

ARCHAEOLOGICAL ANASTYLOSIS OF TWO MACEDONIAN TOMBS IN A 3D VIRTUAL ENVIRONMENT

LA ANASTILOSIS ARQUEOLÓGICA DE DOS TUMBAS MACEDONIAS EN UN AMBIENTE VIRTUAL 3D

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Highlights:

- Use of contemporary digital methods for the 3D geometric documentation of complex burial structures.
- Interdisciplinary approach to implement digital techniques for 3D modelling, including 3D terrestrial laser scanning and image-based modelling.
- Implementation of virtual anastylosis by archaeologists using the 3D models and suitable software.

Abstract:

Archaeological restoration of monuments is a practice requiring extreme caution and thorough study. Proceeding to restoration or to reconstruction actions without detailed consultation and thought is normally avoided by archaeologists and conservation experts. Nowadays, anastylosis executed on the real object is generally prohibited. Contemporary technologies have provided archaeologists and other conservation experts with the tools to embark on virtual restorations or anastyloses, thus testing various alternatives without physical intervention on the monument itself. In this way, the values of the monuments are respected according to international conventions. In this paper, two examples of virtual archaeological anastyloses of two important Macedonian tombs in northern Greece are presented. The anastyloses were performed on three-dimensional (3D) models which have been produced using modern digital 3D documentation techniques, such as image-based modelling and terrestrial laser scanning. The reader is introduced to the history and importance –as well as the peculiarities– of the Macedonian tombs. In addition, the two tombs are described in detail mainly from an archaeological point of view. The procedure of field data acquisition and processing to produce the 3D models is described. Simple and standard methods were employed in acquiring the raw data. Processing was carried out using commercial software. The resulting 3D models and other documentation products have been assessed for their accuracy and completeness. The decisions for the virtual anastylosis are explained in detail and the procedure is also described. The restored monuments are presented and evaluated by the conservation experts. Thus, it is shown how important virtual anastylosis of monuments is to archaeology researchers, as it enables them to conduct in-depth studies, without actually tampering with the monuments themselves. Digital 3D models are contributing to many disciplines, especially in archaeology; they enable a wider audience to easily access both archaeological and geometric information, also offering the user a high degree of interaction possibilities.

Keywords: 3D documentation; image-based modelling; terrestrial laser scanning; virtual anastylosis

Resumen:

La restauración arqueológica de monumentos es una práctica que requiere extrema precaución y un estudio exhaustivo. Los arqueólogos y expertos en conservación evitan normalmente proceder a la restauración y a las acciones de reconstrucción sin reflexión y una consulta detallada. Actualmente, la ejecución de anastilosis sobre el objeto real está generalmente prohibida. Las tecnologías contemporáneas han proporcionado las herramientas a los arqueólogos y otros expertos en conservación para embarcarse en restauraciones virtuales o anastilosis, probando así varias alternativas sin intervención física en el monumento. De esta manera, los valores de los monumentos se respetan de acuerdo a las convenciones internacionales. En este artículo, se presentan dos ejemplos de anastilosis arqueológicas virtuales de dos importantes tumbas macedonias en el norte de Grecia. Las anastilosis se realizaron en los modelos tridimensionales (3D) que se han producido empleando técnicas modernas de documentación digital en 3D, como el modelado basado en imágenes y el escaneo láser terrestre. Se presentan al lector tanto la historia y la importancia como las peculiaridades de las tumbas macedonias. Además, las dos tumbas se describen en detalle desde un punto de vista arqueológico principalmente. Ha sido descrito el procedimiento de toma y procesamiento de datos de campo para producir los modelos 3D. Se emplearon métodos simples y estándar en la toma de datos crudos. El procesamiento se

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llevó a cabo utilizando software comercial. Los modelos 3D resultantes y otros productos de documentación fueron evaluados a partir de su precisión e integridad. Se explican en detalle las decisiones de la anastilosis virtual y también se describe el procedimiento real. Los monumentos restaurados se presentan y evalúan por los expertos en conservación. Por lo tanto, se muestra cuán importante es la anastilosis virtual de los monumentos para la investigación arqueológica, ya que permite estudiar los monumentos en profundidad, sin alterar realmente los monumentos mismos. Los modelos digitales en 3D están contribuyendo en muchas disciplinas, especialmente en arqueología; permiten un fácil acceso a la información arqueológica y geométrica a una audiencia mayor, dando al usuario altas posibilidades de interacción.

Palabras clave: documentación 3D; modelado basado en imágenes; escaneado láser terrestre; anastilosis virtual

1. Introduction

In recent years the geometric documentation of monuments is enhanced and performed using contemporary digital methods. This geometric documentation is an integral part of the subsequent restoration studies already since 1964, as the Venice Charter dictates. The incredible progress of information and communication technology (ICT) and the contribution of computer vision algorithms have enabled photogrammetric processes to easily produce three-dimensional (3D) models of the monuments under study. These 3D reliable, realistic and accurate models can be easily used and exploited by non-experts in new technologies.

They offer many different and challenging uses in many scientific fields, examples of which are published in the relevant literature. Many of them are concerned with the Virtual Restoration or Anastylis of the documented monuments, which quite understandably is of great importance as virtual environment offers the opportunity for alternative solutions to be investigated without intervening to the monument itself, thus taking care of its values and respecting the international agreements.

In this paper, the geometric documentation of two Macedonian tombs which have been revealed in Macedonia, in northern Greece (Fig. 1) close to Thessaloniki, and dating from the 3rd century BC is described. These tombs are (i) *Tomb of Macridy Bey* in Derveni, Thessaloniki, and (ii) *Tomb of Heuzey* in Korinos Pieria, near Katerini. Their names were given after their excavators.

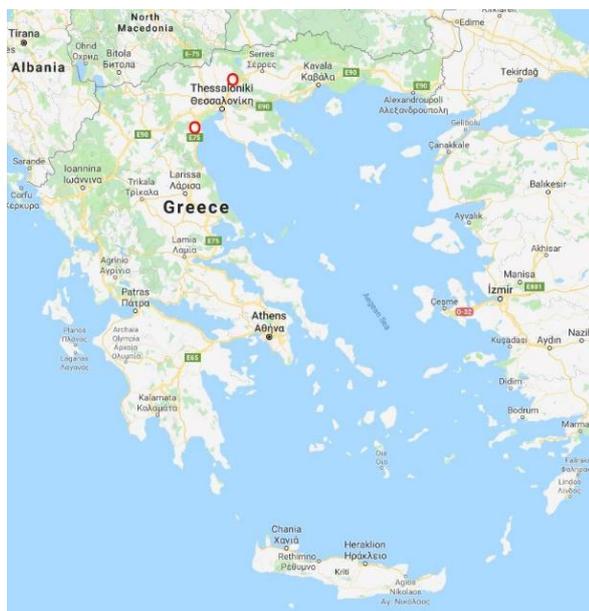


Figure 1: The location of the two Macedonian tombs.

2. Macedonian tombs

2.1. Appearance and typological features

During the 5th and 4th century BC in Macedonia, as in the whole of Greece in general, the cist graves and the rock-cut tombs were the most common type of graves. In that era in Macedonia, due to the prosperity of the Macedonian kingdom, there was the tendency for larger monumental burial structures, which were used by the members of the Macedonian elite, a minority of the high social and economic class. The dimensions of these graves were significantly growing, so their flat roof used so far was insufficient to securely cover them. Early in the 4th century BC in Macedonia, several experiments had been carried out on how to cover these large graves, in order to withstand the weight of the earth above. The need for safe covering, therefore, led to the creation of the vaulted roof, as both the flat and the span roof were not sufficient, as the dimensions of graves grew, creating a new form of burial structures, the *Macedonian Tomb* (Ginouvé, 1993; Andronikos, 1987).

Most of the Macedonian tombs are located in the heart of the Macedonian kingdom, in central Macedonia and in the area of Amphipolis, or in areas where the Macedonian influence was particularly strong, hence the adjective “Macedonian” (Huguenot, 2008). The Macedonian tomb was the choice for internment of the kings and Macedonian elite.

A typical Macedonian tomb is a built chamber tomb with a barrel-vaulted roof, constructed partially underground and covered by an artificial earth *tumulus*. Most of these tombs were constructed using local limestone, while marble was rarely used in specific parts of the tombs such as doors, doorframes, lintels, thresholds, etc. The barrel-vaulted roof and the monumental façade are the two main typological features that differentiate a Macedonian tomb from all the other burial constructions. In plan, a Macedonian tomb consists of a burial chamber, which is either square or rectangular. Often before the burial chamber, one or two antechambers, smaller in size were constructed. Antechambers may also have vaulted roofs or sometimes they are covered by a dropped, flat roof. Whatever the plan of the tomb, an architecturally formed façade was an integral part of a Macedonian tomb. These usually imitate the front of a house or a temple, they are either embellished in a Doric or Ionic order with a pediment and other features such as friezes, metopes and triglyphs or are very simple. These tombs were regularly provided with some sort of entrance passageway, called *dromos*, which leads to the tomb’s entrance *Dromoi* were simply dug into the earth, built or carved into the natural soil and they could either be levelled or sloping downwards, sometimes with steps and their roofs were either flat or vaulted.

The tombs' gates were blocked either by wooden or marble doors or, very simply, with stone blocks consecutively positioned. Interior walls and façades were decorated with plaster and often embellished with colour. The used colours were vivid, and the most impressive examples of tombs show a wide variety of colours such as red, yellow, green, black and blue. Most Macedonian tombs are furnished with one or more wooden or marble funerary couches, sarcophagus and rarely with thrones and chests. In their majority, Macedonian tombs have been looted in the past either entirely or in part (Pantermalis, 1972; Miller, 1972, 1982, 1993; Gossel, 1980; Fedak, 1990; Ginouves, 1993; Huguenot, 2008).

2.2. The Macedonian Tomb of Heuzey

2.2.1. Chronicle of excavation research

That particular Macedonian tomb of Pydna is also known as Heuzey's tomb, since Heuzey was the name of the French archaeologist who discovered it in the years 1855 and 1856. Then the proprietor of a piece of land at Korinos, situated on the region of ancient Pydna, gave permission to the French archaeologist and explorer Léon Heuzey, who travelled in ancient Macedonia, to investigate an underground funerary monument, whose decoration was still visible in the upper parts, but Heuzey could not revive this tomb due to difficult economic conditions of that era. In 1861 Heuzey was authorized by the emperor Napoleon III, to lead the research campaign in Macedonia. Returning to the area in spring of 1861, Heuzey together with architect Honoré Daumet, started investigating this burial place, which was buried under a large tumulus and, although pillaged, was remarkably preserved. Daumet, with coloured paintings and drawings, provides very useful information about the tomb's condition especially for its decoration at that time (Fig. 2) (Descamps-Lequime, 2011).



Figure 2: The tomb of Heuzey in 1861 (Heuzey & Daumet, 1877).

This mission was, indeed, the first archaeological excavation research in northern Pieria. Heuzey, in fact, along with Daumet, are considered the pioneers of Macedonian archaeology. These two, also, discovered another Macedonian tomb with Ionic façade north of the ancient city of Palatitsia, near Vergina, and the ruins of a palace in that area. The result of this research mission was the publication, fifteen years after the mission, of a valuable project titled *Mission Archéologique de Macedoine* (Heuzey & Daumet, 1877).

Despite this impressive beginning in the archaeological research of northern Pieria, it has been more than

a century before the excavations in this region begun. In the context of these investigations, in 1991, the Greek archaeologist Manthos Besios set out again to reveal the tomb of Heuzey, which was re-covered all these years, (Besios, 1991).

2.2.2. Location

The tomb is situated in Northern Greece in the Prefecture of Pieria, near Katerini, in the vicinity of Korinos a few hundred meters east of the Thessaloniki-Athens highway. The tomb is located in the western part of a large tumulus of about 60 m in diameter and 15 m high. Its orientation is northeast-southwest, with its entrance to the southwest (Fig. 3), (Heuzey & Daumet, 1877; Miller, 1972, 1982, 1993; Gossel, 1980; Pantermalis, 1985; Besios, 1991; Sismanidis, 1997; Giannakis, Calogeridis, & Besios, 2000; Besios, 2010; Descamps-Lequime, 2011; Mangoldt, 2012).



Figure 3: Location of the tomb of Heuzey (Heuzey & Daumet, 1877).

2.2.3. Construction and ornamentation

The tomb of Heuzey is a three-chambered tomb of the Macedonian architecture with a carefully formed façade in the Doric order. The tomb consists of a dromos, a vestibule, an antechamber and a main burial chamber. A sloping passageway (dromos), which is 11 m long and 2 m width, leads to the main tomb. The three chambers are covered with a continuous barrel-vaulted roof, while dromos is covered with a separate vaulted roof (Fig. 4). Before dromos, the excavations of Besios, in 1991, unearthed the remains of a first corridor with two sidewalls, made of mud bricks at the top and two rows of a cornerstone at their lowest part. The entrance to the tomb conducted through a wooden elevated modern structure, thanks to which the visitor can see this ancient structure relics (Fig. 5). The tomb of Heuzey is built of limestone blocks according to the pseudo-isodomic system.

At the entrance are still the two marble doors, which closed the entrance of the road (Fig. 6). The walls of the sloping road are covered with a plaster of different

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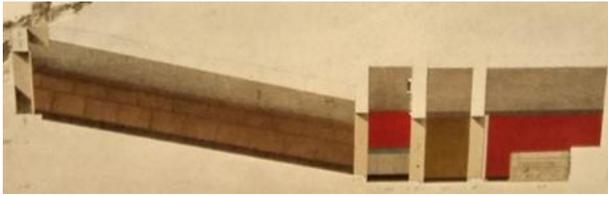


Figure 4: Artist's impression of the tomb of Heuzey (Heuzey & Daumet, 1877).



Figure 5: Ruins of the exterior corridor today.



Figure 6: The dromos of the tomb of Heuzey.



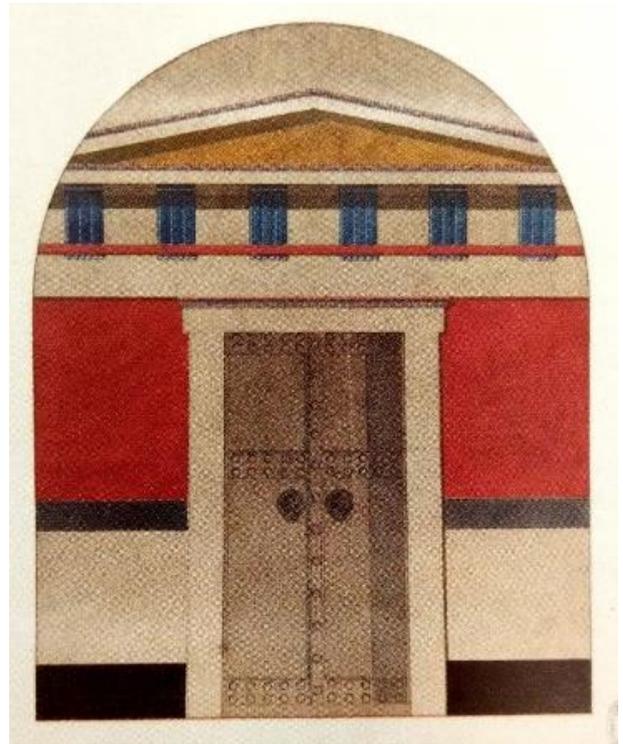
Figure 7: Marble imitation in the decoration of the tomb of Heuzey (Descamps-Lequime, 2011).

colours, white for the vault, marble imitation in the middle of the sidewalls and black for the plinth (Fig. 7); the floor is made of a device of small pebbles covered with a red coating. At the end of the sloping dromos, we reach on a small very shallow vaulted antechamber. All the walls of this chamber were painted: from top to bottom, under the white vault, there was a red zone, a blue band, a white zone and a black plinth. The most interesting feature of this room is the Doric façade on the back wall, which is composed of pillars, triglyphs, metopes and pediment. The façade was also covered with coloured mortar, of which some traces are still visible (Fig. 8). From this

vestibule one can pass to the second vaulted antechamber, higher and narrower than the first antechamber. It was also enhanced with colours: the vault was white, the walls in ochre and the plinth in black. Its floor is made of limestone slabs covered with a thick red coating.



(a)



(b)

Figure 8: a) The façade of the tomb of Heuzey; b) a drawing by Daumet (Heuzey & Daumet, 1877).

At the back, passing a limestone doorframe with two-leaved marble door is possible to enter to the burial chamber, on the floor of which laid the two shattered leaves of the door. Two funerary beds were positioned in an L-shaped arrangement in the left corner of this burial room. The bigger façade of the burial bed represents a relief decoration of a dog with dense fur and the other façade depicts a coiled snake (Fig. 9). The floor of this chamber is of the same construction with the antechamber. A few traces on the walls of the main chamber show that there were four painted zones: black for the base, the main zone in red, a blue-black band



(a)



(b)

Figure 9: The burial beds with the depictions of a) a dog and b) a snake. Pictures were taken at the Louvre Museum¹.

and white at the top. The door of the road, along with the door of the burial room and the decorated facades of the two couches were discovered in the tomb. The door of the burial chamber and the relief representation of the dog are now exhibited in the Louvre Museum, while the door of the dromos and the snake relief are still in the tomb.

There are many different opinions among researchers about the dating of the Macedonian tomb of Heuzey. These views comprise a wide chronological period from the end of the 4th century until the beginning of the 2nd century BC. The most dominant dating is in the last quarter of the 4th or the beginning of the 3rd century BC.

2.3. The Macedonian Tomb of Macridy Bey

2.3.1. The discovery

The Macedonian tomb at Langadas, known as Tomb of Macridy Bey² after its first excavator, Theodoros Macridis, an Ottoman officer, was unfortunately discovered looted in February 1910 after a strong earthquake in the area (Macridy, 1911; Büsing, 1970; Pantermalis, 1972; Miller, 1972; Gossel, 1980; Sismanidis, 1985, 1997; Tzanavari, 1997, 2000; Mangoldt, 2012;). As this area and Thessaloniki in

¹ Burial bed in the Atlas Database of Louvre Museum: http://cartelfr.louvre.fr/cartelfr/visite?srv=car_not_frame&idNotice=31266&langue=fr

² Website of Macedonian Tomb of Macridy Bey: <http://macedoniantombmacridybey.culture.gr/en/>
Figures 11 to 18 taken from the website.

general belonged to the Ottoman Empire at the time, the Directorates of the Ottoman Imperial Museum were immediately informed. A few months later, the tomb was excavated by Macridis, who revealed the already collapsed façade which had, and the tomb's interior (Fig. 10). The excavation was resumed in the 1990s by the Ministry of Culture's responsible Ephorate of Antiquities by the Greek archaeologist K. Tzanavari (Fig. 11). During this excavation, part of the ancient dromos was uncovered. In 2008, the study for the restoration of the monument was prepared by the responsible Ephorate of Antiquities, and implementation of the project began in 2012 with funding from the NSRF 2007-2013 (Athanasidou, Malama, Miza, Sarantidou, & Papatotiriou, 2012; Athanasidou Malama, Miza, Sarantidou, & Papatotiriou, 2015). Work was conducted under the supervision of the Ephorate itself and completed in 2015 (Fig. 12). The 2013 excavations revealed the 8 steps, formed on the sloping road (Fig. 13).

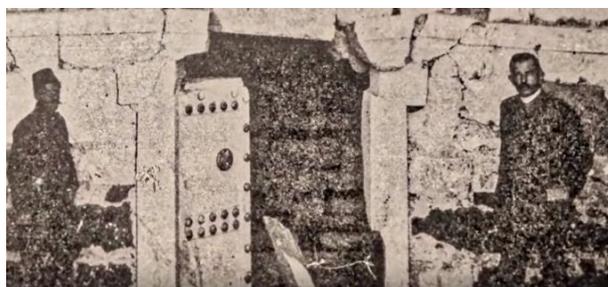


Figure 10: Macridy Bey in front of the burial chamber in 1910 (Macridy, 1911).



Figure 11: Excavation in 1997.



Figure 12: The restored tomb of Macridy Bey.

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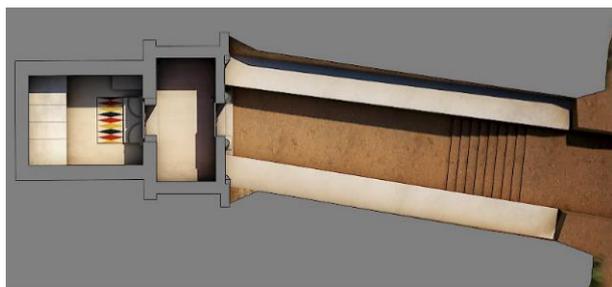


Figure 13: Floor plan of the tomb of Macridy Bey.

The excavator, in the publication of the excavation in 1911, points out that the monument had been looted in the past more than once. The tomb looters, after excavating an underground tunnel of 17 m, invaded into the antechamber by a hole in the façade, without seeing the bronze parts of the outer wooden door, which were thus saved.

2.3.2. Location

The Macedonian tomb of Macridy Bey is located just north of the National Road Thessaloniki - Kavala, in the Derveni area, within the necropolis of ancient Liti, in the prefecture of Thessaloniki. At Derveni, which means "passage" in the Turkish language, the ancient road *Egnatia Odos* was passing. All this area belonged to the vital area of ancient Liti, one of the most important Mygdonian cities (Themelis & Touratsoglou, 1997). In the area of ancient Liti, there are many funeral complexes and variety of graves, which date from the second half of the 4th c. B.C. until the Early Christian years, which proves the long-term use of this area (Tsakalou & Tzanavari, 1992).

2.3.3. Construction and decoration

The Macedonian tomb of Macridy Bey is among the biggest double-chambered, i.e. with antechamber and burial chamber, Macedonian tombs. Its façade is formed according to the Ionic order and a sloping corridor (dromos) leads to the façade (Fig. 13). The tumulus, i.e. an artificial hill, which covered the tomb and the dromos was 19 meters in height and had a diameter of 75 m. Its greater part can still be seen today. This was a major engineering project constructed in antiquity, after the erection of the tomb, with the layering of soil materials in successive strata with a thickness of about 0.80 m. The tomb was set off-centre on the western side of the tumulus. Both the antechamber and the burial chamber, both of varied sizes, were constructed according to the pseudo-isodomic system with brownish limestone blocks laid without mortar in nine layers. The two chambers were covered, with a separate barrel-vaulted roof each. The sloping road (dromos) (Figure 14), leading to the tomb, was 14.70 m long, 3.50 m wide, and there were eight steps at its west end. The sidewalls of the dromos were of mud brick, and had a height of 2.00 m, and ended at the tomb's façade. The floor of the dromos was paved in clay soil and gravel (Fig. 15).

The façade had the form of a tetrastyle monument of the Ionic order. There were two semi-columns in the middle of the wall on either side of the entrance to the antechamber, and two quarter-columns inherent with the antae supporting the entablature and pediment at its ends (Fig. 16). In the centre of the façade, there was a



Figure 14: The dromos of the Macridy Bey tomb.

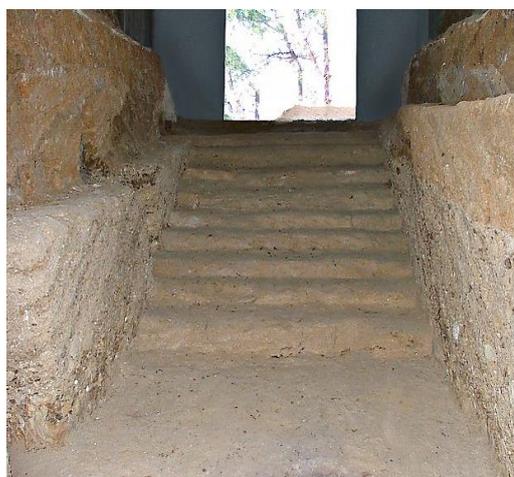


Figure 15: The staircase at the beginning of the dromos



Figure 16: The Ionic façade.

two-panelled wooden door, of which only a few traces have survived, with gilt bronze decoration. Today the entrance threshold, the bases of the two semi-columns, the first wall course, and parts of the quarter-columns and stone blocks delimiting its north and south ends remain preserved *in situ*. A large part of its façade had collapsed before the monument was excavated in 1910. The façade was entirely enhanced by colours. The few remains that have survived down to the present show a variety of colours. The tympanum of the pediment was bright yellow framed by purple while the column capitals and architrave were red and blue (Fig. 17).

The smaller but wider than the burial chamber, antechamber was also ornamented with plaster of varying colours. Remains on the walls show that there were five painted zones, from the base to the top, black on the base, white, grey, red, and white at the top. The antechamber's floor is covered with stone slabs and covered with mortar. A trapezoidal doorway with a marble frame in the Doric order led to the main chamber. This doorway was closed by a marble door which had two panels. This door was taken away and today is in the Istanbul Archaeological Museum. The floor of the chamber was covered with limestone slabs and with



Figure 17: The coloured façade with a wooden door.

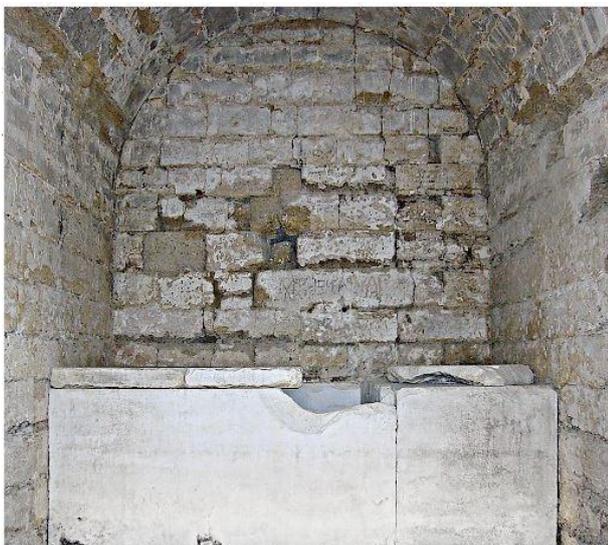


Figure 18: Burial chamber with the burial structure.

mortar. The walls of the burial chamber were coated in white mortar. Along the east side of the burial chamber lies a unique marble burial construction of 1.30 m height. Outside this construction looks uniform, but it is divided internally into two uneven rectangular sections in the sarcophagus and the case. Beneath this construction, a cist tomb was found containing the remains of a wooden coffin indicating the place where the deceased was buried (Fig. 18).

This monumental tomb was constructed for the burial of a single prominent noble person between the second half of the 4th and the first half of the 3rd century BC.

3. 3D geometric documentation

The virtual anastyleses of the two monuments were to be realised on their digital 3D geometric documentation. The 3D geometric documentation was realised using standard Geomatics procedures, i.e. total station measurements, image-based modelling, and terrestrial laser scanning, thus producing realistic 3D models of the two tombs.

Those models were later used both for the virtual anastyleses of the two Macedonian tombs, as well as for the photorealistic visualization and virtual visit for the Heuzey's tomb.

3.1. Raw data acquisition

Standard procedure was followed for the necessary data acquisition. The available instrumentation included the following equipment:

- A TOPCON GT 3003 Total Station, capable of recording angles with an accuracy of 3 seconds and measuring distances with 5mm+5ppm in reflectorless mode
- A DSLR camera Canon EOS 1Ds Mark III, with a full-frame CMOS sensor. For that camera two Canon EF lenses were available. One Canon zoom lens with 16 – 35 mm focal length and one prime Canon EF-S 24 mm standard lens. The pixel size on the sensor is 6.4 μm .
- A FARO 3D 130X terrestrial laser scanner. According to the manufacturer, this particular model may determine the position of the points with an uncertainty of ± 3 mm while acquiring up to one million points/s.

The necessary networks for georeferencing all measurements and data to the same reference system for each of the two tombs were comprised of a four station traverse in the case of the tomb of Heuzey and a six station traverse in the case of the tomb of Macridy Bey. This differentiation was dictated by the local conditions. In the case of the Macridy Bey tomb, the architectural members of the pediment were situated on a different level for static reasons (Fig. 12). The two traverses were carefully measured, and their coordinates determined by an adjustment to provide the reference system for the georeference of all later measurements. In addition, ground control points with specially coded targets were set up in key positions to help scale and georeference of the 3D models later.

High resolution digital images were acquired for image-based modelling the two tombs. Care was taken that the ground sampling distance (GSD) was kept under 2-3 mm, in order to increase the resolution and

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the imaged details. For illuminating the object, a pair of studio flashlights with two medium-size softboxes for taking care of the harsh shadows and ensure even illumination conditions were employed. The digital images were acquired in such a way to ensure enough overlap thus enabling their correct alignment, i.e. the orientation of the images. In Figure 19 two such images are presented.



(a)



(b)

Figure 19: Two overlapping digital images of the main tomb entrance: a) left and b) right images

Terrestrial laser scanning the two tombs was also conducted. Although image-based modelling with digital images could be sufficient, experience with previous implementations has shown (Tapinaki et al., 2019; Moropoulou, Georgopoulos, Korres, Spyarakos, & Mouzakis, 2017) that for determining the surface of the object laser scanning delivers equally accurate but crisper point clouds compared to the Structure from Motion-MultiView Stereo (SfM-MVS) procedure. The point cloud acquired with the FARO terrestrial laser scanner was later completed by sections of the image-based point cloud to deliver the final surface for the rendering of the 3D model. It was decided to keep the density of the point clouds to 3-5 mm. In order to align and georeference the individual scans FARO chessboard targets were put on the object. Their coordinates were also determined via geodetic measurements. Table 1 presents a summary of the data collection.

3.2 Creation of the 3D models

Contemporary practice tends to produce all 2D or 3D documentation products from the 3D models (Tryfona &

Table 1: Data acquired for the 3D documentation.

	No. Images	Size images (GB)	No. Scans	Size scans (GB)
Tomb of Heuzey	539	5.4	7	3.2
Tomb of Macridy Bey	546	5.8	15	6.4

Georgopoulos, 2016). This enables the production of any 2D product and the performance of any 3D additional measurements within the digital environment. For the creation of a 3D textured model, the description of the object's surface is required and, of course, reliable digital images should also be available to apply the texture. Producing a reliable description of the surface is not an easy task. Point clouds, either from terrestrial laser scanning or from SfM-MVS methods, need a lot of processing for removing the noise, cleaning the surface and, most importantly, completing the parts not described and filing the eventual holes. Specialized software is necessary for those actions.

In the case of the two Macedonian tombs, the acquired data were edited properly in order to create accurate 3D textured models. These textured models were utilized later for the virtual restoration, rather virtual anastylosis, for the two tombs.

The 3D model of the tomb of Heuzey was created by combing 3D information from point clouds produced with two different methods: image-based and range-based modelling. In range-based modelling FARO Scene® v.6 software was used for editing the point clouds acquired with the FARO terrestrial laser scanner. Chessboard targets were automatically detected and checked as the software may detect and interpret a different pattern as a target. Then the point clouds of the seven scans were registered with the use of common targets. Afterwards, the reduction of the noise from the point cloud was performed. Also, the point cloud was filtered so as to remove unnecessary scanned points. In case of a very complicated surface, this may lead to incorrect scanned points because of the deflection of the scan beam. The registration of the point clouds was performed successfully with a mean error of 1 mm. The mean distance error of the registered point clouds was 6.5 mm. Figure 20 illustrates the final registered and cleaned point cloud of the monument.

For applying the image-based modelling technique, Agisoft Photoscan® software v. 1.4 was used. Firstly, the images were inserted into the software in five different chunks each one corresponding to each different space of the whole monument. This separation was carried out for better control of the processing of the collected data. The same procedure was followed for each chunk. Firstly, masks were put on images in order to avoid unnecessary information in the produced point cloud. Then targets were automatically detected by the software and then their numbering and positions were checked. Common characteristic points were automatically detected and matched among the images in order to carry out the relative orientation, i.e. the alignment. The result of this processing stage is a sparse point cloud of the object. Coordinates of the control points were inserted for the absolute orientation of the images and the point cloud. Afterwards, the procedure of the creation of the dense point cloud was performed and the five chunks were aligned and merged

together in order to create the 3D point cloud for the whole monument.

Next, both point clouds from the range-based and the image-based modelling were inserted into Geomagic software v. 12 for further editing. Especially these point clouds were combined for the creation of the final 3D model of the tomb. The unnecessary information was removed, and the noise reduction was performed in the 3D point cloud. Then the 3D mesh of the monument's surface was created. The 3D mesh created from the laser scanner's point cloud presents local lack of information which occurred into gaps in the 3D mesh e.g. in cases of occlusions which block the

scanning procedure. In these cases, the point cloud created with image-based modelling was used for filling this lack of information. Also, the 3D mesh was edited in order to have the final 3D mesh of the tomb. The modern roof above the entrance of the tomb was removed from the final 3D mesh (Fig. 21) as it was scanned only from inside and in any case, it did not belong to the original monument being a temporary construction.

Then the 3D mesh was imported in Agisoft Photoscan for applying colour information, i.e. the photographic texture from the aligned images. Figure 22 presents the final 3D textured model of the tomb of Heuzey.

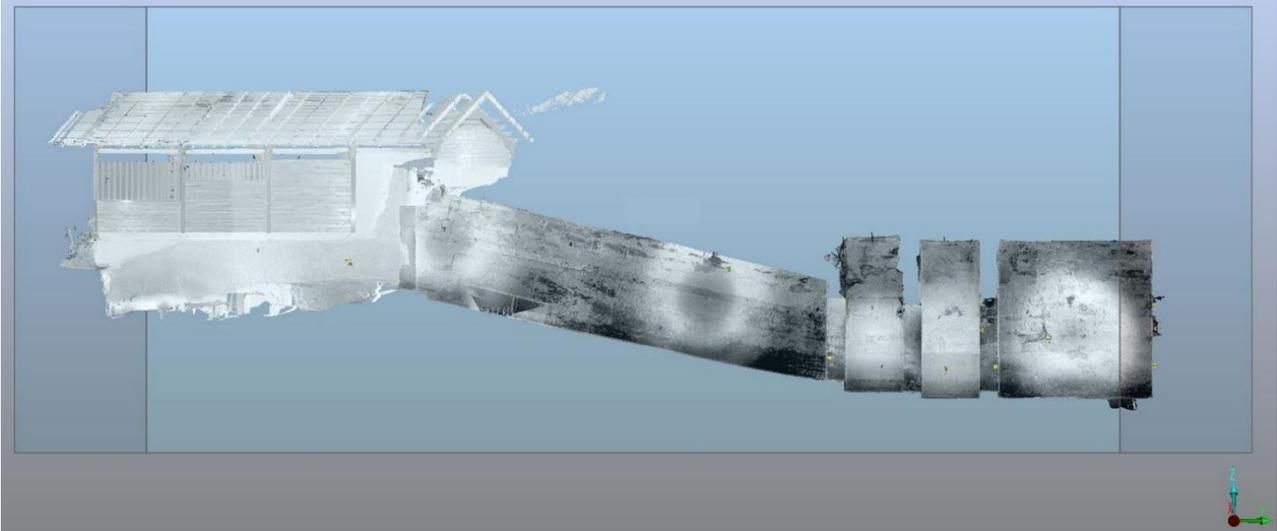


Figure 20: Final 3D point cloud produced by the terrestrial laser scanner (Toska, 2018).

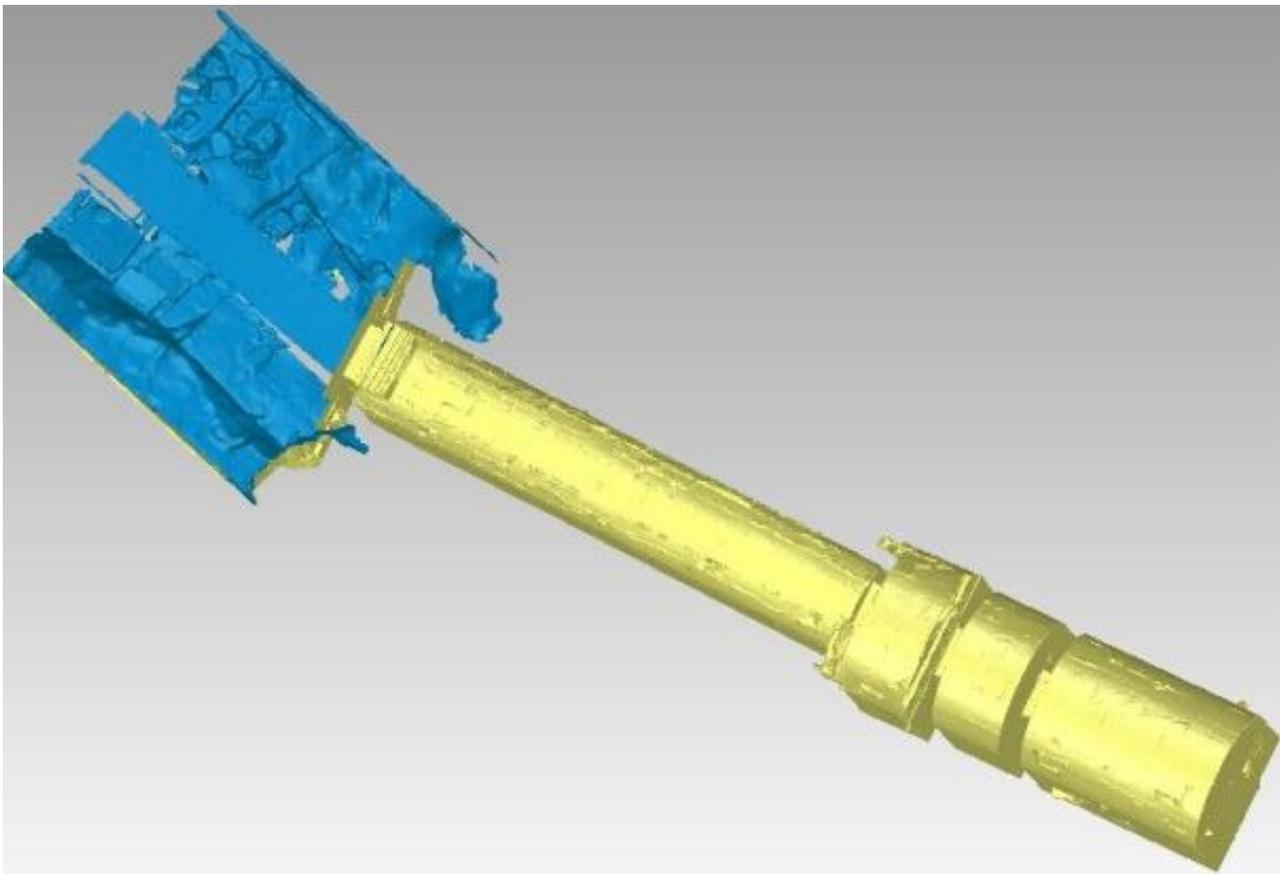


Figure 21: Final 3D mesh without texture (Toska, 2018).

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Figure 22: 3D textured model of the tomb of Heuzey. a) View from SE; b) View from SW (Stampouloglou et al. 2019).

The 3D model of the tomb of Macridy Bay was created solely with image-based modelling technique, as for the time being there was not enough time available to process the terrestrial laser point clouds, which will be done at a later stage. Thus, the procedure followed all standard stages of the SfM-MVS procedure using the Agisoft Photoscan software. In the case of the passageway of the tomb, i.e. the dromos, images could not be aligned because of the textureless surface of the walls of the dromos (Fig. 23) and the software was unable to detect and match characteristic points even with manually detected conjugate points. Processing was conducted in different chunks and after successful alignment, the different chunks were merged and dense point cloud and 3D mesh with texture were created (Fig. 24).

It should be noted that if it had been possible to process the laser scanner data, whose exploitation was considered unworthily time-consuming for the sake of the partial virtual anastylosis of the monument that was being attempted, the surface of the dromos would have been added to the 3D model.

4. Virtual anastylosis

According to the [Venice Charter \(1964\)](#), anastylosis of a monument is defined as the procedure of reassembling and repositioning of parts of the monument, which are lying around. If new material was used to support the anastylosis, it should be clearly

recognizable. However, anastylosis can be also carried out in a virtual environment. In this case, the correct term to be used is virtual anastylosis and the [Seville Principles \(2011\)](#) specifically mention the definition of this term. Especially, virtual anastylosis is the procedure of restructuring existing but dismembered parts in a virtual model.

Virtual anastylosis of a monument is either performed manually, meaning that the user puts the parts of the monument in their right position or automatically with the help of various algorithms. It is a very challenging procedure as it enables the creation of the 3D model of a monument or a part of it with the use of its original parts which should be 3D documented with appropriate accuracy. Virtual anastylosis is also helpful for performing anastylosis in a real environment. Interventions on monuments for their restoration should be performed with caution, while international conventions and widely accepted rules are observed. Decisions should be carefully taken and after ample time for opinion exchange and thorough examination of alternative solutions. For monument reconstruction, the preceding studies should be extremely careful, and all alternatives should be thoroughly examined.

Many projects of virtual anastylosis of a monument have been carried out in recent years. Canciani et al. (2013, 2014) developed a methodology for virtual anastylosis of archaeological elements which belong to the archaeological site of Circus Maximus in Rome.



Figure 23: Sample digital image of the dromos.



Figure 24: 3D model of the tomb of Macridy Bay (Stampoulglou *et al.*, 2019).

The anastylosis was based on the 3D models of fragments that were found at the site and they were 3D digitised. In another project, virtual anastylosis was carried out in the case of the architectural ornamentation of the Teatro Marittimo in Villa Adriana (Adembri, Cipriani, & Bertacchi, 2018). A virtual anastylosis of a Greek Archaic Statue coming from Ancient Sicily was carried out by Stanco *et al.* (2017). Thuswaldner *et al.* (2009) used digital technology in order to perform digital anastylosis at the Octagon Monument at Ephesus.

On the other hand, virtual restoration offers alternative solutions, as it moves the procedure in a virtual environment. This gives the opportunity to evaluate the different alternatives before any actual reconstruction on the monument. This practice has been attempted in the past in many cases with successful results (Lentini, 2009; Matini, Einifar, Kitamoto, & Ono, 2009; de Fuentes, Valle Melón, & Rodríguez Miranda, 2010; Patay-Horváth, 2011; Valle Melón, Lopetegi Galarraga, & Rodríguez Miranda, 2005; Kontogianni, Georgopoulos, Saraga, Alexandraki, & Tsogka, 2013).

The two reconstruction actions described in this paper are perfect examples for performing virtual anastylosis as the original parts had been moved either to museums or in a position different to the original one. These architectural elements are the two doors and the

burial beds of the tomb of Heuzey and the pediment of the Macridy's Bey tomb.

4.1. Virtual anastylosis of the Macedonian tomb of Heuzey

Two partial attempts for virtual anastylosis were carried out. The first attempt involves the two-leaved marble doors of the tomb's entrance. Archaeologists moved them at the sidewalls of the dromos while their real position, according to the first archaeologists who discovered the tomb, was at the entrance. The second attempt is about the front panel of the burial bed, whose decoration is a snake relief and which was moved by the looters from their initial position which was at the left corner of the chamber to the middle of the chamber (Figure 25).

The virtual anastylosis of the door's leaves (Fig. 26) and of the façade of the bed (Fig. 27) was conducted manually with the use of contemporary technological tools of the Geomagic software.

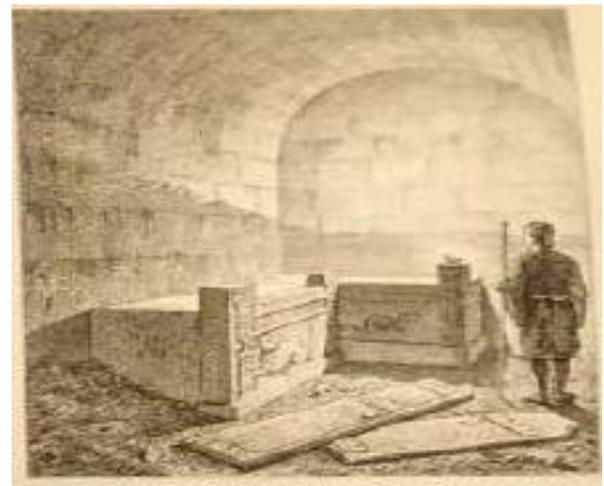


Figure 25: The chamber and the beds as found by the French in 1861 in the tomb of Heuzey (Heuzey & Daumet, 1877).



Figure 26: The virtual restoration of the marble door of the Macedonian tomb of Heuzey. The door leaves in their position today (top left) and the door leaves restored in their correct position (top right and bottom) (Stampoulglou *et al.*, 2019).

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Figure 27: The virtual restoration of the burial bed of the Macedonian tomb of Heuzey: a) The 3D model of the burial chamber without the marble bed; b) and c) The marble bed restored in two alternative positions (Toska, 2018).

4.2. Virtual anastylosis of the Macedonian tomb of Macridy Bey

Scattered blocks and other architectural elements of the tomb of Macridy Bey's façade were gathered and identified by archaeologists and conservationists who

were working for the restoration of the monument. Due to the deformation at the end of the façade's wall, the restoration was performed at the central part because it presents no deviation from the vertical alignment. The restoration work was about the two semi-columns, the northern side of the wall and the centre of the architrave. However, the restoring of the parts that have survived from the pediment's cornice was dangerous. For those reasons, these parts were put on a separate location, an artificial platform above the vaulted roof of the tomb. They were positioned in their original shape to give the idea of the form the pediment to the visitors. The virtual anastylosis of the pediment was carried out with the help of Geomagic software v. 12. The anastylosis of the pediment was partial and included the parts that were put on their right position with certainty and accuracy in order to improve the visual perception of the monument by the visitor. Figure 28 presents the pediment after the editing and before the translation.

3D models of the objects were translated to their original place and finally merged to the 3D digital model of the tomb (Fig. 29).

Today's visitors of the monument cannot easily comprehend the original appearance of the monument, as for safety reasons an actual physical restoration is prohibitive. The virtual anastylosis using Geomagic® software, enables them to grasp the full restoration of the pediment, whose original place was undoubtful, of the Macedonian tomb of Macridy Bey. Virtual anastylosis was performed with the *object mover* tool which allows the user to move or rotate an object manually. This command works on any type of object. The objects to be moved were isolated from the entire 3D model, moved to their original location and finally merged with the model (Fig. 28).

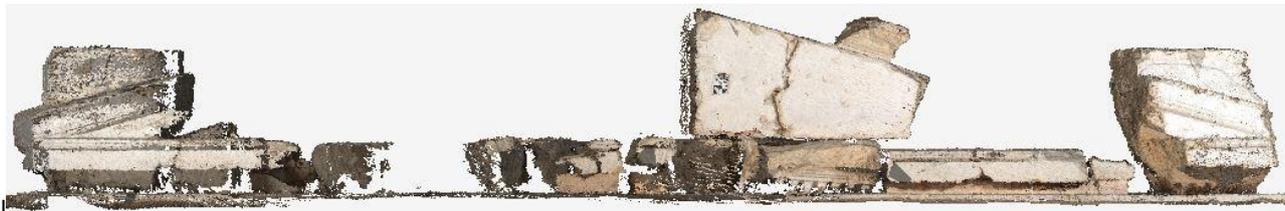


Figure 28: Pediment after the editing process (Stampouloglou, 2018).

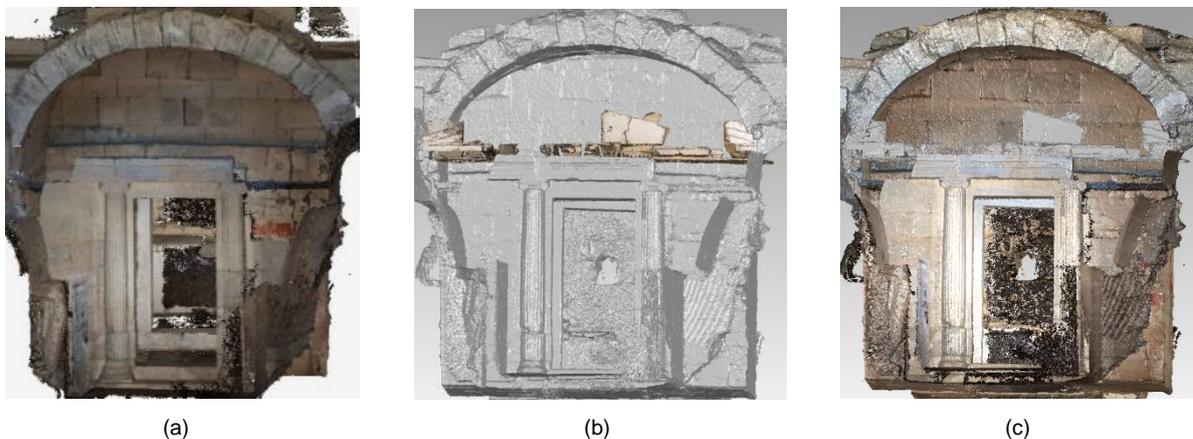


Figure 29: The virtual anastylosis of the Macedonian tomb of Macridy Bey: a) The 3D model of the façade; b) The 3D model of the pediment in its position; c) The reconstructed façade (Stampouloglou, 2018).

5. Concluding remarks

The virtual anastylosis of the two tombs using the 3D models produced by contemporary techniques of digital documentation is possible and can be successful. It has been established that interdisciplinary cooperation is of utmost importance for such tasks. Archaeologists and Geomatics Engineers have cooperated smoothly for this operation. Monument restoration and protection is an interdisciplinary process nowadays and all disciplines have a lot to contribute. Mutual understanding is of utmost importance.

In this article, the virtual anastylosis of two Macedonian tombs is presented. Especially it is attempted to reconstruct the tomb of Heuzey and the tomb of Macridy Bey by moving the displaced or misplaced

elements and positioning them in their original position by using digital tools. Their restoration could not be safely carried out because of obvious technical and safety reasons. Archaeological studies about these tombs are also a useful tool for their virtual anastylosis because they determine the most probable original position of the restored parts. These tasks have not interfered with the original monuments as they are now, thus enabling multiple alternatives to be studied.

For both cases, further actions could be proposed, namely the creation of 3D models of the parts exhibited in foreign museums, such as the Louvre and the Istanbul museums. These models could then be introduced into their original positions into the 3D models of the tombs in order to virtually restore the tombs completely.

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