



## BURIAL ARCHITECTURE. 3D DISSEMINATION STUDY FOR A SELECTION OF BYZANTINE GRAVES

### ARQUITECTURA FUNERARIA. ESTUDIO 3D CON FINALIDAD DIVULGATIVA PARA UNA SELECCIÓN DE SEPULTURAS BIZANTINAS

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#### Highlights:

- Contributing to Byzantine architecture classification in the Middle East, including specific case-studies, interesting both from archaeological and architectural research fields.
- Experimenting and investigating tools for the study, representation and conservation of archaeological finds, combining 3D digital and 3D printing mockups.
- Incorporating resources for promoting and disseminating archaeological and architectural heritage, raising awareness among local Syrian population and authorities, allowing them to rediscover their own heritage, often neglected.

#### Abstract:

The former *polis* of Tall-as-Sin (in the current province of Deir ez-Zor, Syria) grew considerably during Justinian's reign in the 6<sup>th</sup> century AD. Its cemetery, outside the walls, presents an extraordinary Byzantine necropolis, where 163 hypogea graves were documented, thanks to recent archaeological campaigns financed by the Ministry of Culture (PAMES-Sirio Euphrates Middle Archaeological Project). This paper presents the research for obtaining three-dimensional (3D) models of graves, selected in the cemetery, by combining information (obtained from planimetric and photographic surveys of the site) with taxonomic features (types of arcosolia, vaults, accesses, stairways...). The 3D modelling process is carried out using data collected during the survey of the graves. These data are then used to restore the surfaces which cover the burial chambers dug out in the ground. The modelling technique was based on generating surfaces, incorporating the different sections and profiles obtained during the data collection phase. The surfaces generated enclose the volume of the dug-out space so that the definitive grave models were obtained using a simple Boolean operation, removing these volumes from a prism-shaped piece representing a portion of the land, thus emptying the interior. The result has provided a reliable and rigorous graphic basis for the design and printing of 3D mockups, contributing to the dissemination of the exhibition called "A retrospective on five years of archaeological activities in Syria".

**Keywords:** Byzantine necropolis; previous studies; 3D reconstruction; mockups

#### Resumen:

La antigua *polis* de Tall-as-Sin (en la actual provincia de Deir ez-Zor, Siria) cuenta con un importante desarrollo durante el reinado de Justiniano, durante el siglo VI d.C. Su cementerio, en la zona *extramoenia*, alberga un extraordinario conjunto funerario bizantino, con 163 hipogeos documentados hasta la fecha, gracias a recientes misiones arqueológicas, financiadas por el Ministerio de Cultura (PAMES-Proyecto Arqueológico Medio Éufrates Sirio). En este trabajo se presenta la labor realizada para modelar en 3D una selección de las tumbas más significativa del conjunto. Esto ha sido posible combinando información obtenida mediante el levantamiento planialtimétrico y fotográfico del lugar y realizando ábacos y taxonomías de los distintos recursos constructivos empleados (tipos de trazados de arcosolios, bóvedas, accesos, escalinatas...). El procedimiento de modelado tridimensional (3D) se inicia a partir de los datos recabados durante el proceso de levantamiento de las tumbas, con los que se logra restituir las superficies que constituyen la envolvente de cada una de las cámaras funerarias excavadas en el terreno. La técnica de modelado empleada se basó fundamentalmente en la generación de superficies mediante la interpolación entre las distintas secciones y perfiles obtenidos durante la fase de toma de datos. Las superficies así generadas encierran el volumen del espacio excavado, por lo que el modelo definitivo de las tumbas se consiguió mediante una sencilla operación booleana; esta consistió en sustraer estos volúmenes a una pieza prismática que representa una porción de terreno, obteniendo, de este modo, el vaciado del espacio interior. El resultado ha permitido tener una base gráfica fiable y rigurosa para idear e imprimir maquetas 3D, contribuyendo así a la labor de divulgación de la exposición denominada "Una retrospectiva sobre cinco años de actividades arqueológicas en Siria".

**Palabras clave:** necrópolis bizantina; estudios previos; reconstrucción 3D; maquetas

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## 1. Introduction and framework of study

Between 2005 and 2010 a research group from Universitat Politècnica de València, under the direction of Fernando Vegas and Camilla Mileto, collaborated actively in different excavation campaigns and archaeological studies together with Syrian organizations, led by Juan Luis Montero Fenollós of Universidad de la Coruña and Sylvie Blétry-Forestier (2015) of Université Paul Valéry de Montpellier.

Within this framework, the team has collaborated yearly in the PAMES (Archaeological Project for the Syrian Middle Euphrates) archaeological campaigns funded by the Ministry of Culture.

In the initial years of the campaigns, archaeological surveys were carried out in different *tell* of the Middle Euphrates (2005-2007), in the north of the city of Deir ez-Zor, including a detailed study of the Byzantine necropolis of Tall-as-Sin (2005-2007).

At the same time, the team also took part in a study on the Byzantine city of Zenobia (currently Halabiyé), funded by the Université de Montpellier (2007-2010), the Sénat Français (2008), and the French Ministry of Culture (2008-2011) (Fig. 1).

Using resources from the field of architecture and prior related studies, the basic common objective of these archaeological campaigns has been to expound on a region which has barely been researched by modern archaeological science (Talaverano, 2014).



Figure 1: Team of the Syria campaign, summer 2006.

## 2. Christian and Byzantine architecture in Syria

In most architectural terms, the most important finds of these campaigns have been linked to the heritage of the *polis* in the Byzantine era (Sartre, 2011). Without doubt, Syria is one of the most interesting cases for the study of this architecture, as an enclave which was a point of articulation between cultures and religions. Therefore, the importance of Syria can be defined by its merging East and West, and the hybrid nature of its architecture, particularly during the reign of Justinian in the 6<sup>th</sup> century AD.

Justinian's reign is remembered for the ambitious *Renovatio Imperii Romanorum*, a political project to reform the Empire by partially reconquering territories in the West and consolidating *romanitas*. This traditional form of customs, cultures and policies was to be promoted

in all the *poleis* of the Empire, especially in the areas of *limes*, as in the case of the Euphrates river.

Therefore, the efforts of the research teams focused on a specific sector of this river valley, between its two main affluents: Balih and Habur, in the current province of Deir ez-Zor (southeast Syria). This particular area is one where major Byzantine nuclei appeared, although the main studies to date (Mango, 1985, Dentzer J.M., & Orthmann W., 1989) do not provide in-depth details, meaning that there are major gaps in the research on this stretch of the river. In his panegyric opus for the Emperor Justinian (*De Aedificiis*), Procopius of Caesarea describes numerous fortified citadels, showcasing extraordinary stonework (Bessac 1999-2005) seen in religious and military buildings, defensive walls, and different infrastructures (including burial sites) in these regions. Callinicum, Al Kasreh, Tabus, Zenobia, Circesium, Zalabiye and Tall-as-Sin (Fig. 2) are some of the enclaves fortified by Justinian on the eastern borders of the Empire (Krautheimer, 1989).



Figure 2: Location and localization map for the archaeological enclave of Tall-as-Sin.

### 2.1. Data Collection: the enclave of Tall-as-Sin

Tall-as-Sin is an archaeological site (Fig. 3) on the left bank of the Euphrates, 10 km southeast of Deir ez-Zor. This 25-hectare settlement is one of the Byzantine nuclei mentioned above and grew from an ancient Neolithic village (Fenollós et al., 2008). In the late 1970s, partial excavation work started on some of the graves. These excavations were later restarted in 2003 by Syrian teams in an effort to stop looting.

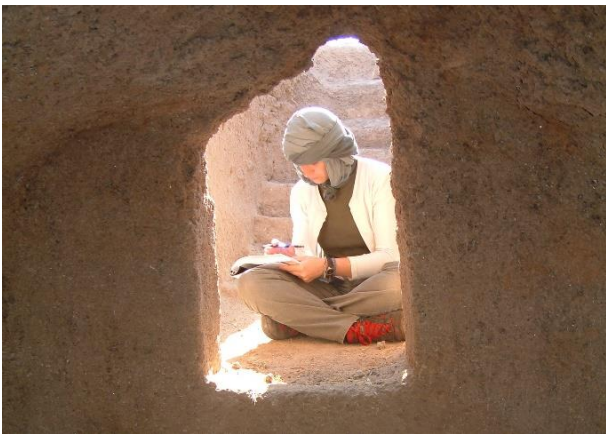
Thanks to the campaigns in Spanish-Syrian missions, in the last decade the excavation was completed on different hypogea. Thus, 163 graves were documented, making it possible to learn about an impressive burial complex from the Justinian era located outside the lines of the wall which protected the former *polis*.

For this, a topographical study was completed with detailed plans of all accessible graves, and different graves looted over the years were excavated and re-excavated to obtain first-hand information on anthropological and funeral ritual aspects. Image-based surveys have been employed for these data collection processes. Photographic images have been used to generate the required details, presented in either a line drawing or scaled image format, as previously published at length by the authors (Vegas et al., 2008-2011).





(a)



(b)



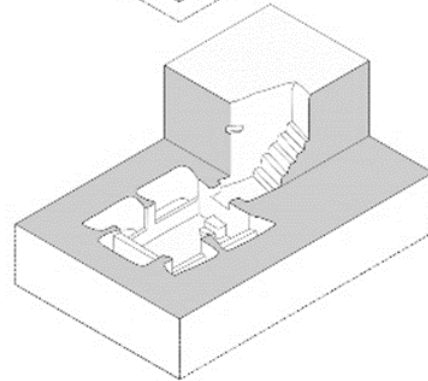
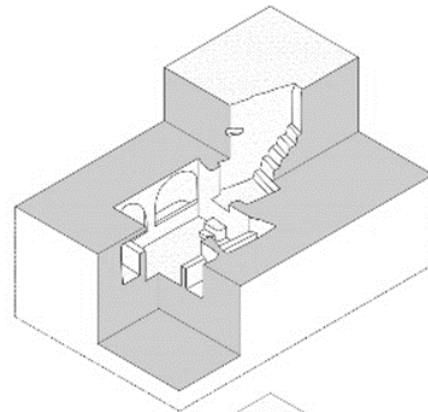
(c)

**Figure 3:** Details about Tall-as-Sin archaeological necropolis (hypogea graves): a) Grave no. 121; b) Grave no. 75; c) Grave no. 89.

Given the technological limitations resulting from the location's socio-economic and social conditions in Syria, the objective proposed was to promote heritage using traditional data collection, analysing the topography with the LEICA geosystems station and photo-rectification of the parallel planes.

As it was also absolutely impossible to use remote acquisition techniques such as drones and 3D laser scanners, rectification provides an alternative to help understand some of the elements and complement the measurement. Given the organic nature of the most deteriorated surfaces, manual construction tools were needed to establish level vertical and horizontal lines of reference. The images were obtained using a camera and calibrated with photogrammetric rectification software.

Major comparison and taxonomic work has been carried out on these hypogea during these campaigns, documenting studies of the different constructive resources used (for example, in the types of the tracery of arcosolia, vaults, accesses, stairs...Vegas *et al.*, 2007). The *in situ* study of these factors and the documentation work of the type of masonry and excavation tools used have made it possible to identify a rather uniform and iterative type of hypogea (Fig. 4).



(a)



(b)

**Figure 4:** Volumetric development for understanding the real fillings-voids ratio of the tombs in order to produce a mockup: a) Example of a grave with 5 arcosolia; b) Example of a grave with 3 arcosolia.

This Byzantine cemetery has only five graves in pits, while the remaining 158 hypogea have stepped up to the open air, going from West to East, leading to a landing and an entrance which is closed off with an organic limestone slab.

Through this entrance, a central space characterized by three arcosolia facing south, north and west, with niches

for burials, is accessed. There are few variants and exceptions in terms of the number and position of the *arcosolia*, although there are different forms of execution, tracery and digging out volumes, usually after having extracted 13.5 m<sup>3</sup> of rock (Mileto et al., 2018). The ground measurements of the graves range from 2.26 m<sup>2</sup> to 5.70 m<sup>2</sup> in the larger ones, which are characterized by finishing details such as basket-handle arches, pillars, inscriptions, and painted or engraved symbols showing an aspiration to painstaking execution. The architecture and typology of these funeral complexes undoubtedly justify a detailed scientific examination of funeral liturgies that are thousands of years old.

### 3. Methodological proposal: from education to dissemination

Heritage is an indispensable element in understanding past civilizations, and becomes even more important when it covers tangential cultural forms such as anthropological rituals and traditions. This is the case of architecture in the Middle East, where the many cultural strata are reflected in surviving extraordinary constructions.

Unfortunately, the systems for the valorization and protection of these architectural legacies in Syria have been, and continue to be, complicated by continuous political instability, natural disasters (Reda et al., 2005), and violent episodes of plundering and looting. Although conflicts have clearly complicated these archaeological campaigns and conservation initiatives, these studies have not been in vain.

Major aspects of the constructive features of Byzantine architecture have been classified and compared, painstakingly revealing and documenting constructive details, materials, and technologies which previously had barely been studied (Laufray 1983-1991).

We must also acknowledge that the difficult political situation in the country has acted as a catalyst for the task of the dissemination of the Byzantine heritage legacy in regions around the river Euphrates.

Internationally, these efforts have translated into the extensive scientific literature on the results of these campaigns (with monographs, articles, publications, websites, conferences... as described in Vegas et al., (2011), Bletry et al. (2015), and Mileto et al. (2008).

Recently a decision was made to add a new perspective to this task, that of disseminating heritage. The promotion of scientific results is for a specialist audience, well-versed in the topic. However, dissemination is geared towards more general public, interested in a simplified faithful representation that has been adapted to appeal to it.

For this reason, an itinerant exhibition has been set up. "A retrospective on five years of archaeological activities in Syria" shows panels and mockups which allow interested groups to closely examine the subject matter by displaying the constructive legacy of Byzantine funeral architecture in Syria.

Based on the data collected during these campaigns, and given the impossibility of returning to the sites for further data collection with the latest technology, the research team has set out to use the existing documentation to recreate 3D models that are as faithful as possible.

The aim was to recreate 3D mockups of the typologies of the tombs excavated based on computer-aided models. This action also allows the general public to get a closer look at the surprising system of dug-out architecture of the funeral complex of Tall-as-Sin. Dissemination begins when the communication of a scientific fact is no longer exclusively reserved to members of the research community but takes on a collective dimension (Calvo Hernando, 2001). The exhibition aspired to use 3D models to raise awareness and help professionals and others to decipher the characteristics of the necropolis.

#### 3.1. Archaeology, dissemination and 3D resources

The diorama was the precursor of the 3D representation of a possible archaeological reality. This system translates into the careful positioning of figures carrying out different archaeological tasks (measuring, filtering, drawing, taking photographs, excavating, etc). Objects are added in simulated settings, painstakingly recreating highly detailed, albeit simplified and schematized, scenarios in order to capture the interest of the public.

In recent decades this solution was rendered practically obsolete by the introduction of 3D graphic virtual reconstruction and recreation of many archaeological enclaves and associated remains.

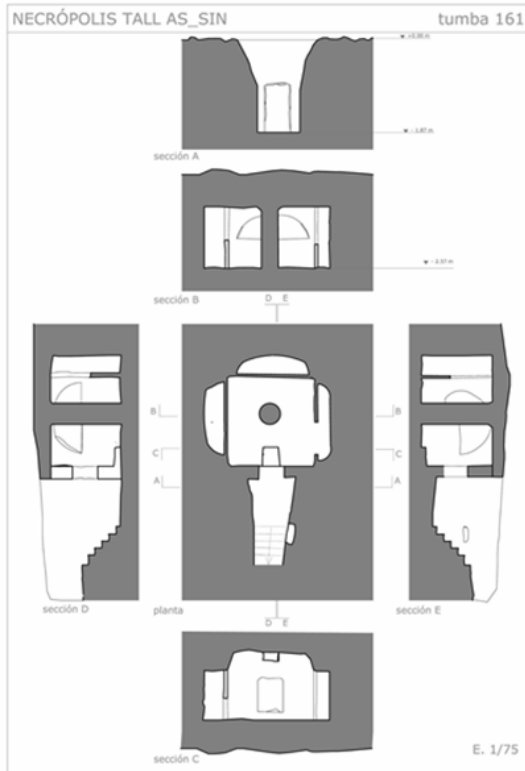
In the field of education, mockups are considered useful and proven resources for aiding understanding of complex archaeological settings. 3D presentation helps to show the scale, proportion, volume, and meaning of settings which have been anthropized to varying degrees with different finds and states of conservation (Henson, 2004; Tryfona et al., 2014).

In architecture, models are tools for project planning to be used before or during the process for generating a design, depending on the circumstances. They are used as resources for checking volumes and the efficiency of spaces, shapes and ratios.

They are also practical for identifying routes or defining the scale of a given built element in relation to its territory, landscape, or urban layout. They can generate architectural spaces independently of other resources such as computer-aided drawings or diagrams. All three options explained fulfil different tasks and are also necessary for the spatial control of projects. For archaeological settings, models are usually produced following project and excavation work. Their role, therefore, is not project planning but rather to aid understanding of a context which has been revealed with varying levels of conservation. In archaeology, mockups are used to present and explain possible finds. The integrity of the archaeological sites sometimes hinders the correct establishment of ratios and parts. The models can thus also reflect volumes which have been lost and help to understand poorly conserved constructive or typological hypotheses (Fig. 5).

In both architecture and archaeology, the typological classification of models can be summed up as a series of tectonic elements, bodies, surfaces and bars, which are interlinked or combined. Based on these premises and five basic variables (shape, size, volume, orientation and texture) the results needed to reflect an abstract but faithful representation of an architectural or archaeological element can be obtained (Knoll & Hechinger, 2001).





**Figure 5:** Examples of planimetric measurements carried out to study the graves of the necropolis of Tall-as-Sin (Grave no. 161).

Depending on the different models can be topographical (for example, of a given territory, landscape, garden); architectural (of an urban setting, building, structure, interior space, or detailed view); or special (of objects, furniture or individual pieces). Over the years, the materials and technology used in the execution of models have changed, as have the speed and accuracy of the results, although mockups continue to fulfill their role. While mockups are used as tools, they are also the result of a design and planning operation. Dug-out architecture is especially hard to reproduce and model with suitable graphics (Hupperetz *et al.*, 2012; Iturbe *et al.*, 2018). A series of preliminary operations are necessary to restore the correct volumes (Valle *et al.*, 2005; Lentini, 2009; Lerma *et al.*, 2014, Banfi *et al.* 2019), as described below for the project for the models of the funeral complex of Tall-as-Sin.

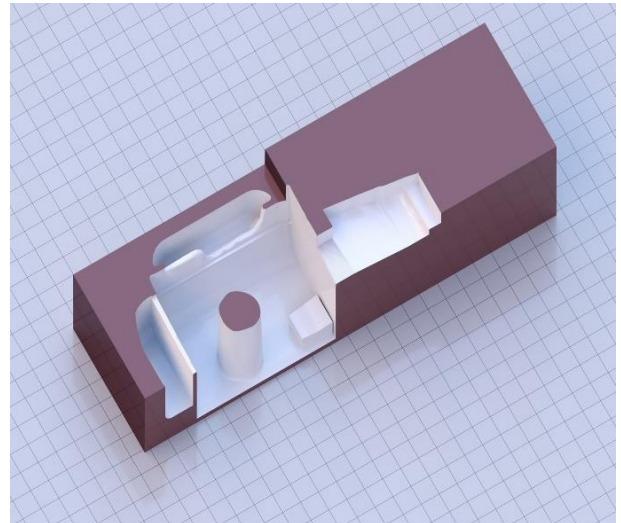
#### 4. Production of 3D digital and 3D printing mockups

In recent decades the world of cultural heritage and archaeology has made full use of 3D methodologies (Kuzminsky *et al.*, 2012, Ponchio *et al.*, 2020). The aim of this is three-fold: to improve the methods for documenting fieldwork (for a better recording, conservation, preservation and restoration of movable and immovable cultural heritage); to open up new lines of study (in order to further explore and advance in the research of the historic, monumental, artistic, architectural and archaeological records); and to make the results of the research and the heritage assets themselves more accessible and appealing to society to update the forms of dissemination using contemporary technologies in line with the actual profile of the society". Based on the above

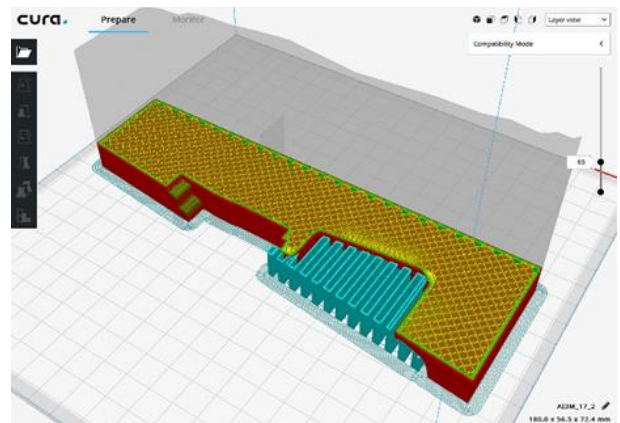
a 3D digital model was produced for the typologies most commonly found in the enclave of Tall-as-Sin.

The 3D digital modelling process is carried out using data collected during the survey of the graves. These data are then used to restore the surfaces which make up the envelopes of the burial chambers dug out in the ground. The modelling technique was based on generating surfaces, incorporating the different sections and profiles obtained during the data collection phase. Using AutoCad version 22.0 by Autodesk CAD software and a set of sections of the grave it was possible to obtain an interpolated 3D surface of the internal morphology of the burial by carrying out a loft operation (an action that helps to create a 3D solid or surface by specifying a series of cross-sections). The Loft command also allows the addition of guides to increase the accuracy of the interpolated surface, so that some additional sections, which were orthogonal to the previous ones, were used in order to obtain a more accurate result.

The surfaces generated enclose the volume of the dug-out space so that the definitive models for the graves were obtained using a simple Boolean operation, removing these volumes from a prism-shaped piece representing a portion of the land, thus emptying the interior. Moreover, some photorealistic renders of the models were produced using 3DSMax and Arnold Render engine 5.0 for a better understanding of the internal morphology of the graves (Fig. 7).



**Figure 6:** Fragment of one of the models generated.



**Figure 7:** Model filleting process using Cura software.

These digital 3D models became “real” by using the 3D printing technique, currently one of the most used rapid prototyping processes. The models were produced using FDM (*Fused Deposition Modelling*), one of the techniques most commonly used for its affordability and versatility.

This technique consists of the construction layer by layer of the model using the fusion of a plastic material filament, usually Poly(lactic acid) (PLA) or Acrylonitrile Butadiene Styrene (ABS), at around 200°C. In this case, PLA was selected as the construction material for several reasons. Firstly, the fumes emitted by PLA are less toxic than ABS fumes during the fusion process. Furthermore, during the printing process, PLA is less susceptible to deformation than ABS.

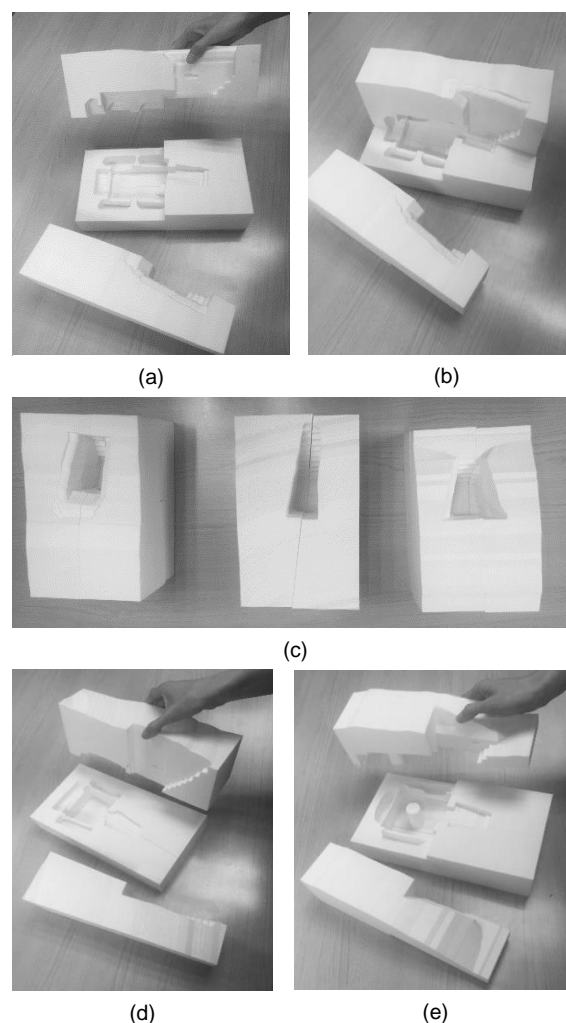
These deformations are mostly caused by stress accumulated when a piece is being printed, due to the thermal difference between layers which can lead to warping in the lower layers, causing the model to become detached from the print bed. In order to prevent this it is essential to increase the model's adherence to the print bed through the preferential use of hot bed printers, whose resistance heats the printing medium to approximately 60°C, guaranteeing greater adherence to the printing base. In the absence of a hot print bed, other possible solutions are the use of adhesive aerosols on the print bed or increasing the contact surface with the bed model using a wing or sufficiently wide flap attached to the outline of the piece in the first few layers of printing. This flap is removed from the model once the printing is complete.

The printing parameters in the software in charge of sending the piece to the 3D printer must be established correctly in order to ensure a good finish. This software fillets the model depending on the layer height desired.

For highly accurate definition the layer height can be set to 0.1 mm, although the printing process is layered considerably with this configuration. Therefore, a layer height of 0.2 mm is an intermediate solution which provides a high-quality finish in an acceptable length of printing time. Other relevant parameters to take into account are the density of the model infill and the thickness of exterior walls. In this case, a wall thickness of 1.5 mm and an infill density of 15% were selected to save on material and reduce the printing time to obtain a sufficiently rigid and opaque model. Figure 7 shows the model slicing process using Cura printing software, currently one of the most popular forms of printing software. The horizontal section reveals the internal structure of the printed piece, while a grid pattern with the specified density is used in infill areas. The support structure, used as temporary support for overhanging sections of the model during the printing process, can be seen in light blue. This auxiliary structure is later removed from the printed piece with relative ease, providing the separation has been adjusted properly to the model walls (Fig. 8), as otherwise both structures may be strongly fused together and difficult to extract.

As these are underground constructions, the spatial configuration of the graves is hidden inside the block of surrounding land. This makes it practically impossible to observe the interior structure of chambers from the outside, while the inside can only be glimpsed through the narrow entrance opening.

Thus, zigzag cuts were used for each individual model to divide them into independent pieces which can be opened to show the interior configuration of the graves.



**Figure 8:** Resulting mockups with the option of assembling/dismantling into 4 blocks, printed at 1:100: a) and b) Grave with 5 arcosolia; c) Set of mockups to show the entrances to the graves; d) Grave with three arcosolia; e) Grave with three arcosolia plus a central pillar.

## 5. Discussion and conclusions

The use of mockups for dissemination continues to be an important resource which does not go out of fashion. Historically, mockups have proved to be clear precursors of modern information systems (Rossi & Cabezos, 2018). Nowadays, the production of mockups is simpler and more accurate than ever thanks to 3D modelling tools and new rapid prototyping systems such as 3D printers, whose great potential and usefulness in the field of archaeology has also been proven (Boochs et al., 2014).

Digital 3D models are contributing to many disciplines, especially archaeology, as they allow a wider audience to access archaeological and geometric information easily while offering endless possibilities for interaction (Stampoulglou et al., 2020).

In this particular case, the mockups and modelling by researchers are for education and dissemination purposes rather than for the intervention and conservation of graves. This explains the accuracy

(Statham, 2019) of these mockups, in keeping with their documentary and study dissemination purposes. However, the existence of digital models, besides these physical media, further contributes to different ongoing studies by the research group, examining burial architecture in other sites in the Middle East, including the city of Zenobia (currently Halabiyé) in Syria, (Vegas *et al.*, 2011) and Tell Keila in Palestine (Manzano *et al.*, 2019-2020).

Other graves (built family mausoleums and burial sites in caves or shelters, completely or partly dug-out) have been found in both these enclaves. The aim of expanding these case studies is to continue to generate scale digital and printed 3D models. In turn, this should make it possible to continue this research for the classification of funeral architecture in the Middle East, with a specific emphasis on comparative typological and spatial studies.

Therefore these models are not designed with project planning in mind but rather to help understand a context which has been uncovered with varying levels of conservation. In this case, 3D models (digital and scale ones) are used to present and explain possible variations in grave typologies both to specialist and general audiences. Although 3D models could be consulted on the screen if they were printed in 3D so that they could be handled by a general audience, including children and older people who may otherwise have been unable to access digital technologies or to understand space through them. Furthermore, in the future if possible, these models should be used to raise awareness among the local population and authorities, allowing them to rediscover their own heritage, often neglected.

Directly handling the printed 3D model makes it easier to understand its underground volume, spatial organization and dug-out architecture. This improved understanding of the heritage object results in its greater valorization and in turn encourages the involvement of the local community in its conservation. This action does not aim to museumize these elements but rather to contribute to their valorization and conservation through a guided interpretation of local heritage.

The integrity of the archaeological sites sometimes hinders the correct establishment of ratios and proportions. However, the models can also reflect volumes which have been lost and help to understand poorly conserved constructive hypotheses.

The mockups reflect the monolithic terrain, which makes it impossible to detect the interior structure of chambers seen from the outside as the inside can only be glimpsed through a narrow entrance opening. Zigzag cuts were therefore made to efficiently divide the models into four

completely independent pieces. This combination of a prismatic and abstract exterior with an articulated interior is an innovative feature of all the mockups. Furthermore, the examples produced display subtle differences (including in arcossolia, types of niches, inclines in staircases, means of access, presence of steps and dug-out volumes) which can be compared through 3D analysis.

Bearing in mind the dissemination approach and the difficult circumstances of these war-torn locations, the mockups are useful tools which can help support future architectural and archaeological typological studies. These examples of dug-out architecture are hard to explain, visualize, and fully understand (as they alternate infills and voids with negative spaces caused by the removal of earth, with irregular entrances and stairs). However, inside there is an almost constant tendency to imitate the formal coding system of built architecture (including arches and vaults) which can be fully expressed by a mockup. In the case of the graves of Tallas-Sin 3D printing has helped to configure these spaces moulded and hollowed out from the terrain, using high-quality 3D models adapted to these cultural heritage artefacts. The proper use of "digital instruments" in this approach has made it possible to produce models and detailed comparisons between these examples of dug-out architecture of this necropolis, one of the most important in the Fertile Crescent in the Middle East.

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