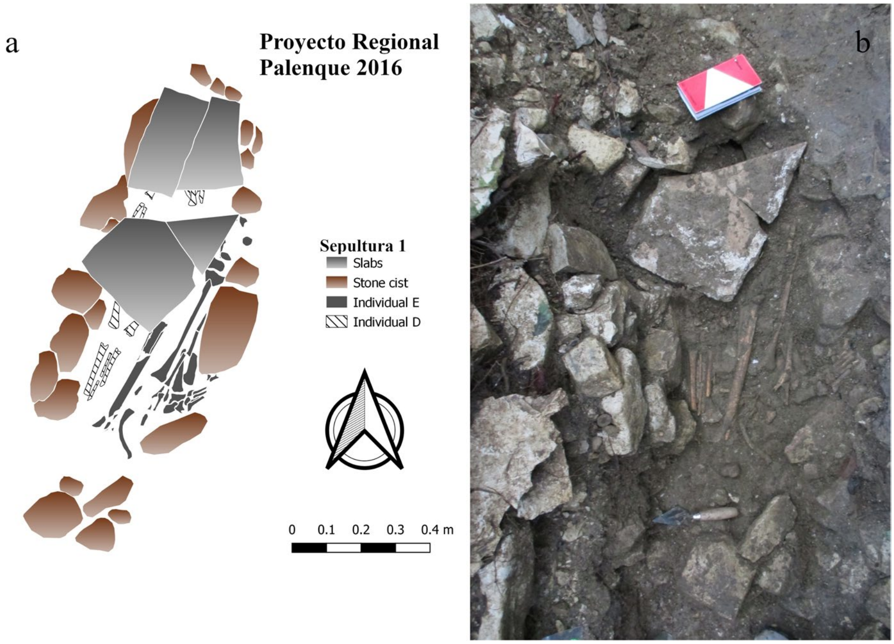


**Fig. 9** Digital drawing of Burial 1: detail of the broken slabs and the infiltrated dirt

## Individual 1D: the Presence of a Wrapping Shroud?

B1D is a 5–6-year-old (based on the diaphyseal length of the long bones) child of undetermined sex, who was interred in an extended supine position. The skeleton is articulated, except for the upper left appendicular skeleton, shoulder girdle, and thorax. The left humerus was broken in half after deposition. The left ulna, radius, and *os coxae* are absent, and the ribs and vertebrae do not align with their original articulations (Figs. 7 and 8). Both the feet are also missing. The location and orientation of certain bones suggest that the individual suffered constriction during the decomposition of the flesh (Fig. 8). In a previous article, De Tomassi briefly proposed that the outline of B1D did not suggest the presence of a shroud but that, instead, this individual was wearing a chest cloth which applied certain constriction to the body (De Tomassi, 2021). Notably, burial shrouds, especially those composed of plant material such as linen and cotton, are highly absorbent and therefore seldom preserve archaeologically outside of unique conditions. As such, interpretations of burial shrouds often come from secondary evidence such as the presence of needles, pins, or other fasteners which held the shroud in place or from archaeothanatological evidence, such as the skeleton showing signs of constriction (Green, 2022; Harris & Tayles, 2012; Nilsson Stutz, 2006; Roksandic, 2002).

Since the previous hypothesis of B1D wearing a chest cloth instead of a shroud was based on 2D data alone, we seek here to evaluate that hypothesis by contrasting the 2D data used at that time with the 3D files which are the object of the present text. Pre-Hispanic Mayas commonly wrapped the departed with textile or mats, and

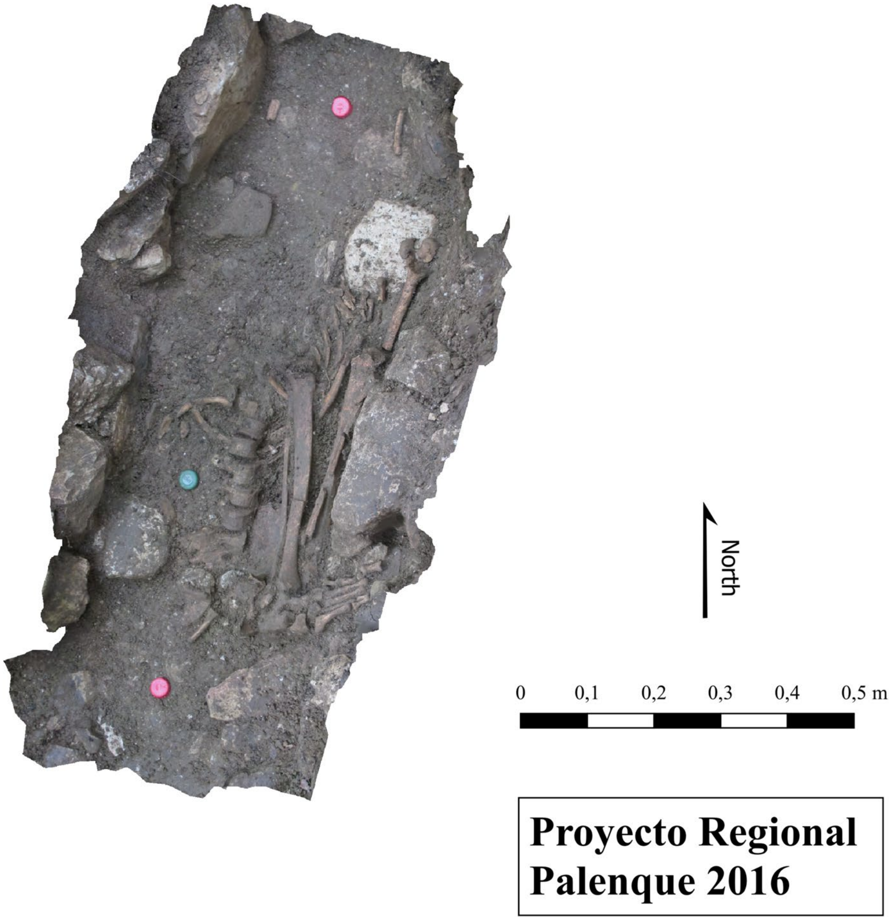


**Fig. 10** Orthophoto of Burial 1: B1E (second layer)

there is direct evidence of funerary shrouds in some exceptionally preserved context, as in the case of royal burials at Calakmul, Southern Mexico (García Vierna & Schneider Glantz, 1996; García-Moreno & Granados, 2000). There are also a few representations of the corpse in Classic Maya art, which show the body wrapped, with the individual's head, ankle, and feet exposed (Reese-Taylor et al., 2006; Fitzsimmons, 2009:61). There are also selected examples of preserved textiles at Palenque, such as in Temple XX (Gonzalez Cruz and Balcells Gonzalez, 2015:106) and Group IV itself (Liendo Stuardo, 2016:179). However, in Palenque's royal burials, the presence of a funerary shroud has been discarded, since constriction is not evident on the shoulder nor clavicles (see Tiesler, 2004b). On the contrary, constriction of the pelvis suggested Pakal was wearing only a loincloth (Tiesler, 2004b, p. 50).

In Group IV, the condition of funerary contexts is not as excellent as it is in royal contexts, thus making it complicated to find direct evidence of the presence of funerary dresses or shrouds. Therefore, we turned to 3D-informed analysis to understand whether B1D was wrapped. The first step was to re-evaluate the archaeothanatological evidence. First, the right clavicle, although fragmented, is highly "verticalized" (Fig. 8b), which is typical of wrapped bodies such that the skeleton shows an almost shrugged-shoulder appearance (Duday, 2009; Roksandic, 2002; Willis & Tayles, 2009). Second, the right forearm suffered an inward rotation, evident in the right ulna positioned laterally to the right radius, which might be evidence for constraint (Nilsson Stutz, 2006; Fig. 8c). Finally, the lower limbs were found to be close to each other *in situ*, such that the knees were almost conjoined in an extreme valgus angle (Figs. 7 and 8).

Let us discuss the position of the bones of the right forearm. The ulna located laterally to the radius can have en explanation different from shrouding. The orthophoto and the 3D model suggest the west wall of the cist collapsed sometime in the past because of natural movements, possibly affecting the position of the distal forearm (Fig. 11; Online Resource 2). Several of the hand's bones are missing, and the remaining ones are highly displaced, suggesting that the collapse of the cist occurred when the body was already decomposed. It is feasible that the right hand was lying palm down, with the radius then crossing the ulna on its superior face. This position of the arms appears in at least one other burial in Group IV, Burial 23 (Liendo Stuardo, 2019:192–193) and may have facilitated the medial movement of

**Fig. 11** Detail of the 3D model (left) and the orthophoto (right) of Burial 1, showing the movement of the stone wall of the cist

the radius. Therefore, there is one strong reason for the radius to have fallen medially from its original position (on top of the ulna) due to the collapse of the cist.

The forearm, then, does not give strong evidence for the presence of a textile wrapping with B1D. Neither do the lower limbs. While the constriction of the knees, tibiae, and fibulae might suggest a shrouding of some sort, the lateral movement of the femur heads suggest the waist decomposed in an open environment. The constriction of the lower legs is feasibly due to the tight position between the walls of the cist and B1E (De Tomassi, 2021, p. 138).

On the contrary, the verticalized right clavicle suggests that a constrain of some sort was employed (Fig. 8b; Online Resource 2). It is possible that, rather than a shroud, the individual was dressed in a chest cloth as previously speculated at Palenque for the royal tombs of *K'inich Janaab Pakal* and queen *Tz'ak-bu Ajaw* (González Cruz, 2000; Ruz Lhuillier, 2013). Though such garments did not cause clavicle constriction in the royal burials (González Cruz, 2011; Tiesler, 2004a, 2004b), B1D presents a different case. The presence of a bone pin near the neck supports this theory, as similar pins have been found closing chest clothes in Palenque's royal tombs and are often interpreted as fasteners for garments or shrouds (De Tomassi, 2021; Scherer, 2019; Scherer et al., 2014). Since there is no evidence suggesting the royal bodies were wrapped in a tight shroud, it is possible that also B1D was wearing only a chest cloth. Interestingly, in this case, the garment was tight enough to cause the verticalization of B1D right clavicle.

To summarize, while skeletal evidence initially suggested the idea of a burial shroud, the analysis of the context, enhanced by 3D visualization, confirmed that almost all this evidence can have a different explanation. B1D may not have been wrapped in a shroud but instead wore a tightly fitted funerary dress, possibly a chest cloth, which was probably tight enough to create the patterns seen here. This supports the idea that wrapping bodies in shrouds may not have been common in Palenque, contrasting with customs observed at Calakmul. Our 3D-informed analysis strengthens the previous hypothesis that some individuals at Palenque may have worn a chest garment during burial.

## Individual E: Secondary Reopening and Original Position

B1E is a highly altered young adult (20 years[4]) male burial, whose remains show signs of post-depositional disturbance. The body was buried in an unusual position at Palenque, with the legs flexed on the left side (Table 1) and the left tibia and fibula found atop the right lower limb (Figs. 7, 8, and 9). The right leg and foot, the pelvis, and the thoracic vertebrae were the only articulated elements of the skeleton. Most of the thoracic and cervical vertebrae (except for fragments of the atlas and axis), cranium, mandible, and most teeth are missing. Numerous bones were found far from their original articulation, such as the clavicle located at the southern end of the cist, about 50 cm from its original joint site (Figs. 7 and 8; Online Resource 2). The left foot is also mostly missing.

[4] Based on an average between pubic symphysis (18 years) and auricular surface (20–24 years).

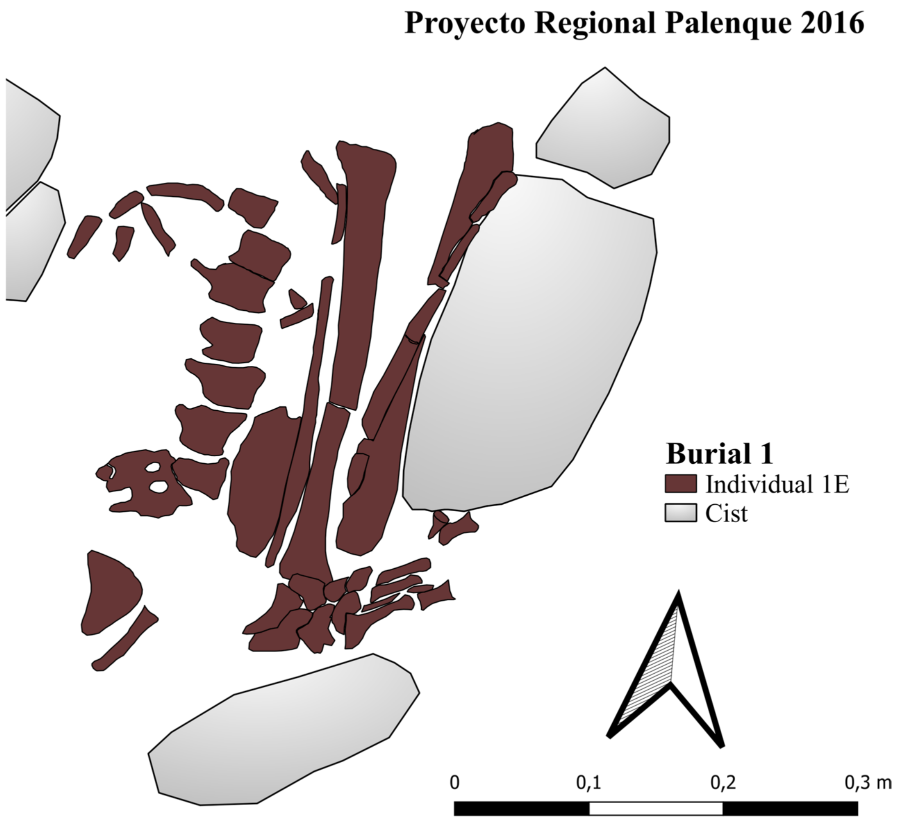


**Fig. 12** Digital drawing of B1E (second layer)

At Palenque, after a body decomposed, cists were commonly reopened to alter the skeletal content, typically resulting in the removal of skulls and long bones (Núñez, 2011). We argue there is archaeological and archaeothanatological evidence to propose that this individual was subjected to postdepositional intentional alteration. While the displacement of some small bones might be due to non-human causes, such as roots or rodents, we observed no indication of gnaw marks or other evidence of animal activity. The upper body of B1E is highly altered, considering the lack of thoracic and cervical vertebrae, plus the displacement of the upper limbs. Especially, it is hard to think that the absence of teeth, which are the most durable element in the human skeleton, results from diagenesis alone.[5] The presence of fragments of the atlas and axis would additionally exclude the possibility that the head was severed from the neck. Therefore, while some alterations might be due to other causes, these can hardly demonstrate that the burial was not ritually reentered. It is more likely that the context was intentionally reopened and the lack of stone slabs

[5] There was only one tooth associated to this individual, a premolar, found between their femurs, whose size is consistent with Individual 1E's age.

above the burial may serve as confirmatory evidence since these slabs were often broken after or during secondary rituals at Palenque (Núñez, 2012). The articulation of the right foot, pelvis, lumbar vertebrae, and most of legs confirm B1E was ritually reduced.

The post-mortem alteration of B1E also confirms the posterior intrusion of the loose sediment mentioned above. The articulation of the labile joints of B1E's right foot may suggest that this part of the body could have decomposed in a filled environment (Figs. 10 and 12; Online Resource 3). However, the disarticulation of the sacro-iliac joint, with the collapse of the sacrum, is evidence for decomposition in an empty space, where gravity facilitates postero-lateral disarticulation of the pubic symphysis and rotation of the femora in extended supine burials (Duday, 2009, p. 32) (Figs. 10 and 12; Online Resource 3). The right foot is located in what appears to be a hole among the stones of that side of the cist, probably due to the poor quality of the walls of the burial. We posit that this appendage was not protected by the cist and was in fact covered by dirt soon after been deposited. As such, it is safe to state that the infiltration of dirt is posterior to, and possibly consequence of, the stone slab's removal.

Having defined that the burial was reopened, we now aim to discover the original burial position of B1E. The 3D reveals insights into the burial position. The legs were flexed to the left, and while the right ribs were found underneath the legs, some were also discovered beneath B1D's legs. The lumbar vertebrae provide evidence for the position of the torso of B1E. The 3D model shows evidence of the lateral rotation of L2 and L1 to the right around their longitudinal axis. This arrangement may suggest the individual was lying on his back. In fact, the lumbar spine can perform axial rotation, whereby the inferior articular process of the upper vertebra ramming into the superior articular process of the lower one. This movement is quite limited, approximately only 8°, according to Kalichman and Hunter (2007, p. 72).

The lumbar vertebrae exhibited different phases of decomposition, such that L1 and L2 decomposed differentially from L3 to L5. This is a normal pattern for the vertebrae when decomposing (Duday, 2009, pp. 32–34), suggesting that the ligament between L2 and L3 decomposed earlier, allowing these differential responses to gravity. The sacrum collapsed toward the right side of the body, which is consistent with the decomposition of flexed individuals lying slightly on their side in an empty environment (see Duday, 2009: 33–34), but in doing so, it did not provoke movement of the vertebrae, suggesting the lumbosacral joint had decomposed when the alteration of the sacrum occurred (Figs. 12 and 13).

The 3D model makes visible the axial rotation of L2 and L1 (Fig. 6). It is hard to quantify the degree of axial rotation since the bones moved along the three possible axes. Nevertheless, the movement was probably significant since the inferior articulate process of the upper vertebrae moved past the superior articular process of the lower ones (Online Resource 1). This might have happened because of the fragmentation of the articular processes and/or because the movement occurred after the decomposition of the articulations. Only with the 3D model of the individual vertebrae did we notice the right inferior articular process of L4 inserts perfectly into a mark on the superior body of L3 (Fig. 14a and b; Online Resource 1). This supplies information regarding the taphonomic preservation of bones. Moreover, it

**Fig. 13** Detail of the lumbar vertebrae of B1E, from the 3D model

is additional evidence of the strong alteration the skeleton suffers during and after decomposition, possibly due to both natural and cultural factors.

To conclude, the detailed study of the movements of the lumbar vertebrae helped in supporting that lateral rotation occurred after decomposition in an open environment. This, plus the presence of the right ribs on the left of the skeleton, and the movement of the sacrum to the right, might be evidence for a slight flexed lateral position, with the body laying slightly on its left side.

## Sequence of Deposition

Based on skeletal evidence and the analysis of the burial context, we propose the following deposition sequence.

1) Initial deposition of B1E:


**Fig. 14** 3D models of vertebrae L3 and L4: **a** showing the mark on the body of L3; **b** the movement of L4 caused its right inferior articular process to insert into the mark on L3; **c** detail of the insertion

B1E was initially placed in the burial slightly flexed on his left side. This position is supported by several skeletal elements: the flexed legs, the articulated right foot and ankle, the lumbar vertebrae, and the ribs on the left side of the spine.

2) Subsequent deposition of B1D:

After B1E had decomposed, B1D was interred, indicating that the burial was reopened. The strongest evidence for this sequence is that some of B1E's ribs are located underneath B1D's legs, suggesting that B1D was deposited on top of B1E's skeletonized remains. Additionally, it might have been difficult to fit two bodies, in a non-decomposed state, into the narrow space of the cist (Andrew Scherer, personal communication, 2024). B1D's legs seem to be accommodated according to B1E skeleton so he was feasibly already decomposed when this happened.

3) Second reopening and alterations:

The third event is a second reopening of the burial. Evidence for this includes the following:

a. Broken and missing slabs.
b. Post-depositional infiltration of sediment.
c. The absence of B1E's teeth.

d. General taphonomic changes to both skeletons, including the loss of B1D's feet, alterations to B1E's left foot and clavicle, displacement of B1E's sacrum and right femur, and disturbance to B1D's upper left body.

These changes suggest that B1E's skull was intentionally removed, and other bones were displaced during this event. Some of the alterations, however, may have been unintentional consequences of the ritual. Specifically, B1D's upper body was disturbed in the area where B1E's cranium would have been (Fig. 8). Other than the left radius, most of B1D's bones are present but are fragmented and disordered. Currently, we hypothesize that this disarray might have resulted from the collapse of the slab cover, either due to gravity or intentional breakage, which partially destroyed B1D's upper left appendicular skeleton. Alternatively, this fragmentation could also be a result of intentional manipulation. Regardless, this evidence confirms that B1D was already skeletonized when the second event occurred.

The primary argument against this deposition sequence is the length of the cist, which suggests that it was built to accommodate more than one individual in a flexed position. However, this does not exclude the possibility that the burial was initially intended for two individuals. While currently these individuals have not been radiocarbon dated, such analyses would likely provide an extra layer of exciting information to interpret the depositional sequence.

## Conclusion

This work presented a case study from Palenque Group IV we used to evaluate the viability of digital photogrammetry to document in 3D funerary contexts in the Maya area. The main goal of this research was to provide valuable data to enhance the analysis of taphonomic alterations and pre-Hispanic cultural practices. While careful drawings, knowledge of decomposition, and burial dynamics are crucial to unpacking taphonomic and post-burial effects, this paper demonstrated that 3D documentation techniques, such as digital photogrammetry are viable approaches to shed new light on burial architecture, slopes and gravity, and elevation at the visual level.

The 3D-informed analysis we performed on Group IV's burial increased our understanding of pre-depositional, depositional, and post-depositional funerary practices households carried out in Palenque's domestic groups. Previous work argued that Palenque's royal deceased individuals were surely dressed before their inhumation (González Cruz, 2011). However, such inference in domestic burials is rarely supported by direct evidence. Our approach allowed to infer the existence of a specific kind of cloth that B1D was wearing before their burial. While this individual was buried in the classic Palenque-style (extended supine position), our analysis of the almost imperceptible necrodynamics of B1E allowed us to understand that the latter was deposited in the less common lateral flexed position. Finally, our analyses of the skeletal preservation within the burials suggest that the burial cist was re-opened at least one time in the past and that additional events were likely due to non-intentional occurrences such as the collapsing of the cist stone slab covering.

Building on Freiwald (2019) and Miller Wolf (2019), we conclude that due to the typical poor preservation of pre-Hispanic Maya burials, it is compelling to develop and apply detailed methodologies of excavation, recording, storing, and analysis that can provide viable photographic documentation of Maya funerary contexts. Our findings show that by introducing vertical and horizontal dimensions, the 3D documentation of burials can optimize archaeothanatological analysis of funerary contexts located in tropical areas, which share similar geo-environmental characteristics with Palenque. More specifically, as highlighted by our 3D-informed analysis of Burial 1, we believe that 3D documentation and analysis workflow discussed in this paper can generate a deeper understanding of the cultural, biological, and even economic filters (*i.e.,* looting and modern disturbance) that affect pre-Hispanic burials in the Maya region.

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## Declarations

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