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3D SURVEY FOR THE ARCHAEOLOGICAL STUDY AND VIRTUAL RECONSTRUCTION OF THE SANCTUARY OF ISIS IN THE ANCIENT *LILYBAEUM* (ITALY)

LEVANTAMIENTO 3D PARA EL ESTUDIO ARQUEOLÓGICO Y LA RECONSTRUCCIÓN VIRTUAL DEL SANTUARIO DE ISIS EN LA ANTIGUA* LILYBAEUM *(ITALIA)

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Highlights:

- 3D survey for archaeological building reconstruction and documentation.
- Close-range photogrammetry applied to floor surfaces for recording and virtual reconstruction with realistic textures.
- Use of virtual reconstruction approach as an effective tool for enhancing valorization and knowledge of archaeological remains.

Abstract:

In recent years, the use of three-dimensional (3D) models in cultural and archaeological heritage for documentation and dissemination purposes has increased. New geomatics technologies have significantly reduced the time spent on fieldwork surveys and data processing. The archaeological remains can be documented and reconstructed in a digital 3D environment thanks to the new 3D survey technologies. Furthermore, the products generated by modern surveying technologies can be reconstructed in a virtual environment on effective archaeological bases and hypotheses coming from a detailed 3D data analysis. However, the choice of technologies that should be used to get the best results for different archaeological remains and how to use 3D models to improve knowledge and dissemination to a wider audience are open questions. This paper deals with the use of terrestrial laser scanners and photogrammetric surveys for the virtual reconstruction of an archaeological site. In particular, the work describes the study for the 3D documentation and virtual reconstruction of the Sanctuary of Isis in *Lilybaeum,* the ancient city of Marsala (southern Italy). The Sanctuary of Isis is the only Roman sacred building known in this archaeological area. Based on the survey data, it has been possible to recreate the original volumes of the ancient building and rebuild the two best-preserved floors –a geometric mosaic and an *opus spicatum*– for a first digital reconstruction of the archaeological complex in a 3D environment.

Keywords: 3D survey; virtual reconstruction; terrestrial laser scanner; close-range photogrammetry; archaeology; mosaic

Resumen:

En los últimos años, el uso de los modelos tridimensionales (3D) en el patrimonio cultural y arqueológico para los propósitos de documentación y difusión están aumentando. Las nuevas tecnologías geomáticas han reducido significativamente el tiempo de trabajo de campo y procesamiento de los datos. Los restos arquitectónicos se pueden documentar y reconstruir en un entorno digital tridimensional (3D) gracias a las nuevas tecnologías de levantamiento 3D. Además, los productos generados con las tecnologías modernas de levantamiento se pueden reconstruir en entornos virtuales a partir de bases e hipótesis arqueológicas sólidas que provienen de un análisis detallado de los datos 3D. Sin embargo, la elección de las tecnologías que se deberían usar para obtener los mejores resultados en diferentes objetos y cómo los modelos 3D para mejorar el conocimiento y la divulgación a un público más amplio son cuestiones abiertas. Este artículo aborda el uso de los escáneres láser terrestre y de los levantamientos fotogramétricos para la reconstrucción virtual del Santuario de Isis en *Lilybaeum*, la antigua ciudad de Marsala (sur de Italia). El Santuario de Isis es el único edificio sagrado en la ciudad romana en esta área arqueológica. Sobre la base de la toma de datos, es posible recrear los volúmenes originales del edificio antiguo y reconstruir los dos suelos mejor conservados, un mosaico geométrico y un *opus spicatum*, para una primera reconstrucción digital del complejo arqueológico en un entorno 3D.

Palabras clave: levantamiento 3D; reconstrucción virtual; escáner láser terrestre; fotogrametría de objeto cercano; arqueología; mosaico

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1. Introduction

New geomatics techniques have significantly reduced time-consuming fieldwork for archaeological buildings documentation. An example of the potentialities offered by the new recording technologies is the creation of 3D models of the archaeological heritage through range-based and image-based systems (Remondino & El-Hakim, 2006). Their use is a widely discussed topic in both archaeological literature and practice of the last decades (Galeazzi, 2016; Sapirstein & Murray, 2017; Historic England, 2017; Historic England, 2018). However, it should be underlined that not all the recording systems have the same features.

Terrestrial Laser Scanner (TLS) acquisitions are the most accurate geometrical data among modern range-based systems, but its capability to capture textures and colour information it is not yet so reliable. Photographic cameras integrated on TLS are often inadequate to reproduce rich decorative and detailed compositions. Thus, no high-quality textures using the RGB (Red, Green & Blue) values acquired by TLS can be created –despite it is possible to map RGB values of the point cloud– without high-resolution images from an external camera. Otherwise, photogrammetry produces highly detailed photographic textures and reliable ortho-images, enabling deepest analyses especially for detailed surfaces, like a mosaic or a fresco (Lo Brutto & Dardanelli, 2017; López-Martínez, Calvo-Bartolomé, & García-Bueno, 2019). Due to these differences, photogrammetry and TLS are often integrated to produce a unique detailed 3D model of an archaeological building or site (Grussenmeyer et al., 2011; Fiorillo, Jimenez, Remondino, & Barba, 2013). In many cases, the combination of both surveying techniques concerns the digital images employment onto the range-based 3D model, where images are used to improve the realistic perception of the scene (Lerma et al., 2011).

Thus, evaluating potentialities and limits between the two approaches and considering the difference of each case study, the right choice on the most appropriate technique should be done. A poorly accurate survey can lead to the loss of relevant information for archaeological analysis, also precluding the re-use of these products for further purposes. Otherwise, highly detailed surveys can allow detecting smallest features, offering the deepest analysis on specific elements, useful not only for better documentation but also for conservatives aims or detailed virtual reconstructions (Tucci, Bonora, Conti, & Fiorini, 2017).

Accurate 3D documentation is also constituting a central step in the field of archaeological Virtual Reconstruction (VR). The remains still *in situ* or special finds collected during the excavations are considered as objective sources in the reconstructive process (Demetrescu & Fanini, 2017). Their 3D models in virtual environment modelling have great importance in order to achieve a more realistic scenario, closer to the historical reality. Different sources (drawings, descriptions, comparisons with similar elements) can thus be harmoniously integrated within the 3D models of the current remains to rebuild graphically the archaeological heritage starting from a reliable basis.

Many laboratories and institutions have been using 3D scanning systems and 3D modelling techniques to document and disseminate information on particular archaeological sites in both cultural and scientific domains (Ercek, Viviers, & Warzé, 2010; Denker, 2017; Younes et al., 2017; Gabellone, Ferrari, & Giuri, 2017; Gherardini, Santachiara, & Leali, 2019). However, despite the great number of opportunities that come from VR, this research field is still strongly influenced by the unscientific approaches applied to the archaeological contexts and by the lack of a shared and easily useful methodology that can be used in different case studies. In order to emancipate VR works from its aesthetic value, to assume the role of an effective tool for scientific analysis in archaeology, researchers have addressed the problem concerning the process behind VR (Demetrescu, 2018). They were developed new semantic languages, as the use of stratigraphic archaeological terms and methodology (Demetrescu, 2015), and new workflow to define VR application at the archaeological heritage (Kuroczynsky, 2017). But, at present, there is no shared methodology behind most VR works; this is due both because software packages (commercial and open-source) allows anyone to essay this type of activity, and because often ontologically valid methods are complex, discouraging their application.

VR activities can provide valuable new information for the knowledge and interpretation of ancient building remains, validating the reconstruction hypotheses through the reasoning about structural aspects, building techniques employed, used materials, etc., also encouraging new studies and further research perspective. Moreover, it should be noted that most of the sites involved in relevant VR projects are also the best preserved and the same for which more sources are available for their reconstruction –e.g. the ancient Rome (https://www.romereborn.org/) or Pompei (https://www.pompejiprojektet.se/). This condition, accentuates an already existing gap between main and secondary attractors, leaving out the potential of those sites that more than the others need to be explained and rebuilt for knowledge to a wider public.

This paper aims to investigate the possibilities of using different 3D survey techniques and archaeological VR for documentation and knowledge of the Sanctuary of Isis in *Lilybaeum*. The archaeological remains of *Lilybaeum*, the ancient Punic-Roman city of Marsala (southern Italy), are preserved inside the Archaeological Park of Lilibeo. The Sanctuary of Isis is considered the only known sacred building of this area and one of the most interesting discoveries of the last years into the site. Despite the poor state of building preservation, it has been possible to recreate the original volumes of the ancient complex and partially rebuild it in a digital 3D environment.

The work was based on 3D data acquired during a TLS survey for the whole complex and a close-range photogrammetric survey for the two best-preserved floors –a geometric mosaic and an *opus spicatum*. The 3D surveys allowed us to document in detail the archaeological context, improving the interpretation and knowledge of the site and creating a VR of the preserved floors for visualisation aims.

2. The Sanctuary of Isis in *Lilybaeum*

The Archaeological Park of Lilibeo, extended 28 ha inside the city of Marsala, preserves a considerable area of the ancient *Lilybaeum*. The ancient city was founded in the first half of 4th century BC by the Punic and about two centuries later, in 242 BC, at the end of the First Punic War, was conquered by the Romans.

During the Roman Age, the city was progressively monumentalized, as shown in some areas, such as the main street –*Decumanus Maximus* (or *Plateia Aelia*)– and the residential area.

Three city-blocks were excavated between 1939 and 2008 (*Insulae I*, *II* and *III*) bringing to light the remains of some rich houses (Fig. 1). One of the most interesting buildings was discovered in the area of *Insula III*. It is a monumental complex interpreted as a sacred area dedicated to Isis goddess (Fig. 2).

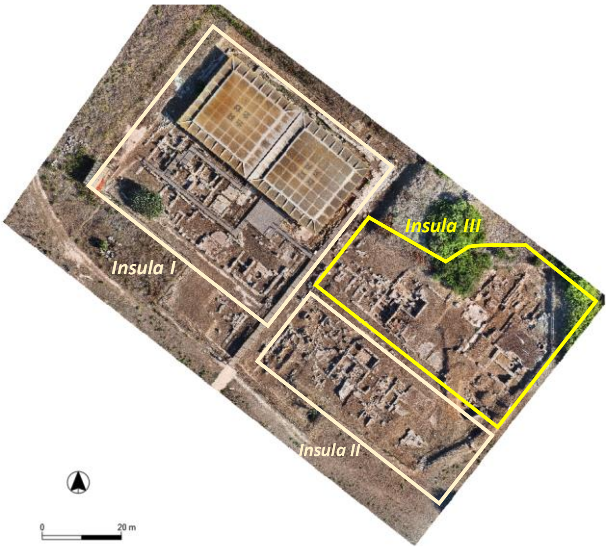


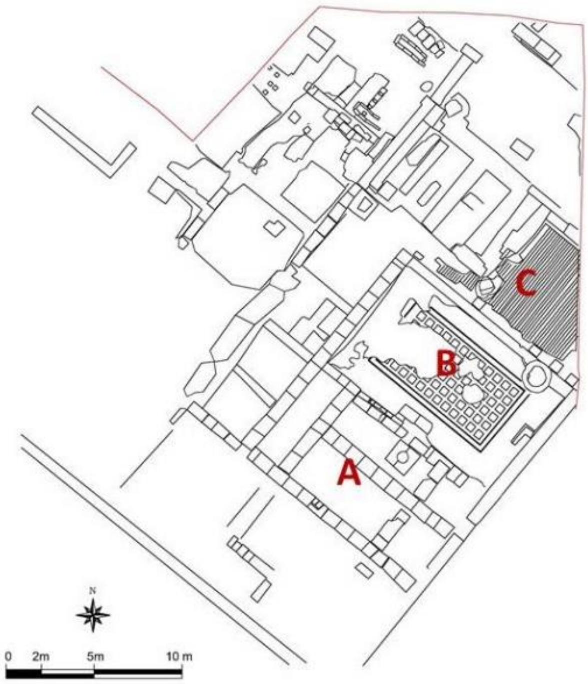
Figure 1: Ortho-image from UAV of the area of *Insulae I, II* and *III* inside the Archaeological Park of Lilibeo (from Ebolese, Lo Brutto, & Dardanelli, 2019).

Figure 2: Sanctuary of Isis in *Lilybaeum*: view of the excavation area from North (from Giglio Cerniglia et al., 2012).

The main phase of this area seems to concentrate on the 2nd and 3rd century AD (Giglio Cerniglia, Palazzo, Vecchio, & Canzonieri, 2012). Polychrome marble fragments used as wall cladding, decorated stuccos, several sculptures remains and marble inscriptions find out during the excavations, testify the relevance of the archaeological context. Unfortunately, the reuse of the area, as necropolis since the 5th century AD and for agricultural or productive activities during the Islamic age (10th century AD), have sensibly compromised the earlier structures integrity. In addition, the consistent masonry spoiling of the walls has led to the destruction of a large part of the Roman age complex.

Thanks to the excavations, it was possible to identify the building plan, divided into three main building units (A, B and C), perhaps interconnected, placed in higher level with respect to the surrounding space (Fig. 3).

(a)



(b)

Figure 3: Sanctuary of Isis: a) ortho-image from UAV (from Ebolese et al., 2019); b) CAD drawing of the building preserved structures.

The entire complex is bordered to the north by a 4 m wide road, while a lengthened structure along the entire western front is visible. This structure is limited on the west side by a low wall with the upper part rounded, delimited by a waterproof layer, whose functions could be related to water. The materials found in contact with the bottom level of this structure allows to date the end of the last phase of use in the Augustan age.

The unit A (the southern unit) was totally destroyed in the past removing strata below the floor level, deleting any information about its interior aspect. Perhaps during the removal of the floor, as well as the layers below, were also stripped the blocks of a well inside the unit A.

The unit B (the central unit) was paved with a polychrome mosaic (7.80 m x 12.20 m) with geometric decoration widely patched in the past with inserts of marble slabs (Fig. 4). A small podium is attached to the back wall on which a female statue could be stand. A circular structure, perhaps a *silos* for food storage, cuts the mosaic at the N-W angle until the rock layer. It is related to the post-abandonment phase when the area was perhaps used for agricultural or productive use. Moreover, on the southern side of the mosaic, a large rectangular cut is visible, relative to a threshold removed during the spoiling phase.

The unit C (the northern unit), perhaps an external portico, is characterised by an *opus spicatum* floor (6.25 m x 6.85 m), built with small bricks arranged in a herringbone pattern, severely damaged by post-abandonment spoiling (Fig. 5). The brick covering adapts to the profile of a base, placed at the floor centre, of which only the foundation is visible.

Figure 4: View of the mosaic floor in the unit B.

Figure 5: *Opus spicatum* floor in the unit C .

Due to the collapse of overlying structures and vegetation, but also to the usual decomposition of preparation layers, both preserved floors in units B and C show several deterioration traces, as the collapse of the surface until the loss of the mosaic tesserae and the small bricks of *opus spicatum* during the centuries. Thus, for conservative reasons, they were covered after the end of the excavation in 2008.

3. The 3D survey

In order to achieve the best advantages from different recording techniques, two surveys were planned: a TLS survey and a close-range photogrammetric survey.

The TLS survey was used to acquire the 3D geometry of the whole complex, obtaining a point cloud useful for the modelling phase by means of a Non-Uniform Rational Basis Spline (NURBS) model; the obtained solid model was used for the creation of the final virtual model in the VR phase.

For the mosaic and the *opus spicatum* floor, close-range photogrammetry was chosen; the goal was to obtain an ortho-image from which to acquire information on the surface's geometry, as well as the possibility to acquire colour pattern samples. The information acquired from the ortho-image was used, together with excavation photos for additional colour samples, for a kind of virtual restoration of the surfaces. With this procedure, it was possible to generate new textures performing the original floors features. Subsequently, new textures were applied to the 3D model during the VR phase for the virtual model creation (Fig. 6).

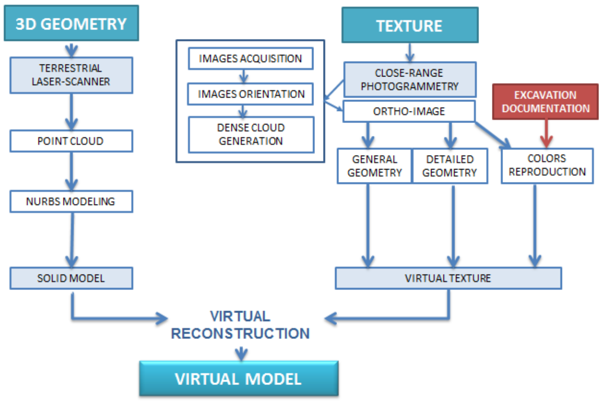


Figure 6: Workflow of survey and modelling phase.

3.1. TLS survey

TLS survey was undertaken after some preliminary tests to evaluate the best settings of each scan. Scan parameters were estimated taking into account the geometric features of the structures, the most suitable device locations to reduce time acquisition and point-cloud resolution on the object with regard to the object-sensor distance.

The survey was conducted on a single day of fieldwork after a deeper cleaning of the area. The laser scanner used was a FARO Focus 3D S120. The adopted scan scheme has 10 external scans, arranged along the perimeter of the excavation area, and 10 internal scans, avoiding shadow zones (Fig. 7). For all scans (external and internal), the vertical field of view was set between 0° to -62.5°.

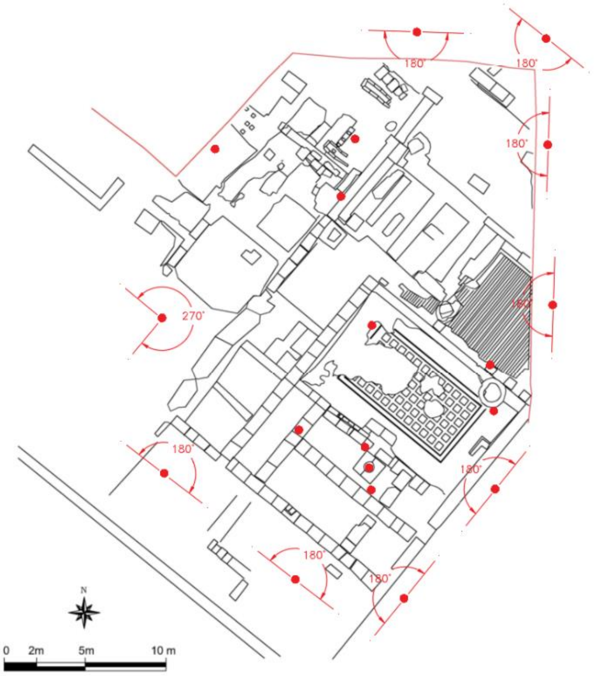


Figure 7: TLS survey of the Sanctuary of Isis area with the positioning of external and internal scans.

External scans were carried out mostly along the N-E and S-E edges, in a higher position related to most of the structures, trying to capture as many elements as possible (Fig. 8). A resolution of ½, corresponding to a resolution of 3 mm at 10 m, and a horizontal field of view of 180° was set for almost all the external scans in order to optimise the time required for each scan.

Internal scans were carried out setting full horizontal field of view (360°) at different resolutions, depending on the position of the scan point. A laser scanner acquisition was planned from the central area, in a higher position than the others; this scan was used as a reference to which align all the other internal scans.

In the case of underground structures, as the well in the unit A and the *silos* in the unit B, more scans were planned. Especially for the well, it was necessary to acquire a scan from the inside, positioning the device on the bottom, while two other scans were carried out from the outside, near to the entrance, in order to connect all of them in the alignment phase (Fig. 9). Considering the proximity of the device to the underground structures, a resolution of 1/8, corresponding to a resolution of 12 mm at 10 m, was suitable.

Figure 8: View of external scan from N-E.

Figure 9: Scan of the well into the unit A from S-E.

Point clouds registration was conducted within the Autodesk Recap software v. 5.0.4.17. All scans were aligned to the main point cloud performed from the central area of the complex. Every single scan was firstly added to the main one using manual registration process, identifying some points/target positioned around the perimeter of the area. Then, an automatic registration process was performed for all the scans. Only for the three scans of the well, they were matched together and then merged to the main one; in this way the underground structure was connected to the upper level.

Finally, a point cloud of 143 million points was resulting and after the spatial resampling to 3 mm distance, it was reduced to 70 million points (Fig. 10). Cloud Compare v. 2.9.1 was used for spatial resampling.

(a)

(b)

Figure 10: Sanctuary of Isis: a) final point cloud of 70 million points from TLS survey; b) point cloud section with the underground structures.

3.2. Close-range photogrammetric survey

In order to acquire detailed documentation of the existing floors, a close-range photogrammetric survey was carried out; the survey was aimed to obtain an ortho-image to be employed for interpretation and reconstruction of the original features of the mosaic and *opus spicatum* remains.

Survey planning took into consideration some aspects related to the presence of superficial shadows due to the walls remains and to the lower level of the structures respect to the limits of the excavation area.

A nadiral stereoscopic coverage with endlap and sidelap of 70% was planned (Fig. 11). Images acquisition was carried out using a Nikon D5200 digital camera – equipped with a 24-55 mm lens and pixel size of 3.9 µm with an effective resolution of 6000 pixels x 4000 pixels– mounted on a telescopic pole, with the camera sensor almost parallel to the floor plan. During the images acquisition, the lens was set to manual focus after adjusting it to the camera-to-object distance chosen for the photogrammetric project (Fazio, Lo Brutto & Dardanelli, 2019).

(a)

(b)

Figure 11: Mosaic and *opus spicatum* floor: a) Close-range photogrammetry survey planning; b) Camera mounted on a telescopic pole.

To obtain a Ground Sample Distance (GSD) of about 0.5 mm, a camera-to-object distance of 3 m and a focal length of 24 mm were considered; with this condition, each image covered an area of about 3 x 2 m.

Additional convergent strips were also acquired to increase data redundancy along the northern and western edges.

A total of 328 images were needed to survey an area of approximately 177 m². The main parameters of image acquisition are shown in Table 1.

Table 1: Main parameters of the image acquisition.

No. Images	*Camera-to-object distance (m)*	*GSD (mm)*	*Coverage area (m^2)*
328	3	0.42	117

Some coded and no-coded targets were placed on the floors in small parts where tesserae and bricks were lost. The coordinates of the targets were measured by a transverse topographic survey with a Leica TPS 1105 total station. Overall 38 points were measured and used as Ground Control Points (GCPs) and as Check Points (CPs) in the orientation phase.

A Structure-from-Motion (SfM) photogrammetric workflow was executed using the commercial software package Agisoft Metashape Professional (v. 1.5.1 build 7618).

Camera parameters were automatically computed by Agisoft Metashape software during the orientation phase (photo alignment and photo optimization processes). For image orientation, 23 targets were used as GCPs while 15 targets as CPs; an RMSE in XYZ of about ±2 mm was obtained with the GCPs and of about ±3 mm with the CPs (Table 2).

Table 2: Residuals achieved in the image orientation.

Type points	*No. points*	*RMSE (mm)*				
		X	*Y*	*Z*	*XY*	*XYZ*
GCPs	23	1.31	0.97	1.24	1.63	2.05
CPs	15	1.7	0.98	2.34	1.97	3.06

Following the processing workflow, several products were generated:

- a dense point cloud of 277 million points with an average resolution of 1 mm;
- a texturized mesh model of 18 million faces;
- an ortho-image with a resolution of 1 mm (Fig. 12).

4. Virtual reconstruction

The main objective of creating a virtual 3D model of the Sanctuary of Isis in *Lilybaeum* was to suggest a first hypothetical reconstruction of the building spaces during the last phase of use, in the late Roman age (4th century AD) and, particularly, to reproduce the preserved floors as they originally were.

The regularity of the building volumes was re-established by eliminating some elements unrelated to the last phase (such as the *silos* of the unit B that cuts the NE mosaic corner). Some coeval elements were

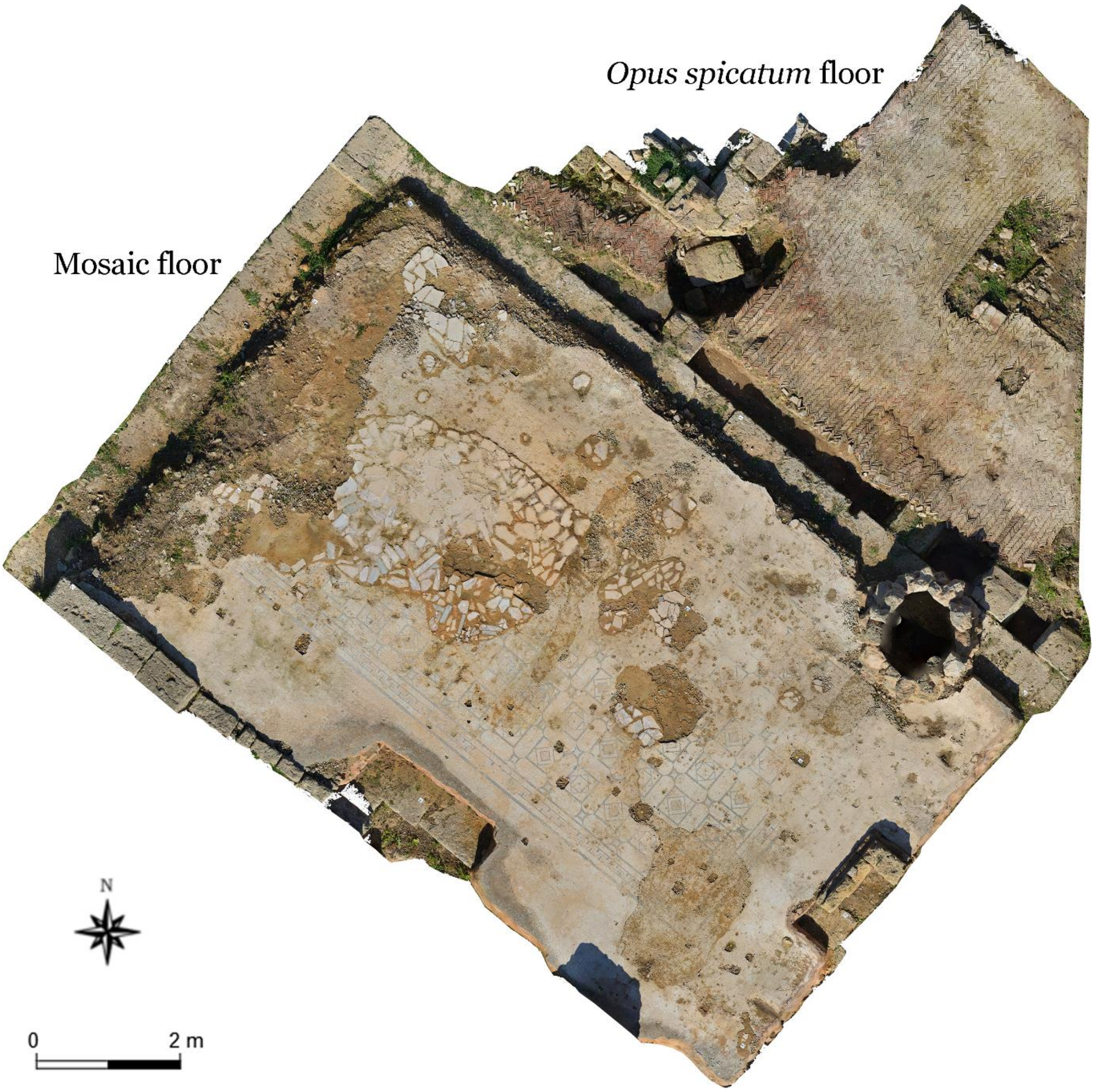


Figure 12: Ortho-image with a resolution of 1 mm of the two floors.

instead maintained and reconstructed (such as the podium still visible along the back wall of the unit B and the removed threshold, which connects the units A and B). The geometrical features and the linearity of the mosaic and of the *opus spicatum* surfaces, modified by the collapse of the lower levels, were reproduced by sampling small original portions of both floors and recomposing the old layout.

The VR process was divided into two phases:

- the reconstruction of the main 3D geometries of the building volumes through approaches of 3D modelling;
- the reconstruction of the original surfaces of the preserved floors as a kind of virtual restoration, filling the superficial gaps to obtain new textures of both floors to be applied onto the reconstructed 3D model of the building.

4.1. 3D modelling

3D representation of an archaeological stratigraphy is a process that involves careful planning and continuous comparison with the data collected on-site. Particular attention should be given to the integration between 3D surveyed data and historical sources; for example, a precise iterative feedback strategy was defined in Guidi, Russo, & Angheleddu (2014) in order to check each important interpretative step during the VR. This approach is based on a sequence of archaeologist's controls on the modelling evolution, starting from a volumetric simplified version to the best-detailed one.

A survey exclusively reproduces the upper visible surfaces of an architectural element on the archaeological scene, but not its 3D complexity of stratigraphy (Valente et al., 2017). For example, the volume of a wall is defined as a Stratigraphical Unit (SU), linked through relations of anteriority or posteriority to the walls that lean against it (more recent) or to which it leans (more ancient). The identification of these relationships is applied in archaeology as masonry stratigraphy analysis, which determines which wall was built before another. This practice is fundamental to define a sequence of interactions between walls masonry, identifying different architectonical phases.

As discussed the walls, even the three-dimensionality of a floor can be defined by the perimeter walls that circumscribe it. The three-dimensionality of a floor is instead defined by the levels on which it rests, which often are the preparation layers above the virgin ground or more ancient floors, as in our case.

Both floors, the *opus spicatum* and the mosaic with their respective preparation layers, rest on older floors (e.g. the *opus signinum* floor 20 cm below the *opus spicatum* in unit C). The thickness of each floor, visible in the stratigraphic sections and even in the point cloud of the TLS survey, allowed us to reconstruct each floor layer in its three dimensions in the modelling phase, and to isolate them as single architectural elements.

The point cloud generated by means of TLS was used for the whole building 3D geometric reconstruction. The 3D model was created as a NURBS model, using the modelling software Rhinoceros. Considering the predominantly linear development of the structures to be rebuilt –the floors and their perimeter walls– this type of modelling was evaluated as the best solution compared to a polygonal model, which reproduces all the surface irregularities due to the natural deterioration of the floors. In fact, the NURBS model offers several advantages such as a reduced file size, easier management of the 3D model and the possibility of improving the 3D model in the future by integrating additional parts of the building. Moreover, developments can be achieved in the future, integrating the NURBS model with a parametric BIM model in order to increase the monitoring of the state of monument conservation (Banfi, 2017).

The used modelling approach was based on the extraction of the object's geometry (vertical and horizontal sections) from the point cloud mainly in Cloud Compare software. The generation of sections from the point cloud allowed detecting floors elevation with respect to the lower levels. The number and position of the sections were not fixed but they were based on the features and conservation status of structures. In fact, due to the deterioration of some parts, more sections were required to perform the main volume (Fig. 13).

On the basis of the masonry stratigraphy analysis, the walls were reconstructed as single continuous elements where it was possible to read the arrangement of the blocks. However, to define some volumes where walls were spoiled, not visible into the point cloud but identified during the excavation, the voids produced by the spoiling trenches were used as a reference. To do this, a plan of the building, integrated with the excavation data, was used. The plan was imported in Rhinoceros and then was scaled according to the point cloud sections (Fig. 14).

The limits of each room were thus precisely defined by tracing the excavation plan. The survived floors and the podium were reconstructed until the high suggested by the point cloud sections. For the walls instead, it was chosen to increase the elevation compared to the current state, bringing theirs to a height of 3 m from the level of the floors (Fig. 15).

Finally, the textures of both floors were applied to this model through a mapping process (see Section 5.).

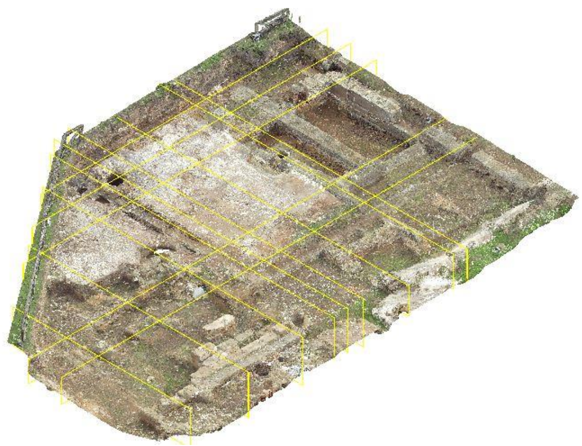


Figure 13: Positions of point cloud sections.

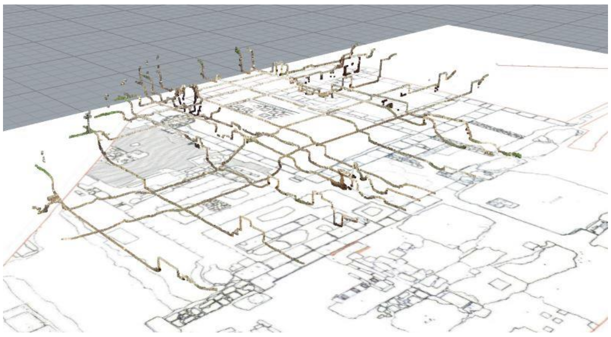


Figure 14: Superimposition of point cloud section on the excavations plan.

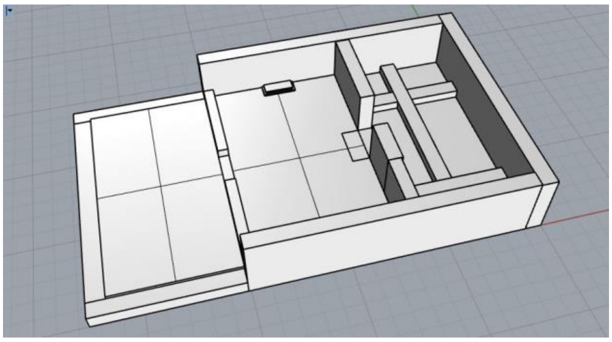


Figure 15: 3D solid model.

4.2. Floors texture reconstruction

The VR of damaged floors surfaces can be seen as the process that starts defining geometrical features of both mosaic and *opus-spicatum* floors, such as sizes and geometrical schemes, and then considering issues related to the colour reproducibility. For both these steps, the ortho-image generated by means the close-range photogrammetry survey was used as a reference.

From the geometric point of view, the reconstructed mosaic extension is 11.60 x 7 m. Its decorative scheme is based on a frame with the pseudo-meander decoration of 8.35 x 4.60 m, 0.35 m wide, placed approximately at the floor centre. Inside it, there are six lines of twelve squares per each, characterised by the systematic and alternate repetition of two squares with different decorative motifs. Each square measured 0.41-0.42 m per side, enclosing smaller square and rhombus alternated, both of 0.25 m each per side. The vertices of each of the major squares were connected by smaller concave squares. All these decorative elements, made with different coloured tesserae, were projected on a uniform white background.

For the *opus spicatum* floor, the reconstructed dimensions evaluated for the entire floor were 6.28 m width and 11.50 m length. It was realized juxtaposing series of small bricks (11 cm long) in a herringbone pattern 15 cm wide, along the whole extension of the space.

Figure 16 shows the general geometry of the two floors reconstructed from the ortho-image.

Figure 16: Close-range ortho-image overlaid onto the UAV ortho-image: geometrical scheme and reconstructed dimensions of the two floors.

While the 2D geometry of both surfaces was obtained directly from the ortho-image, for colour reproducibility some problems were found. Usually, the VR of damaged ancient floors –mainly focused on mosaics surfaces– was a non-metric process based on the modular repetition of pattern sampled by the undamaged parts. In this way can be simulated mosaic integration of losing parts (Monti & Maino, 2018; Santachiara, Gherardini, & Leali, 2018). In our case, this approach was not very sustainable due to a thin layer of liquid cement laid on the floors as consolidating after the excavation to avoid the progressive loss of the surface materials, compromising the colour visibility.

Only small unmodified parts of the *opus spicatum* allowed to acquire samples of bricks directly on the ortho-image, recreating long strips to use as a pattern. Strips were thus assembled and used to cover the entire floor extension.

Mosaic patterns generation was more complex and carried out tessera by tessera. In fact, it is totally covered by the greyish patina, thus some photos acquired during the excavation were used to sample colour information. From the excavation photos, in which the original colours were still visible, individual samples of tesserae were acquired; two or three samples for each used colours; using different shades of the same colour it was possible to maintain a realistic effect of the surface. On the same photos, each decorative element –two main squares, the smaller concave squares and a part of the frame decoration– were virtually restored, replacing tesserae position where the originals were lost (Fig. 17).

Figure 17: Mosaic surface reconstruction: different samples of tesserae used for the virtual restoration of a decorative square.

After this procedure, each of these elements was placed inside a module extracted from the ortho-image (Fig. 18). Finally, the module was reproduced sequentially, covering the entire reconstructed extension of the mosaic (Fazio et al., 2019). A further solution to preserve a realistic surface effect, especially for the white background, was achieved by maintaining a transparency value of around 20% with the ortho-image kept below as a reference.

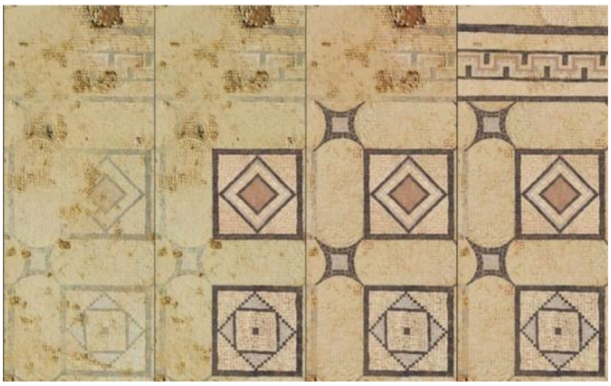
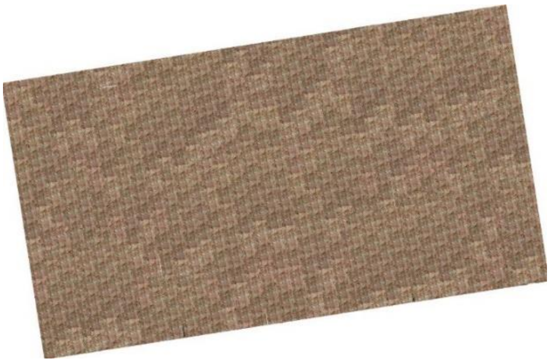
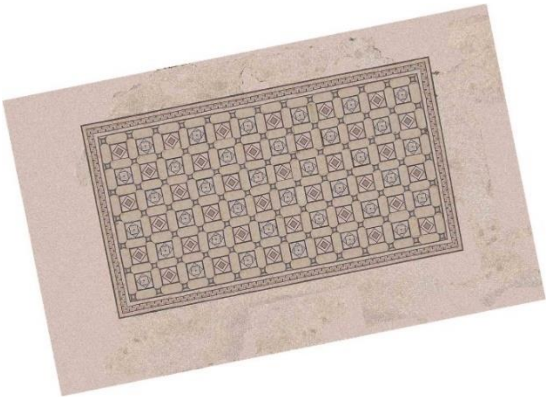


Figure 18: Mosaic surface reconstruction: steps of mosaic pattern restoration (from Fazio et al., 2019).

Once both surfaces were rebuilt, they were individually exported to an image file maintaining a high resolution. Thus, two new detailed textures were been reconstructed for the 3D model mapping (Fig. 19).



(a)



(b)

Figure 19: Final output surface reconstruction: a) *opus spicatum*, b) mosaic.

5. Textures mapping

Texturing work was carried out within the Blender software where the original NURBS model was imported. Each of the main elements –walls, floors, thresholds, the podium– has been given a different material, for easy and immediate identification of the main architectural components (Fig. 20). In particular, for the mosaic and the *opus spicatum*, two distinct materials were attributed in order to subsequently be able to apply the two separate textures previously realized (Fig. 21).

The textures were thus individually imported and assigned to each respective floors via the command <UV unwrap>. A further adaptation of the textures was done by stretching the corners at the vertices of the respective faces, intervening in the <UV/image editor> work area.

6. Discussion

The proposed VR of the Sanctuary of Isis in the ancient *Lilybaeum* derived from both the hypotheses formulated on the basis of archaeological data (from published work and direct observation) and the 3D model analysis. In fact, according to Forte (2014), the VR processes "should come from user feedback, data observation, and the interaction of «bottom-up» (acquisition) and «top-down» (interpretation) activities".

Already during the planning phase for data acquisition, many information useful for archaeological analysis and interpretation were evaluated. A further step for a better knowledge of the archaeological context was reached also during the integration phase of the acquired datasets, as well as between them and the other sources used.

The combined use of photogrammetry and TLS has allowed acquiring a highly detailed 3D and 2D documentation of all the remains preserved *in situ*, mainly pertaining to the last phase of use, in the late Roman age (4th century AD). The VR was carried out exclusively for those architectural structures in use until before the abandonment. Some remains, acquired during the TLS survey, which cannot be dated with certainty to the last phase, were not considered for the VR.

The floors, the perimeter walls and the partition walls were reconstructed using NURBS modelling approach. The perimeter walls were reconstructed assuming a height of 3 m from the floor level; for the partition walls of unit A, as well as for unit C (probably a terrace, as the brickwork of *opus spicatum* would suggest), the reconstruction of the walls has maintained the level currently preserved.

Unfortunately, the absence of well-preserved walls prevents a clear hypothesis of the position of the openings (doors and windows) that connected the various units to the external area. Only the two doors that connected the three units internally were identified thanks to the still visible traces of their removed thresholds (Giglio Cerniglia et al., 2012). Openings towards the outside, although conceivable, were not been reproduced due to the uncertainty in their hypothetical position.

The mosaic and the *opus spicatum*, respectively in the units C and B, which had been built on two previous floors, were certainly in use in the 4th century AD. The floors reconstruction carried out with a methodology that can be considered as a sort of virtual restoration, allowed to recreate their appearance as should have been in the past. Thanks to the detailed analysis of the surfaces, it was possible to accurately highlight features of the decorative scheme, but also, for the mosaic, establish the number of tesserae required for the execution of each module. For example, the length of 41 cm of a main square module side corresponding to 41 tesserae employed, and the same for the smallest squares, etc. These considerations, at the base of the ancient mosaics realization, are today very useful in the case of conservatives planning, allowing computing the number of tesserae required for integrations to the floor surface. In our case, the identification of the geometrical elements for the mosaic and *opus spicatum* floors allowed the virtual restoration of surfaces and the generation of new textures that show their original appearance. The textures were thus adapted into the 3D NURBS model, creating a virtual model suitable for visualisation in both cultural and scientific fields. However, it should be underlined that the approach proposed for the floors virtual reconstruction can only be applied in cases where the surfaces are decorated with geometric patterns, which can be reproduced in sequence; in addition, a sufficiently large portion of the floors must be preserved to allow the reconstruction of the decorative scheme (Monti & Maino, 2018). In other cases, such as figurative mosaics, in which the surface is partially preserved, it might be more difficult to formulate reliable hypotheses around the virtual reconstruction without additional sources (e.g. photos, drawings or description).

(a)

(b)

Figure 20: 3D model: (a) current state, (b) virtual reconstruction.

The precarious state of conservation of the walls was the main limit for the total reconstruction of the building in the current state of knowledge of the site. This condition also prevented the reconstruction of the walls as they would have been, with frescoes and decorated with precious plaster frames of which numerous remains have been found. In fact, the constant deterioration of the area, added to the lack of a clear definition of the chronological sequence, would not have allowed going further in the VR, without entering into the field of mere hypotheses.

7. Conclusions

In this paper, the Sanctuary of Isis complex has been documented by means of different 3D survey technologies. The paper shows how to generate high-quality 2D products of floors surfaces using close-range photogrammetry, enabling a detailed VR process of this kind of surfaces. Moreover, the use of TLS for the creation of a detailed 3D model of the whole area allowed us to analyse the volumes of the main units, the dimensions of each room, the relationships between architectural elements as well as the relations of anteriority or contemporaneity between construction phases. These data will be used in the future for metrological analyses on the building itself and to integrate the data acquired on this Isis complex within a broader perspective, investigating the development of the building inside the *Insula* III and inside the urban Roman plan of *Lilybaeum*.

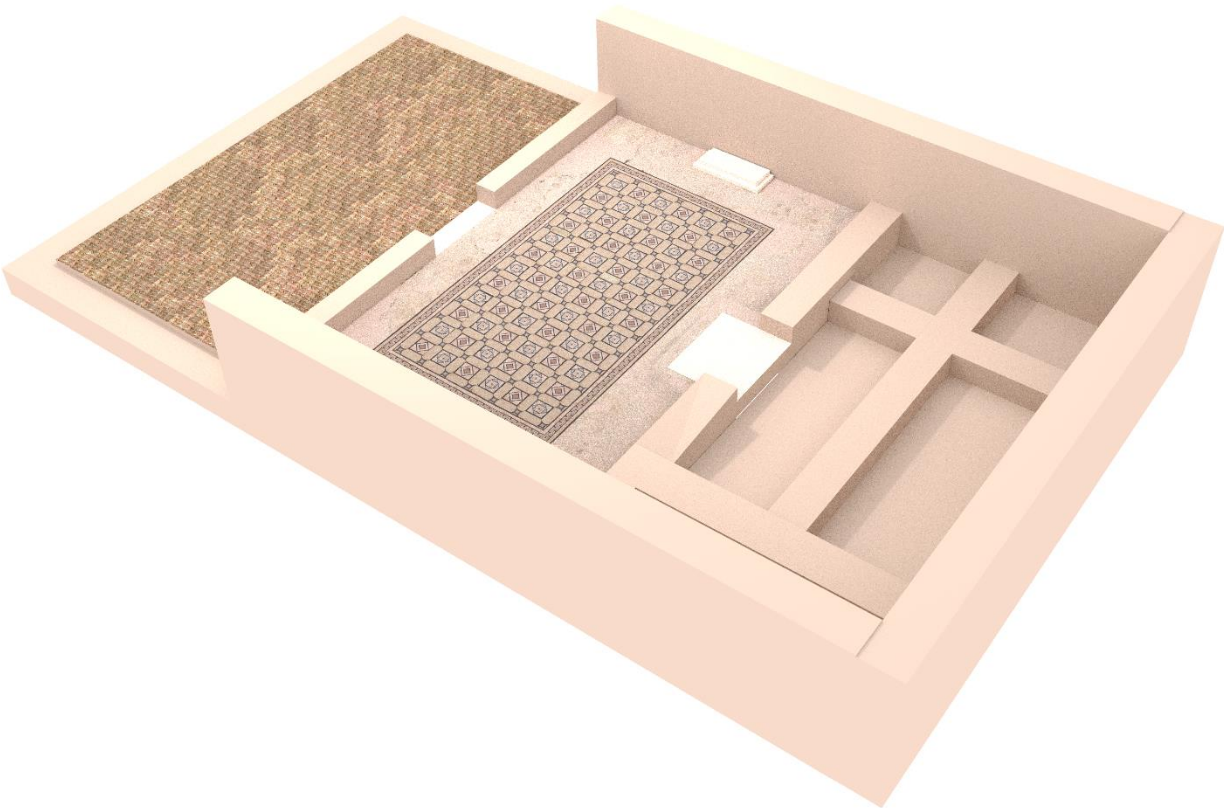


Figure 21: Final 3D texturized model.

The combined use of photogrammetry and TLS has therefore proved to be a very useful approach not only for the documentation of the archaeological context, but also for dissemination purposes. In fact, the virtual model generated constitutes valid support for the use and visualisation of a site that at the moment is scarcely legible, due to the poor preservation of masonry.

The different technologies used for the surveys have proved to be particularly effective. Thanks to the SfM/photogrammetry workflow a high detailed ortho-image has been obtained. However, for complex architecture, TLS seems to be still the right choice. In fact, despite several limits, such as shadow cones in the point cloud due to the positioning of the device, the colour reproducibility, survey cost and the time-consuming work-field and data processing, the use of TLS is the most suitable to guarantee good results for archaeological sites. The combined use of both systems is therefore of great utility in the case of complex surveys, for which different degrees of accuracy are required. These considerations are particularly valid in the case of projects that involve VR, reopening the discussion about different possibilities of employment of survey resources/products for VR.

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