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# Achieving Universal Accessibility through Remote Virtualization and Digitization of Complex Archaeological Features: A Graphic and Constructive Study of the *Columbarios* of Merida

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**Abstract:** Currently, there are heritage assets that have been extensively studied and documented, but sometimes this information is not fully accessible to users. The aim of this research was to establish protocols and methodologies to promote collaborative work between the disciplines of architecture, restoration, and archaeology, through the results offered by Building Information Modelling (BIM) tools, and to use them for Heritage Building Information Modelling (HBIM). The methodology applied employed data collection with fast and low-cost tools (UAV) to subsequently generate a photogrammetric survey to serves as the basis for three-dimensional modelling. In this parametric model we implement all the information obtained by professionals from different disciplines, which also serves as a means to publicise and disseminate the heritage asset. The case study was the archaeological site of *Columbarios*, located in Mérida, a UNESCO World Heritage City. We obtained an effective interdisciplinary work methodology for heritage management under a collaborative BIM environment. The study has allowed us to make the archaeological remains available to visit from anywhere in the world through Augmented Reality (AR) and Virtual Reality (VR) technology.

**Keywords:** HBIM; photogrammetry; point cloud; collaborative methodology; model documentation; accessibility; heritage; archaeology; restoration; architecture

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## 1. Introduction

Nowadays, when tackling heritage restoration and conservation projects, a large amount of information is required: precise planimetry, historical and archaeological studies, the characterisation of constructive and material elements, the state of conservation, etc. On many occasions, this documentation is not standardised, as its systematisation is left to the individual criteria of the technicians involved in each project. Furthermore, the work generated by each one is not made available to the rest of the technicians, which makes the process of searching for documents to develop projects tedious and complicated. At other times, it even leads to the duplication of work, especially when it comes to drawing up a plan of the current state of the heritage assets.

The aim of this research is to generate a methodology that allows us to unify, codify, and standardise the documentary and graphic management of cultural heritage and make it accessible to technicians who develop projects in the future. The application of the HBIM method to heritage projects offers great advantages when it comes to obtaining information, ordering and systematising existing documentation, and obtaining data with greater reliability [1–4].

This methodology was put into practice in an archaeological area located in the World Heritage City of Mérida (Badajoz). In this area there are three buildings of Roman origin dating from the first century AD (Figure 1a,b). These buildings are of funerary origin,

and each one belonged to a family to house the cremated remains of its members. Their names, origins, and social status are known from the epigraphs and paintings that have been preserved. Thus, we have the mausoleum of the Niger family, which is triangular in plan and built with granite ashlars, the mausoleum of the Julios, trapezoidal in plan, and a smaller one with a square plan that belonged to the Voconios family, the latter built with masonry walls lined with lime. Inside the Voconios building, there are still portraits of the members of the family who were buried there. At present, the interior of the mausoleums cannot be visited due to the small space and for the conservation of the paintings (Figure 1c,d).

**Figure 1.** Current state of the buildings under study. (**a**) Outside view of the buildings; (**b**) outside of the *Voconios* building; (**c**) inside of the Julios building. Here we can see the niches where the urns containing the cremated remains of the Julios family were deposited. (**d**) Inside of the *Voconios* building. Remains of the Roman paintings of the members of the family who were buried there are preserved.

Excavation of these buildings began in 1927, and since then they have been known as *Los Columbarios*—from the Latin *columbarium* (dovecote), so called because of their resemblance to the niches where the ashes of the deceased were deposited [5].

These structures were chosen as a pilot project since all the documentation was made available to us by the *Consorcio de Mérida*, which allowed us to speed up the documentary search process and to focus our efforts on generating workflows and systems that improve communication between the agents involved in the different phases of the project.

The archaeological record [6,7] is a rigorous documentary process that requires precise graphic support, since as the archaeological remains are exhumed, spatiotemporal relationships are established that allow us to know the evolutionary process of the site in general. Therefore, the non documentation or graphic inaccuracy of any archaeological element means a loss of information, as the process of archaeological excavation is irreversible. This graphic documentation process has evolved over time. A few years ago, it was carried out with photographs attached to the excavation sheets; later, in the 1990s and 2000s, 2D computer-assisted drawings were used; and nowadays, data are collected

via photogrammetry, which contextualises each stratigraphic unit into three dimensions, making this method the most rigorous and efficient [8,9].

The existing planimetry of the Columbarium was carried out in 2004, using traditional 2D methods, as can be seen in Figure 2, which is a page from the published monograph *Los Columbarios: arquitectura y paisaje funerario* ("The Columbarium: architecture and funerary landscape").

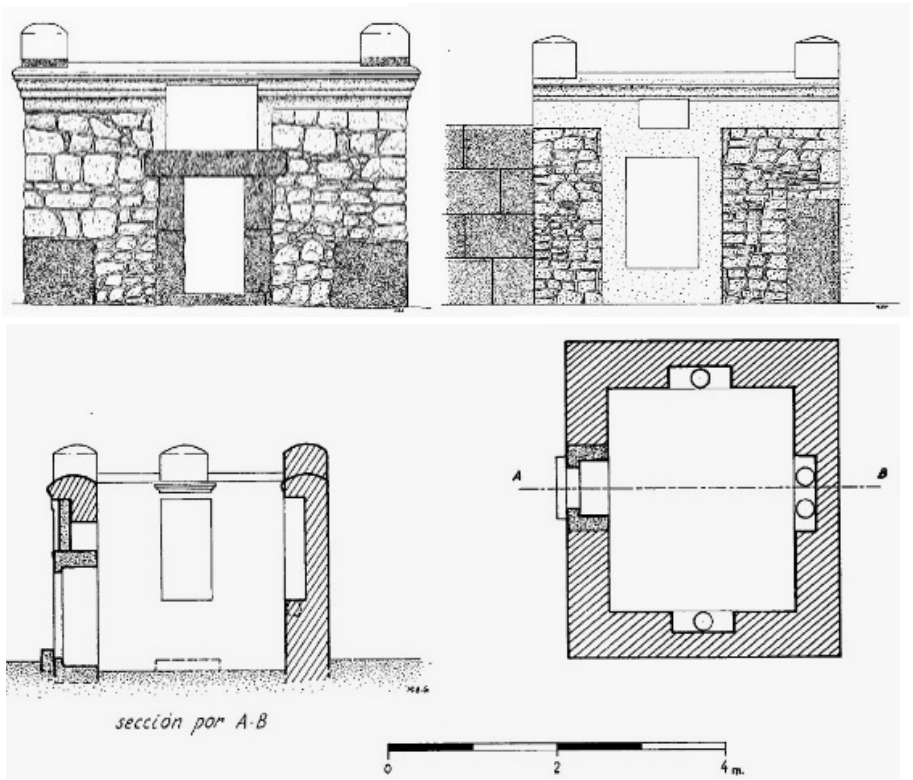



**Figure 2.** Existing planimetry published in the monograph *Los Columbarios: arquitectura y paisaje funerario*.

Therefore, one of our objectives is to carry out a survey using low-cost tools that are available to everyone, with photogrammetry from photographs taken with a drone, which will serve as the basis for obtaining a three-dimensional HBIM model that contains not only very precise graphic documentation, but also semantic information on the heritage asset.

This facilitates access to the documentation generated, efficient communication, and rigorous work processes in all the disciplines involved in heritage management [10,11].

This same model allows us to disseminate and musealise this heritage in a more enriching way, providing a multifaceted vision and information that responds to people's diverse concerns.

With the use of augmented reality (AR) and virtual reality (VR) inverted technologies, we can visit these structures from anywhere in the world and even enter those places that cannot be visited due to conservation and/or accessibility issues. In this way, we are disseminating heritage in a sustainable way [12].

## 2. Background and Related Works

The BIM methodology has been implemented in different countries, reaching different levels of maturity depending on a series of factors. Each country has its own norms or BIM standards, governed by organisations that contribute to the writing and updating of these, which are adapted to the needs and cultural characteristics of each country [13].

In the case of Spain, a BIM Commission was created to carry out the work necessary for its correct implementation in the public works specifications (Figure 3).

**Figure 3.** Timetable regarding the implementation of BIM in Spain.

Directive 2014/24/EU of the European Parliament proposes improvements in contracting and bidding through the BIM methodology, which offers benefits to streamline and improve productivity. In 2018, the Ministry of Development of the Government of Spain prepared a roadmap so that, in 2020, all phases of projects, equipment, and public infrastructures were executed in BIM, applying this objective to both new construction and rehabilitation.

The Italian school has pioneered this methodology for documenting, storing, sharing, and managing information on the vast heritage they possess, thus working to optimise heritage management processes, which are constantly updated [14–16].

Throughout history, as cities have evolved, buildings have been added and removed [17,18]. Thanks to tools that allow us to carry out photogrammetric surveys and generate Historical Building Information Models (HBIM), we can investigate cities with greater precision, because having a virtual map allows us to establish relationships between elements that seem unconnected and yet are related to each other; in this way, we can obtain more information about the evolution of the buildings or the urban layout.

In this area, we find research such as that carried out at the Convent of San Pietro de Deca in Torrenova (ME), where a virtual reconstruction was carried out with representation of different morphological phases that show the evolutionary changes of the building [1].

Another of the great discoveries that these survey and data management methods have allowed us to make was a section of a 12th-century wall in Cáceres, a World Heritage City. BIM tools generate a virtual model whereby each construction element can be classified and refined according to its nature or period by applying filters; they also allow us to glimpse elements that are hidden to the naked eye, put them in relation to each other, and thus discover its layout with great precision [10,19,20].

Currently, in Extremadura (Spain), there are virtual models of eight historic bridges. Thanks to this work, it has been possible to document these buildings with millimetre-fine precision by obtaining a point cloud, which reveals data that is difficult to access, such as on the inner part of the arches of the bridge. This enhances efficiency when tackling an intervention project. It also creates an accurate record in the event of a natural catastrophe that leads to the destruction of any of the bridges [21].

There are other academic works that have contributed to generating workflows for the three-dimensional reconstruction of architectural heritage with the use of HBIM systems. Some of them are the interventions carried out in the church of Santa María La Real de Mave (Palencia) [22] and the castle of "The Comuneros of Torrelobatón" (Valladolid) [23].

The BIM model made of the Roman Theatre of Sagunto also deserves mention [24], as well as the Royal Cloth Factory of Brihuega in Guadalajara [25].

These tools also offer interesting possibilities for the management of archaeological cultural heritage [4], with investigations such as that of the Sanctuary outside the walls of the city of Tusculum, one of the best-preserved buildings of the entire site but less well known. The BIM model has been used to establish a basis for the modelling of archaeological remains and to synthesise current studies and knowledge of the heritage element so that future research can enhance, complement, or correct it [26].

These work systems are very useful in archaeological sites such as the one in Mérida, where we find a vast heritage with buildings that are the result of the addition of different periods.

Making our heritage known makes society aware of the importance of its conservation and protection; therefore, one of the fundamental principles in heritage management is its dissemination. With the virtual models generated for the purpose of studying and documenting heritage, heritage sites can also be visited through virtual reality (AR and VR) inverse technologies [27–29]. Three-dimensional modelling provides a new opportunity to use this technology to present information about objects and give virtual tours of historic buildings [30]. This new approach to heritage dissemination helps children and young people become interested in history and value the cultural heritage that surrounds them [31].

This new approach has had a great impact on tourism, especially after the COVID-19 pandemic, when cities and countries closed down, and people started to use virtual reality technologies. This also promotes future tourism, as it has been found that people have shown interest in travelling to visit the site after experiencing this type of technology [32].

This also has a direct application to the field of education, as it allows us to design learning environments enhanced by technology so that children and young people become interested in history and value the cultural heritage that surrounds them [31,33].

In this sense, we find research that contributes to advancing the use of these technologies, such as the seminar "Digital and Documentation: Databases and Models for the enhancement of Heritage", which promotes the topics of digital modelling and virtual environments applied to the documentation of architectural scenarios and the creation of museum complexes through communication programmes using immersive technology [34].

## 3. Materials and Methods

The proposed methodology arises from research work in which, through a practical example, protocols and workflows are established. The tools and formats used are in dialogue with each other, allowing for the generation of a collaborative BIM environment in which a multidisciplinary team can work effectively [35]. The work was structured in several phases with clearly differentiated milestones, which permitted us to achieve the objectives set (Figure 4).

In the first phase, a work plan (BEP) was defined that serves as a basis for all the agents involved in the generation and use of BIM models and the information obtained from them in the different phases of the project. Subsequently, a recapitulation of the documented information and previous work was carried out through publications and the archive of the *Consorcio Ciudad Monumental de Mérida*, which provided graphic documents, excavation reports, and photographs (all the information provided remains clearly reflected in the work). A study and analysis of the different documents provided for the work, cleaning of vector files, and classification of information was carried out. After obtaining the necessary information and files, the second phase was developed, which consists of the elaboration of the model through a photogrammetric survey, generating a point cloud that serves as support for the following phases of the work.

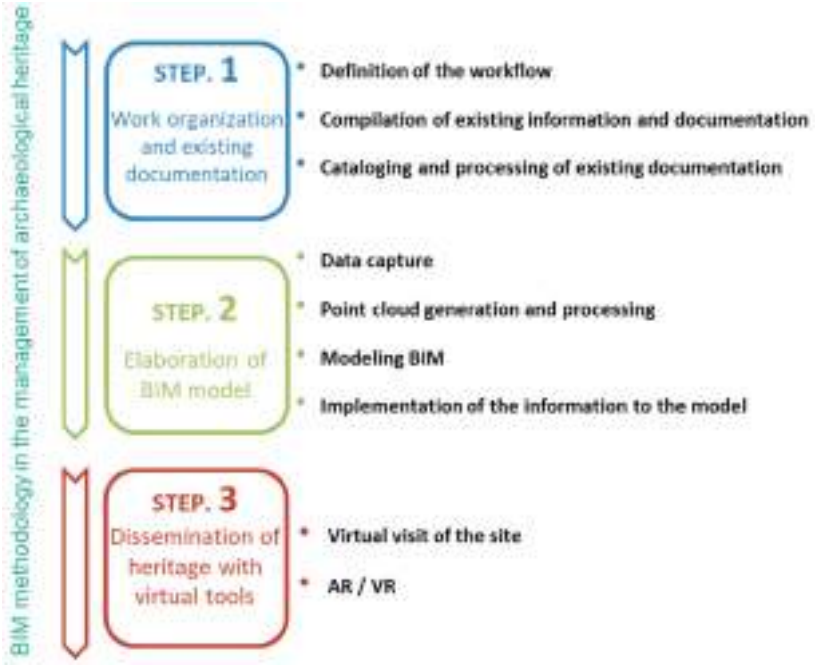



**Figure 4.** Outline of the methodology applied in the development of the work. The tasks carried out in each phase of the work process are defined.

These steps include generation and processing of the point cloud, topography generation, modelling of the heritage element using the software Revit (for Microsoft Windows, currently developed by Autodesk), and implementation of all the information in the model. For the treatment of the archaeological information, the possible capture methods will be established and taken into account in future excavation campaigns, and a protocol for the implementation of the existing vectorial information to our model will be established.

With this data, a BIM model was generated that gathers all the information in real time.

Finally, in the third phase, possible proposals on the dissemination of heritage will be proposed, in which the potential of the BIM method will be exemplified, and through all this, the optimization of heritage management [15].

### *3.1. PHASE 1: Definition of the Work Environment*

The entire city of Mérida is considered a unique archaeological site, with evidence of its state in different eras. In the present, its urban development combines the modernization of its urban nucleus with the historical remains of its past.

The comprehensive management model of the Mérida Consortium, a reference public entity, without a doubt, at a national and international level, is based on four fundamental pillars: documentation, research, conservation, and dissemination of Mérida's heritage. Based on the existing multidisciplinary work structure in this institution, we were able to develop our workflow and process under the umbrella of the BIM method, relying on the practical example of the Columbarium enclosure.

These archaeological remains are currently in an enclosure that can be visited by the public; however, they are far from the control point, which means that on many occasions they go unnoticed by the visitor. In addition, access to them is not adapted, since the dirt road is irregular and there is a steep slope to reach the door. These funerary buildings are some of the few archaeological remains that have survived to the present day almost completely, and they even have paintings of the people who were buried inside.

These paintings are hidden from the view of the visitor because the interior is physically inaccessible due to the small size and to the need for conservation.

### 3.2. PHASE 2: Survey and Elaboration of BIM Model

#### 3.2.1. Capture of Geometric Data of the Current State of the Property

Traditionally, plans were made by measuring with traditional tools. In heritage, carrying out a survey with these methods is costly and inaccurate, since it is difficult to accurately capture the irregularities and singularities of all the heritage elements, which results in errors.

Today, to undertake any type of intervention in a heritage asset, it is essential to make reliable, three-dimensional digital models to be able to understand, plan, and carry out projects [36,37].

For this project, for the generation of the point cloud, we used photogrammetry, which is a precise and noncontact 3D measurement technique based on various high-quality images, which allows for accelerating the collection of geometric data from a building or object [38]. This point cloud provides us with geometric information with almost millimetre precision; however, it does not provide any additional information, which is why it is necessary to make a BIM model from the generated point cloud.

#### 3.2.2. Materials and Resources

For the capture of geometric data of the heritage asset under study, a DJI Mavic Mini drone was used, which is an ultralight and portable drone with a transmission distance of 2 km, 3-Axis Gimbal, and 12 MP for HD 2.7 K videos [39].

The use of this drone is allowed, due to its weight, without the need for a pilot's license.

In addition, with the total station Geomax model Sipp 20 R 5″ 250, points were obtained that allowed us to geolocate the archaeological remains.

It should be noted that this method is very effective, and optimal results are obtained at low cost, meaning that it may be within the reach of most professionals.

#### 3.2.3. Capture Photos by Drone

Data capture was carried out in three stages: The first stage covered the environment where the buildings are located, which allowed us to obtain an exhaustive topography, determining the exact slopes and regularities. In the second stage, the exteriors of the structures was assessed independently and in the third stage the interiors, so as to allow us to obtain point clouds with different parameters depending on the level of detail, according to the importance of the each of the elements of the heritage asset and the limitations of computer resources [40,41] (Table 1).

**Table 1.** Drone data collection parameters.

| **Topography** |
| --- |
| - Trajectory: parallel horizontal sweeps at a constant height of about 8 m, forming a 1 m separation grid<br>- Maximum sweep height: 8 m<br>- Distance between the different sweep lines: 1 m<br>- Inclination of the drone camera: 90° |
| **Outside of Building** |
| Vertical sweeps:<br>- Trajectory: from top to bottom making parallel lines. It must be ensured that each image taken is superimposed in a 1:3 proportion.<br>- Maximum sweep height: 4.5 m<br>- Distance between the different sweep lines: 50 cm<br>- Inclination of the drone camera: 0° |

**Table 1.** *Cont.*

| Outside of Building |
| --- |
| Horizontal sweeps:<br>- Trajectory: a grid was made in two parallel directions<br>- Maximum sweep height: 4 m<br>- Distance between the different sweep lines: 50 cm<br>- Inclination of the drone camera: 90° |
| **Inside of Building** |
| Vertical sweeps:<br>- Trajectory: from top to bottom, making parallel lines<br>- Maximum sweep height: 3 m<br>- Distance between the different sweep lines: 30 cm<br>- Drone camera tilt: 0°/45°/90°<br>As it is not feasible to carry out horizontal sweeps due to the dimensions of the site, we carried out vertical sweeps, taking photos with different inclinations of the drone's camera. |

#### 3.2.4. Point Cloud Generation

For the generation of the point cloud, Agisoft Metashape (for Microsoft Windows, currently developed by Agisoft) software was used.

Two files were worked on in parallel, one for the archaeological structures (Table 2), and the other for the topography (Table 3). Both used the same reference system; however, they had a different definition of detail [42].

**Table 2.** Number of photographs taken for the generation of partial point clouds of buildings.

| Chunk | Number of Photographs |
| --- | --- |
| 01_EXT_N-J | 356 |
| 02_EXT_V | 362 |
| 03_INT_N-J | 419 |
| 04_INT_V | 515 |

**Table 3.** Number of photographs taken for the generation of point clouds of topography.

| Chunk | Number of Photographs |
| --- | --- |
| TOPOGRAPHY | 760 |

The steps to follow to generate the point cloud are as follows (Figure 5):

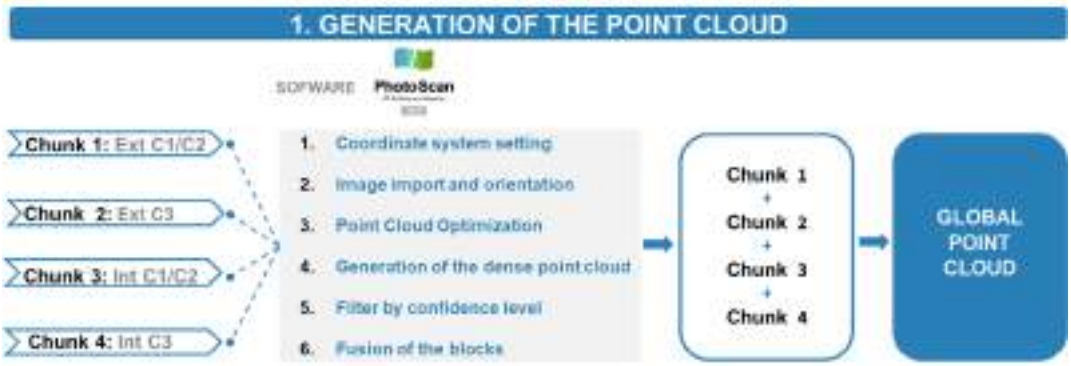



**Figure 5.** Workflow scheme for point cloud generation of heritage buildings.

We structured the workspace into several "chunks", which corresponded to each phase of data collection. In this way we made partial point clouds, which later were merged to give rise to the global point cloud.

Adjust the coordinate system: for capturing data, several types of coordinate systems were used (Figure 6):

- The photos obtained with the drone were georeferenced with the WGS 84 system (EPSG:4326). WGS84, World Geodetic System 84 (World Geodetic System 1984).
- The points were obtained for the station with the ETRS89/UTM system.

**Figure 6.** Reference System Adjustment Parameters.

ETRS89 is a three-dimensional geodetic reference system used as a standard for high-precision GPS georeferencing in Europe.

For this model, we used this reference system, as it is the one used by the *Consorcio de Mérida* to georeference the findings of archaeological excavations.

Import and orient images: The images were imported in different chunks, making them coincide with the different data collection campaigns.

In this way, we worked with low-tech resources and controlled the adjustments and links of the different point clouds in a more optimized way.

To perform the alignment, an overlap in the order of 20% or 30% between sets of adjacent points is generally required; furthermore, in said overlap, there must be at least one special objective (corner, sphere, plane) identified that allows common points to be found between the point clouds.

We oriented the images using the following settings for the buildings (Figure 7) and for the topography (Figure 8):

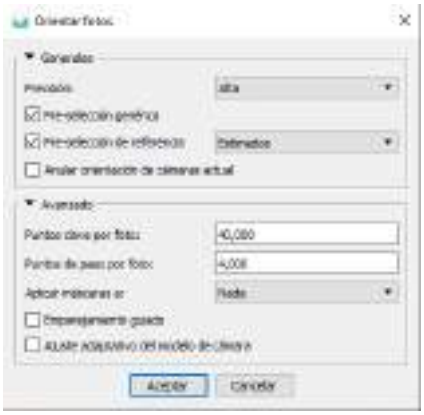


**Figure 7.** Photo Orientation Parameters of the buildings.

**Figure 8.** Photo Orientation Parameters of the topography.

- Precision: we wanted it to be high to obtain great detail of the buildings, since there are paintings and decorative details that we want to see in the model.
- Mask: we did not apply the selection of masks in the photographs, since for this we would have had to select in each photograph which elements we wanted to be processed. In our case, the cleaning and filtering process was carried out posteriori once the dense point cloud was generated. In this way, we optimized time.

The scattered point clouds of each block were obtained independently of the buildings (Figure 9).

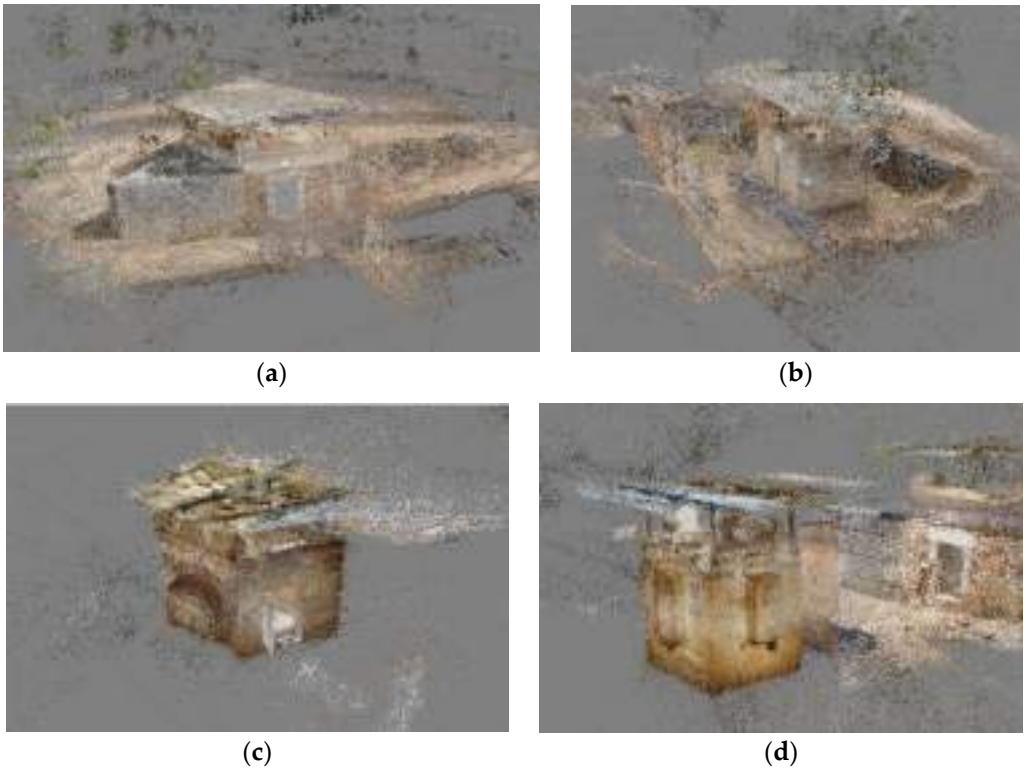


**Figure 9.** Scattered point cloud generated independently for each block into which we divided our working environment. (**a**) Sparse point cloud of the exterior of the Niger and Julios buildings (01_EXT_N-J). (**b**) Sparse point cloud of the exterior of the Voconios building (02_EXT_V). (**c**) Sparse point cloud from inside Niger and Julios buildings (03_INT_N-J). (**d**) Sparse point cloud of the interior of the Voconios building (04_INT_V).

In a parallel way, in a different file, the scattered point cloud of the environment was obtained, which was subsequently used for modelling the topography (Figure 10).

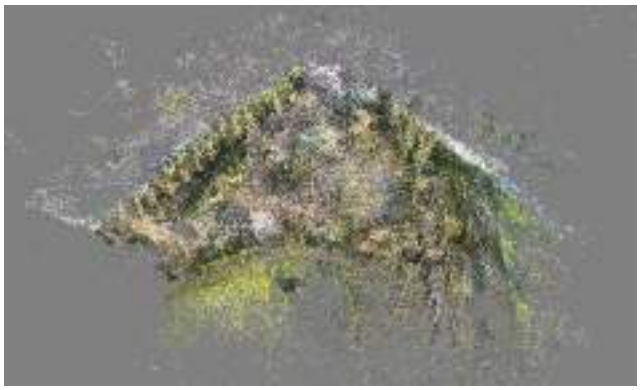


**Figure 10.** Sparse point cloud of the interior of the topography.

Point cloud optimisation

Seeking greater precision, we selected only the images with a margin of error less than 0.5 m within the sparse point cloud. The rest of the images outside that margin of error were eliminated from the frame.

In addition, we included the images that generated waypoints or anchor points with the same precision as before, seeking total coherence of the model.

This error range of 0.5 m translated into a maximum error of 2 cm in the final dense cloud if we took into account that the points generated first were anchor points of the final cloud.

Dense point cloud generation

Point clouds capture accurate and detailed geometry of an environment, thus facilitating the process of extracting information from complex and realistic geometrics of scanned elements [43,44].

In this research, point clouds were used as a fundamental tool to simplify the modelling phases within the BIM environment. Thanks to this combination, it was possible to obtain reliable results for the overall construction of the building.

When generating the point cloud, we could define the quality depending on the work to be carried out later, as it is not always convenient to generate point clouds with high quality for a greater optimisation of resources, as this requires very powerful computer equipment.

Once the dense point cloud is generated, each block contains a large number of points that define the model; however, many points appear that impair the definition of the model.

Filtering by confidence level

Subsequently, in order to use the raw point cloud, a series of steps such as cleaning and filtering of the measurement noise is performed. Generally, cleaning and filtering are user-guided because a certain level of interpretation of the scene is needed (e.g., identification of clean points of trees, people, or outliers).

After filtering each dense point cloud, the number of points is reduced considerably. This ranks the points with the highest accuracy, eliminating all points that could generate large errors and deviations from the model (Tables 4–6).

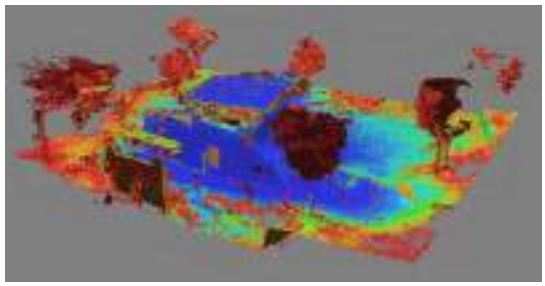
**Table 4.** Dense point cloud parameters of each building block after confidence level filtering.

| Chunk | Number of Photographs | Point Cloud Quality | Number of Points before Filtering | Confidence Filter Range | Filtering with Range 5–100 | Point Reduction Factor |
|---|---|---|---|---|---|---|
| 01_EXT_N-J | 356 | High quality | 22,082,004 | 5–100 | 12,722,611 | 1.73 |
| 02_EXT_V | 362 | High quality | 22,790,359 | 5–100 | 10,657,133 | 2.13 |
| 03_INT_N-J | 419 | High quality | 19,330,746 | 5–100 | 12,616,462 | 1.53 |

**Table 4.** *Cont.*

| Chunk | Number of Photographs | Point Cloud Quality | Number of Points before Filtering | Confidence Filter Range | Filtering with Range 5–100 | Point Reduction Factor |
|---|---|---|---|---|---|---|
| 04_INT_V | 515 | High quality | 22,241,228 | 5–100 | 21,591,613 | 1.03 |
| Topography | 760 | Medium quality | 46,921,980 | 10–100 | 17,526,328 | 2.67 |

**Table 5.** Point cloud generation process in Photoscan of the exterior of the Niger and Julios buildings.



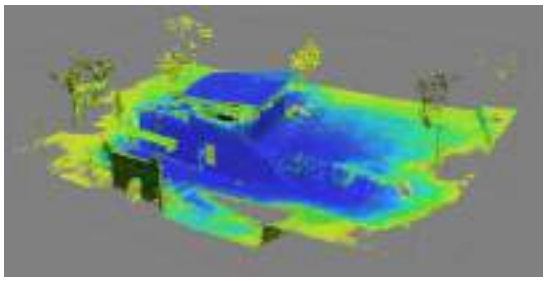
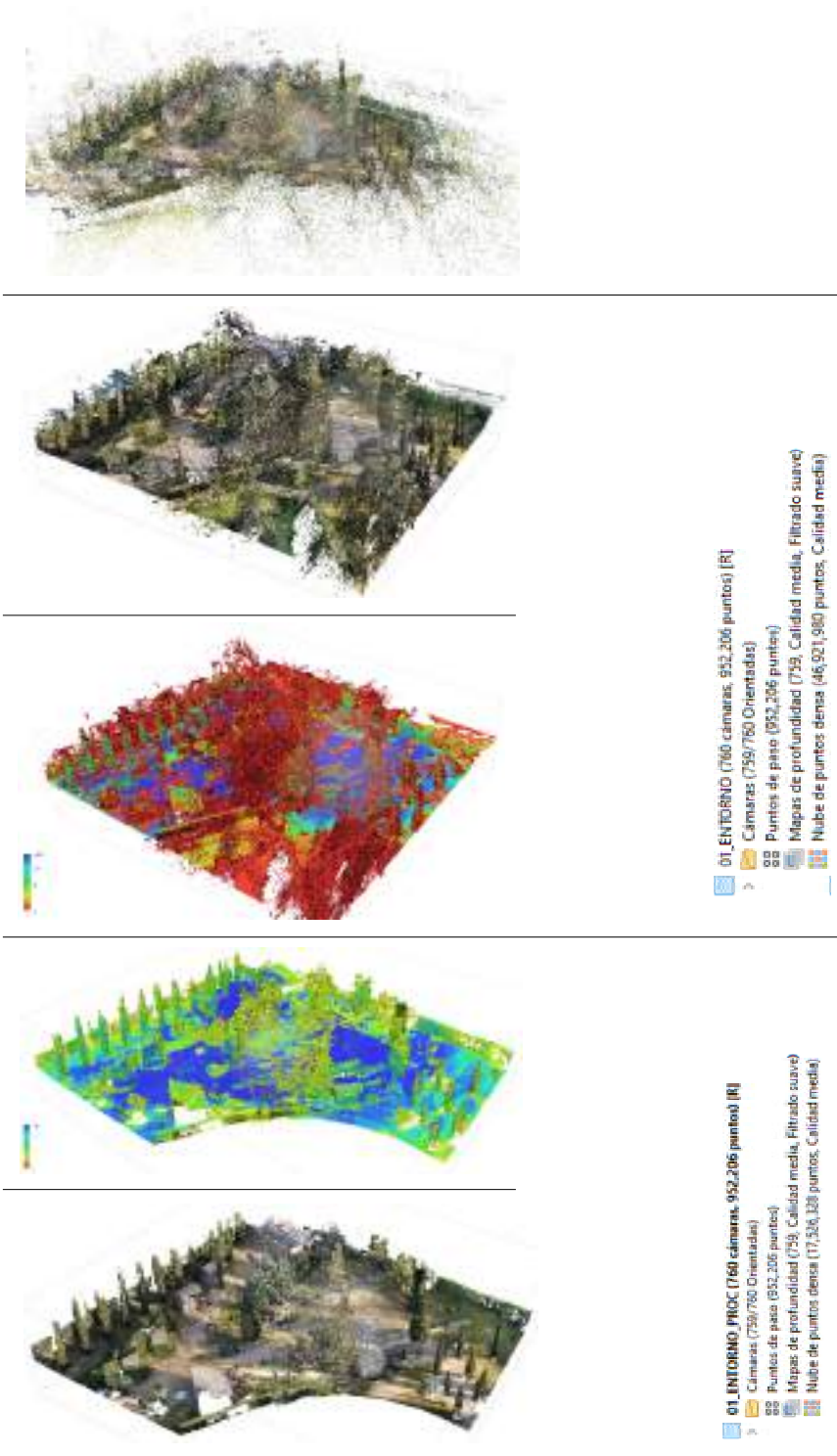


**Table 6.** Point cloud generation process in Photoscan of the topography of the environment.




Partial point cloud merging

Once the whole process was carried out with each of the partial point clouds (blocks), the point clouds were aligned with each other. The alignment of the point clouds was performed using an algorithm based on Iterative Closest Point (ICP) [45].

ICP is a method of optimising point clouds, in which one point cloud is kept fixed while the other is transformed to better match the reference. This algorithm revises the transformation in which translation and rotation are combined as necessary to minimise an

error metric, usually a distance from the source to the reference point cloud, as the sum of the differences between the coordinates of the matched pairs.

The fusion of the different point clouds can be performed in two different ways:

One-step merging: with this method, all partial point clouds are merged at once. However, it is not advisable to merge in this way because it requires a lot of computer resources, and we cannot control whether any of the partial point clouds are aligned incorrectly.

Merging in several steps: this is done using a summation criterion, in which two point clouds are merged beforehand, to which the others are added one by one. This method is slower, but errors can be controlled better, and each merging process does not require so many computer resources, allowing us to continue working with other software at the same time.

In order to merge the models, it is important that the point cloud overlaps, so that the merging is done immediately and automatically.

In our case, the merging of the different point clouds was carried out in several steps, following a summation criterion (Figure 11), in which blocks 01 and 03, which correspond to the point cloud of the exterior and interior of the Niger and Julios buildings, were merged beforehand.

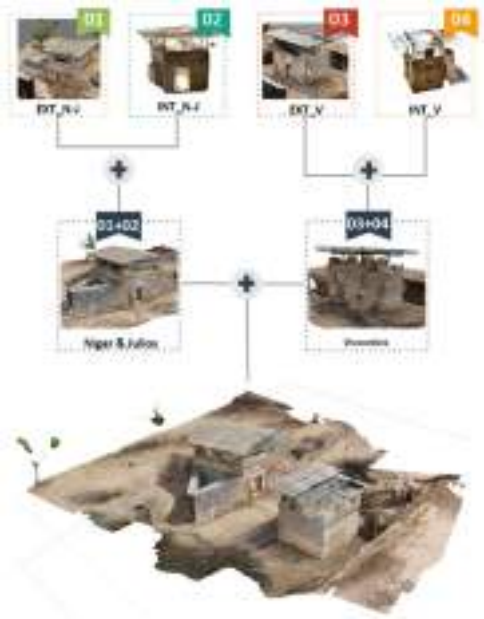



**Figure 11.** Scheme of the work process followed, from obtaining the partial point clouds to obtaining a single complete point cloud. It can be seen that the fusion of the different blocks was carried out in several stages.

Subsequently, blocks 02 and 04, which corresponded to the point clouds of the exterior and interior of the Voconios building, were merged.

Finally, the point clouds of the buildings were merged. A complete model of the three buildings (Niger, Julios, and Voconios) was created.

In order to merge the models, it is important that the point clouds overlap, so that the merging can be carried out immediately and automatically. If this is not possible, the merging should be forced by using markers.

The markers were used to merge the point clouds of the interiors with the exteriors, as in the interior the georeference of the images captured by the drone was requested, as being an interior and having a metal cover, it generated interference and was not as precise as in the exterior.

Mesh and texture generation

In addition to generating the dense point cloud, we can generate a 3D mesh of its polygonal surface as a data preprocessing method. The generated mesh is composed of

triangles on top of the point cloud itself. This mesh is also edited to fill holes in the cloud, as well as to refine and reduce the points of the model through smoothing operations, as we have seen in work by Remondino and El-Hakim [46] and Rodriguez-Moreno et al. [47].

This mesh can be given a texture, generating an optimal model to be read and processed by different software that will allow the property to be visualised in great detail (Figure 12). However, it is not useful for working with modelling software such as Revit, as it cannot be sectioned or worked with directly (we used the dense point cloud directly for this purpose).

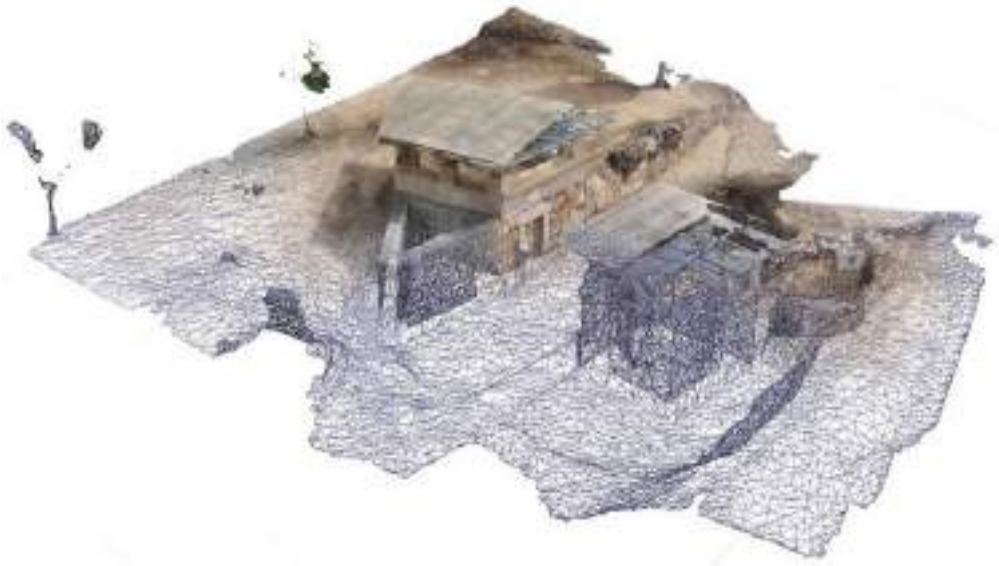


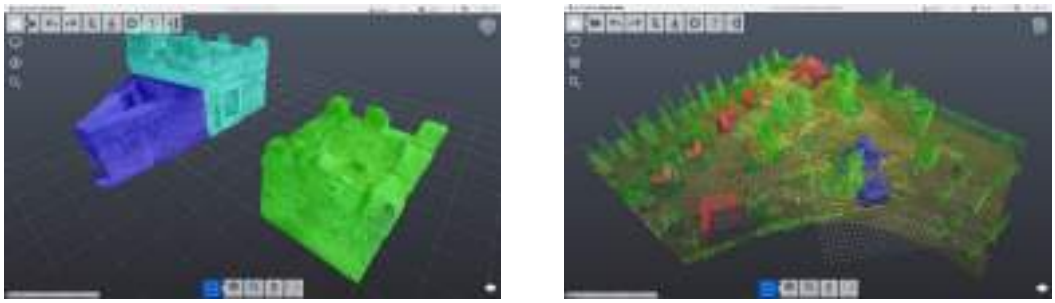
**Figure 12.** Mesh and texture generation with Photoscan.

#### 3.2.5. Point Cloud Processing

After generating the complete point cloud, we processed the cloud before importing it into Revit for modelling (Figure 13).

**Figure 13.** Workflow for further processing of the dense point cloud. The points are classified according to the nature of the points.

We used Autodesk ReCap Pro software, with which we were able to classify the point cloud; later, in Revit, we were able to control the visibility of each of the generated layers (Figure 14).



(**a**) (**b**)

**Figure 14.** Results obtained from the classification of the point cloud made with Recap. We used a colour code that allowed for better visibility. (**a**) Screenshot of the processing and classification of the point cloud of the buildings with Recap. (**b**) Screenshot of the processing and classification of the topography point cloud with Recap.

A useful classification for heritage projects is as follows:

- Vegetation: In this layer, we introduce all points that belong to trees and shrubs to be able to visualise the heritage asset without any kind of interference that may affect it
- Topography: In this layer, we introduce the points that belong to the terrain itself, which, in addition, allows us to export it independently and thus be able to generate the topography in the modelling phase.
- Heritage element: It is important to clearly define the original element from the rest, thus allowing us to visualise it in greater detail.
- Contemporary constructions: With this classification, we manage to separate the original elements of the building from those that are not. In a case where a survey is made of a building that has undergone transformations throughout history, a classification of all the elements by construction stage could be made, and in this way, a key to the facades, for example, could be made.

This classification allows us to visualise in Revit only the elements we are interested in and separate the point cloud in different Recap files in case we are interested in having the point cloud of a specific element.

#### 3.2.6. Modelling

Today, technological breakthroughs in photogrammetry and laser scanning have accelerated geometric data collection methods [48,49]. In addition, technological developments have also been described as influencing the processing tools for scanned data [50], as this step is becoming increasingly automated. However, although many 3D modelling technologies have been developed recently, the process of 3D modelling using photogrammetry data is still a manual and time-consuming process. Therefore, a change in workflows and procedures is required to speed up 3D geometric modelling [51,52].

It is true that despite the great efficiency of the BIM method, as well as the modelling of newly constructed buildings, in the field of heritage this process is not optimised, having certain limitations when modelling the irregular and heterogeneous surfaces that are generally present in heritage buildings and that give them a unique character. Therefore, due to the lack of automatization to generate the surfaces generated by a point cloud in parametric objects, the process can be considered slow and complex.

In this work, we surveyed the model with REVIT software and generated a model that integrates the design, documentation, and digital management of the building. This generated model is a dynamic one into which all the information that is generated in the future could be implemented over time.

It must be taken into account that this modelling is an approximation of the real element, as the irregularities of the wall are not reflected, so we will keep the point cloud associated with the model.

In the following, we describe the methodology followed for the generation of the model, making this process as operative and efficient as possible, so as to serve as an example for future work (Figure 15).

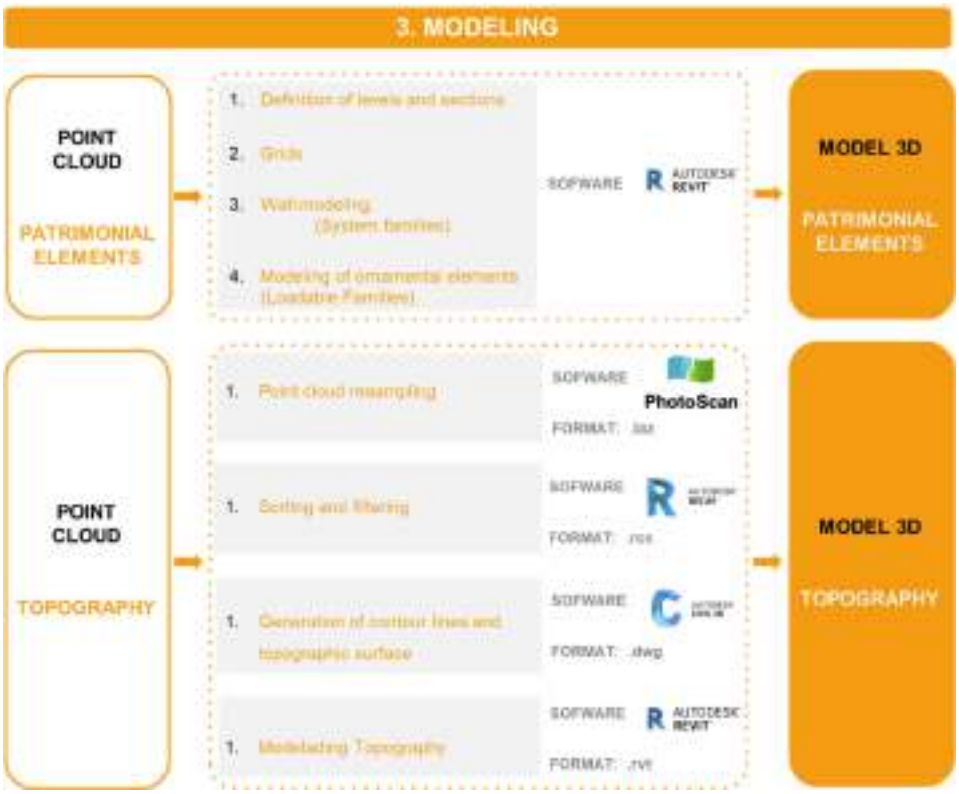



**Figure 15.** Diagram of the 3D modelling process from the point cloud obtained. Two different methods are defined, one for the buildings and the other for the topography.

Heritage building modelling

Once the definitive point cloud was obtained after the generation and processing described above, in this phase of the work we used it as a guide for the parametric modelling of the heritage buildings.

For modelling in Revit, we used two types of families: systems and loadable. The system families are used for the modelling of simple geometries, and the loadable families for the modelling of exclusive and specific elements, such as the ornamental elements in this case.

Once the point cloud was loaded in high quality with the Recap points classification, we started with the modelling of these elements, following the next steps:

- Definition of levels and sections on the point cloud: We made cuts in both the plan and the section to show precisely the geometric profile of the elements.
- Grids: A system of grids was placed on the ground plan to help us model.
- Modelling walls with Revit using the As-Built add-on: In heritage, it is common to have very different construction elements in the same building; therefore, we used a complementary Revit application called As-Built, which allowed us to automatically choose the type of wall within the Basic Wall family.

With As-Built, we can create walls quickly and accurately directly in the point cloud. The software automatically selects the most appropriate wall type according to the given wall thickness. If an appropriate wall type cannot be found, As-Built automatically creates a new, adapted wall type. It also allows us to automatically align walls to create rectangular planes (orthogonality) and continuous axial alignments, even over several floors. Tolerances

to be observed must be defined and can be reviewed in detail later for each wall component (Figure 16).

**Figure 16.** Screenshot of the modelled walls of the heritage buildings made with Revit software.

Modelling of ornamental elements

In this type of construction, it is very common to find cornices and mouldings as singular ornamental elements.

These elements must be modelled externally by creating loadable families.

The resulting elements are placed within an HBIM library that could be reused (after editing their default parameters) in future projects with a similar architecture or element.

We identify the types of cornices we have in our buildings, and with each of them we create a family that we will later load into our 3D model (Table 7).

**Table 7.** Modelling of the decorative elements: Cornices.

| Location | Photograph | Point Cloud Section | Modelling Element |
|---|---|---|---|
| Inside niche Voconios | | | |
| Main facade Julios | | | |
| Inside niche Julios | | | |

We create a specific folder with all the family files generated.

When modelling the cornices in 3D, we must first edit the wall. To do this, in the section called "modify wall attributes", we load the cornice profiles that correspond to this type of wall.

Subsequently, using the sweep wall tool, we place it on the wall we have.

With the point cloud included in the 3D model, we can obtain details of the decorative elements with great precision. Unlike traditional systems in which a calliper is used for contours, we can obtain data without having to move to the site and can even obtain details of elements placed at great heights, whereas with a traditional system it would be necessary to use auxiliary means to be able to reach them.

Topography modelling

For the modelling of the topography, the workflow shown in Figure 17 was generated.

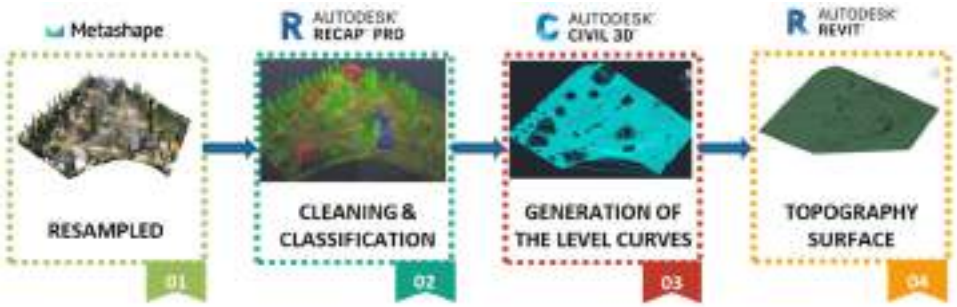



**Figure 17.** Diagram of the working process of the topography modelling from the obtained point cloud to the Revit topographic surface.

This was done automatically by importing the .dwg file generated from Civil 3D. In the tab Mass and Location, we used the command Topographical surface and selected the option create from import/select import copy. We selected the .dwg file that we prepared with Civil 3D.

In Revit we combined both the generated topography and the point cloud, in high quality, and made adjustments to the points where we wanted to increase the definition.

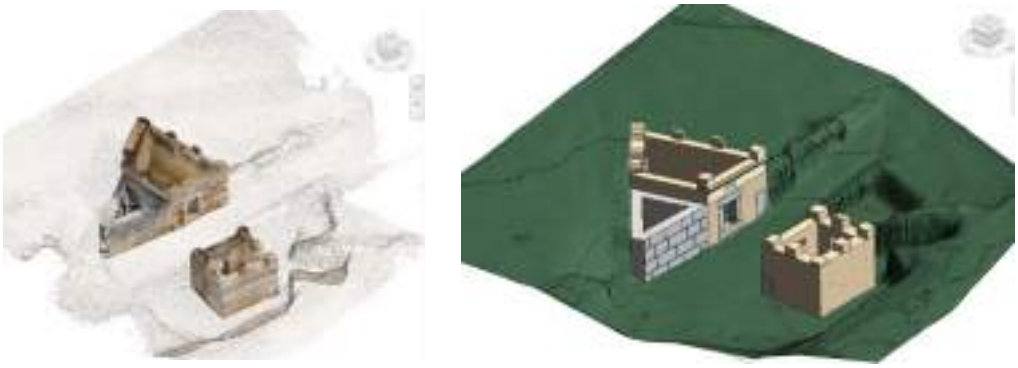
This process is the result of multiple tests with different detail parameters.

It is a fast and simple workflow. The most tedious part is the cleaning of the point cloud data (which varies greatly depending on the quality and nature of the site). However, the results are more than acceptable [53].

So far, we have made the parametric model, which contains all the geometrical information we obtained from the point cloud (Figure 18). However, we have to bear in mind that this model is an approximation of the real element, since many of the imperfections or deviations are not fully defined in the model. We could consider the model as an ideal reconstruction of the property element. That is why we kept the point cloud superimposed on this model, so that we could have the most accurate information according to the type of work we need to carry out.

### 3.2.7. Inputting Qualitative Information into the Model

The 3D model contained all the geometric information with great precision that we obtained from the point cloud [54]; however, the importance of the heritage elements lies above all in the large amount of intrinsic information that they possess; they can be considered a document in itself. This is why it is essential to implement this semantic information in the model (Figure 19).



(**a**) (**b**)

**Figure 18.** Different visual styles of the model. (**a**) Full point cloud view (buildings and topography) in Revit. (**b**) View of the Revit model of the buildings and topography.

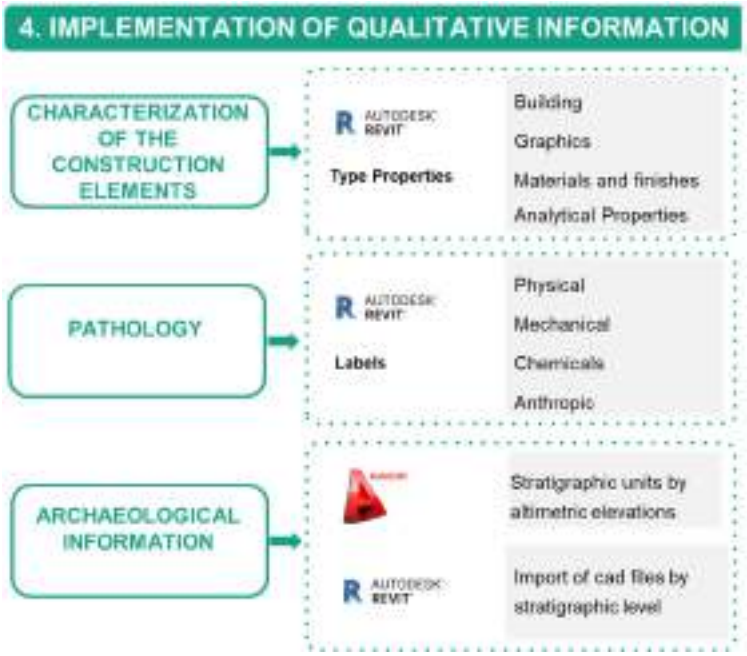



**Figure 19.** Diagram showing the type of qualitative information implemented in the parametric model and software used.

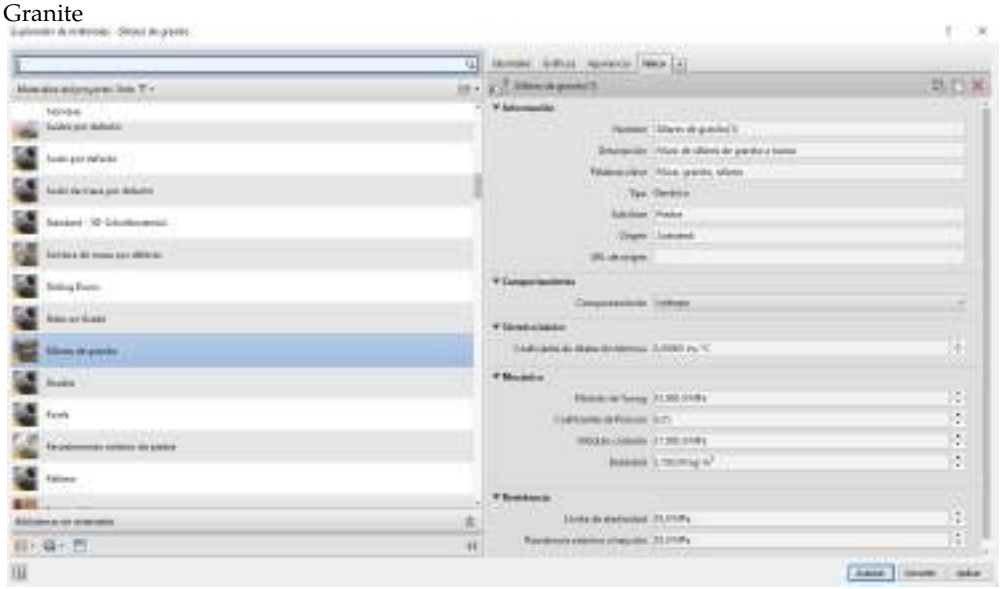
In this phase of generating the BIM model, it is necessary to have a multidisciplinary team of architects, archaeologists, historians, and restorers, among others, in which each one brings to the model the knowledge of his or her field.

Characterisation of modelled building elements

Once the main structural elements were modelled, which in this case study were the walls, we introduced as much information as possible.

The walls of any heritage building contain a large amount of information—for example, different construction phases, pieces reused from other structures, overlapping of elements, different materials, etc. (Table 8).

**Table 8.** Example of characterization of construction elements, in this case, of a wall of granite ashlars.

| **Stone Granite Ashlar Wall** | |
|---|---|
| Identification and description | Stone granite ashlar wall |
| Definition of the layers | Granite ashlars: 50 cm thick |
| Definition of material characteristics | Granite  |

Dating: Using the phases tool, the different structures and elements can be grouped by period.

Identifying the wall: In the property bar, the elements can be described, and photos can be attached.

Definition of the composition: This can be carried out by editing the type properties.

Definition of the material properties: One can detail the characteristics of the materials. In this process, it is advisable to carry out laboratory tests on the materials and add the data obtained to the model.

Pathology

In this section, we set up a system to implement the pathological information in the 3D model. To do this, we used existing conservation reports of the *Columbarios* carried out by the technicians of the *Consorcio de Mérida*.

First, we established a criterion for classifying and identifying the types of lesions according to their origin or cause. With this classification, we can define with scientific and technical rigour each of the pathological processes that affect the heritage property.

According to the studies published by architect Juan Monjo, a professor at the Polytechnic School of Madrid, lesions can be classified according to their origin: physical, mechanical, chemical, or anthropic.

For each of these groups of injuries, categories and subcategories are established according to the causes that generate them. This system for defining injury processes was obtained from rehabilitation treatises [55,56].

In Table 9 we see the classification of the lesions that cause pathological processes in the properties.

**Table 9.** Classification scheme for lesions that cause pathological processes.

| | Family | Type | Subtype |
|---|---|---|---|
| | Physics | Damp | Capillary, filtration, accidental |
| | | Dirt | By deposit, by differential washing |
| | | Erosion | Meteorology |
| | Mechanics | Deformations | Arrow collapse |
| | | Cracks | By loads |
| | | Cracks | For support |
| | | Detachments | Continuous linings |
| | | Erosion | Shocks, friction |
| | Chemistry | Rust | Surface |
| | | Corrosion | Pre-oxidation, differential aeration |
| | | Organisms | Xyloxan mushrooms, xyloxan insects Vegetation |
| | Anthropic | Improperly performed repair; missing elements | |
| | | Incorrectly carried out repair; constructive deficiencies | |
| | | Dirt; graffiti | |

This can be done by entering keynotes in the model (Figure 20).

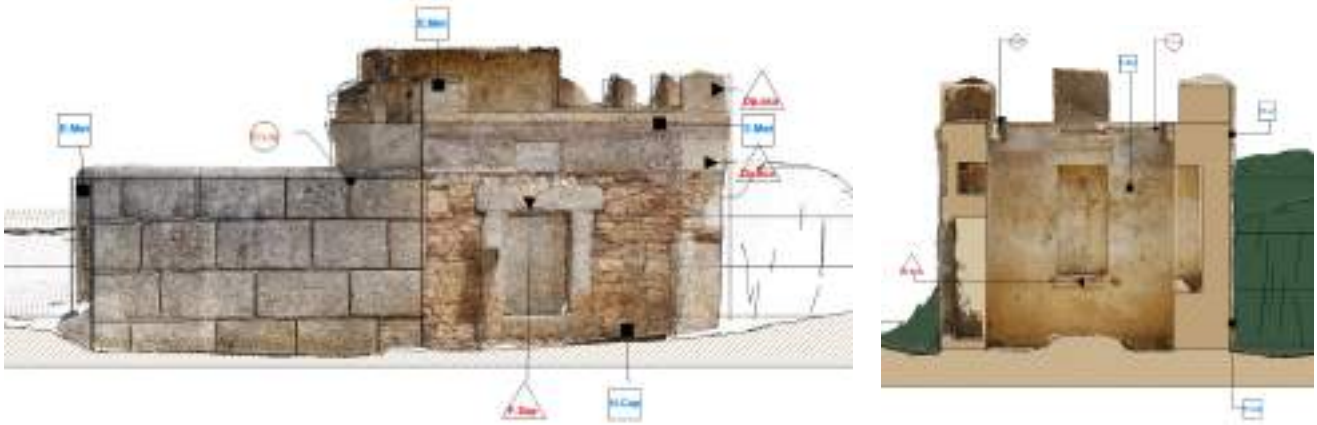
To differentiate each family of lesions, we created a label family with the different symbols (as shown in the table above), which is stored in the HBIM Library.

We created a legend with each type and subtype of lesion, elaborating a .txt file, which was saved in the library and subsequently loaded in the configuration of the keynote creation.

When a new lesion type is diagnosed, we can add the legend to the .txt file saved in the library.

Figure 21 shows two views of what the injury map of the columbaria would look like according to the data provided by the *Consorcio de Mérida*.

**Figure 20.** Screenshot of injury legend entered in Revit as keynotes.



(**a**) (**b**)

**Figure 21.** Example of a pathology plan showing the lesions of each of the constructive elements of the buildings. (**a**) Injury map of the Niger and Julios building elevation. (**b**) Map of lesions. Cross section of the Voconios building.

Archaeological information

Due to the nature of the heritage property we are working on, it is important to define how to incorporate the information obtained from the excavation campaigns into our project.

We detail two work systems, one incorporating the information that is already documented, and the other proposing a future work system to document the information and implement it in the models.

Currently, in an archaeological excavation, all the remains found in the different excavation campaigns are documented and drawn in 2D in AutoCAD, assigning each stratigraphic unit to a layer. In addition, each stratigraphic unit is labelled with a code and the elevation at which it is located. For this purpose, orthophotos extracted from photogrammetry are used as a support to draw the archaeological remains in more detail. However, there is no photogrammetry of this enclosure, since in the year in which the

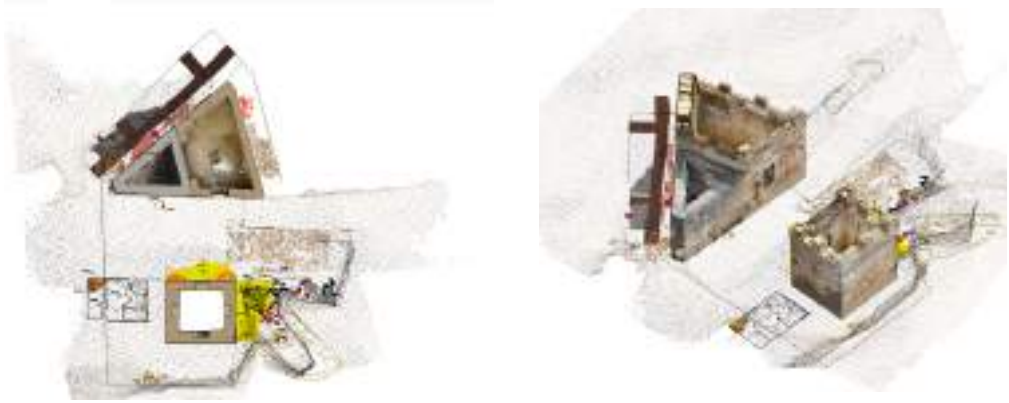
different excavation campaigns were carried out around these structures, this technique was not well-developed.

In this paper, we introduced the data obtained from the excavation via the following steps:

The documentation of the different excavation campaigns can be found in AutoCAD.

In the AutoCAD file, each stratigraphic unit is selected and moved to the indicated elevation, thus converting the 2D AutoCAD file into a 3D file with the different strata; in this case, we separated the different strata by historical periods into different AutoCAD files.

In this way, we insert the AutoCAD files into the Revit model, depending on each stratum, and we are also able to observe the exact height of the different stratigraphic units, which make it easier when carrying out any adaptation project on the site, as we would have all the information to date and would avoid unforeseen events when carrying out excavations for trenches or foundations (Figure 22).



(**a**) (**b**)

**Figure 22.** Plans with the documentation extracted from ancient archaeological excavations. (**a**) Top view of the archaeological documentation introduced in the model. (**b**) Perspective view of the archaeological documentation introduced in the model.

For the future, we propose using the same system of work described above to document archaeological remains.

Photographic reporting of the remains by stratum.

Generation of a point cloud for each stratum using Agisoft Photoscan.

Classification of the points by stratigraphic units using Recap software.

Importing the Recap file with the different layers into Revit.

In Revit, different phases can be created in which filters can be applied depending on the archaeological remains that are extracted, those that are left visible, and those that are left covered, so that all the documentation remains in a 3D model.

## 4. Results

By applying the methodology proposed in the case study of the *Columbarios* of Mérida, we can highlight several results based on the objectives initially set.

The first objective was to develop a workflow applying new low-cost and precise technologies that optimise the management of the heritage of a World Heritage City such as Mérida [29,30,57,58].

A new structure was generated for the work of a multidisciplinary team (Figure 23), which includes the process of data capture and surveying using point clouds, which allowed us to generate more geometrically precise models; in addition, with the introduction of qualitative information to the digital model, the information from each of the areas responsible for heritage management was unified, which means an improvement in the efficiency of the work processes. This work paves the way for the gradual implementation of the BIM method in this institution, thus reducing the costs of projects and studies.

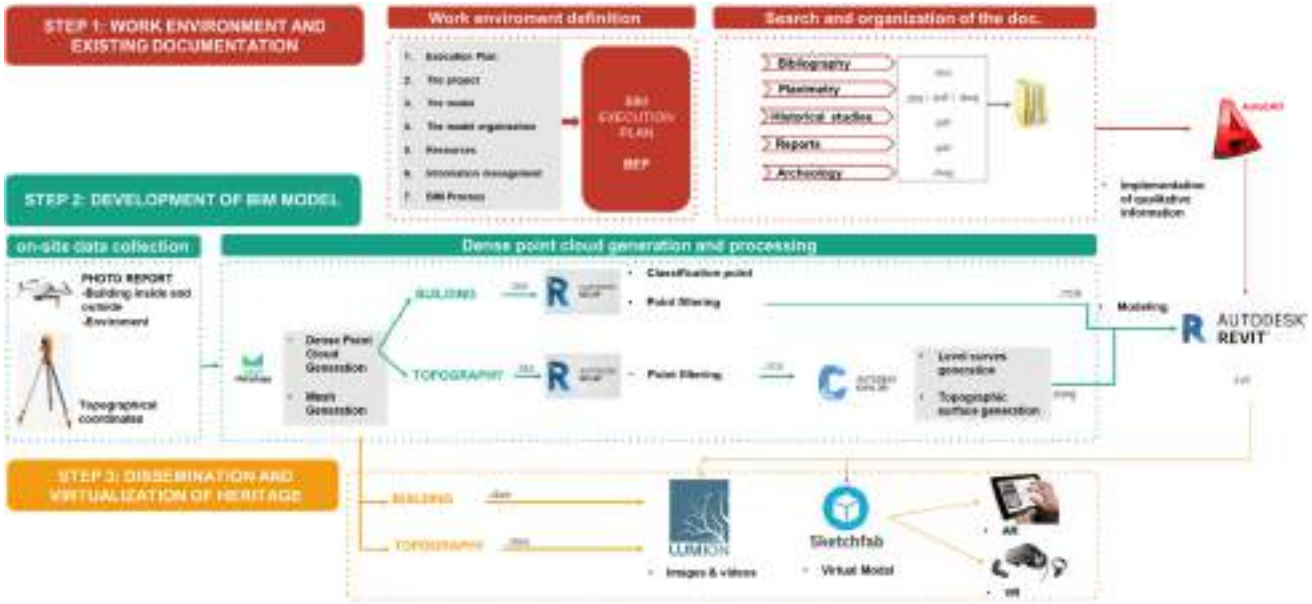



**Figure 23.** Scheme of the protocol and workflow from data capture to heritage dissemination.

In response to the need to obtain precise and accurate planimetry of the investigated element, we obtained an HBIM model of the *Columbarios*, a heritage asset for which there were very detailed archaeological studies, but the planimetry and graphic documentation had been obtained by traditional 2D methods and was not updated with current technologies.

The capture of data for the creation of a planimetry by means of photogrammetry was carried out using the UAV system in a few days, obtaining a highly accurate point cloud. This system is very efficient, as in a short time it was possible to obtain photographs of a large area of land that allowed us to carry out a topographical survey of the surroundings, which in an archaeological site open to the public is essential for planning accessible museum adaptation projects.

This method was a success for the digitisation of heritage that lacked up-to-date and accurate planimetry, which is crucial for heritage management (Figure 24).

An HBIM model with great geometric precision was obtained and served as the basis for different methodological proposals for the implementation of information from different disciplines, opening up paths for further research for the systematisation and optimisation of work in different fields.

With this HBIM model, we have within reach all the existing information generated by all the agents involved in the heritage management process [59,60].

In addition to the geometric data (Figures 24 and 25), we can visualise other information of a semantic nature, such as the characterisation of the materials and construction systems (Figure 26a), information extracted from the excavation campaigns (Figure 26b), or even the deterioration and pathological process (Figure 26c). All of this allows us to analyse the evolution of the monument throughout the different historical stages, which helps us to understand and contextualise the heritage that has come down to us, and to use it to disseminate it (Figure 27).

This model is a powerful tool that uses low-cost methods that allow us to analyse our heritage quickly and efficiently, thereby supporting the daily work of professionals in different fields.

Finally, an important part of this research project is the visualisation of heritage in an informative way.

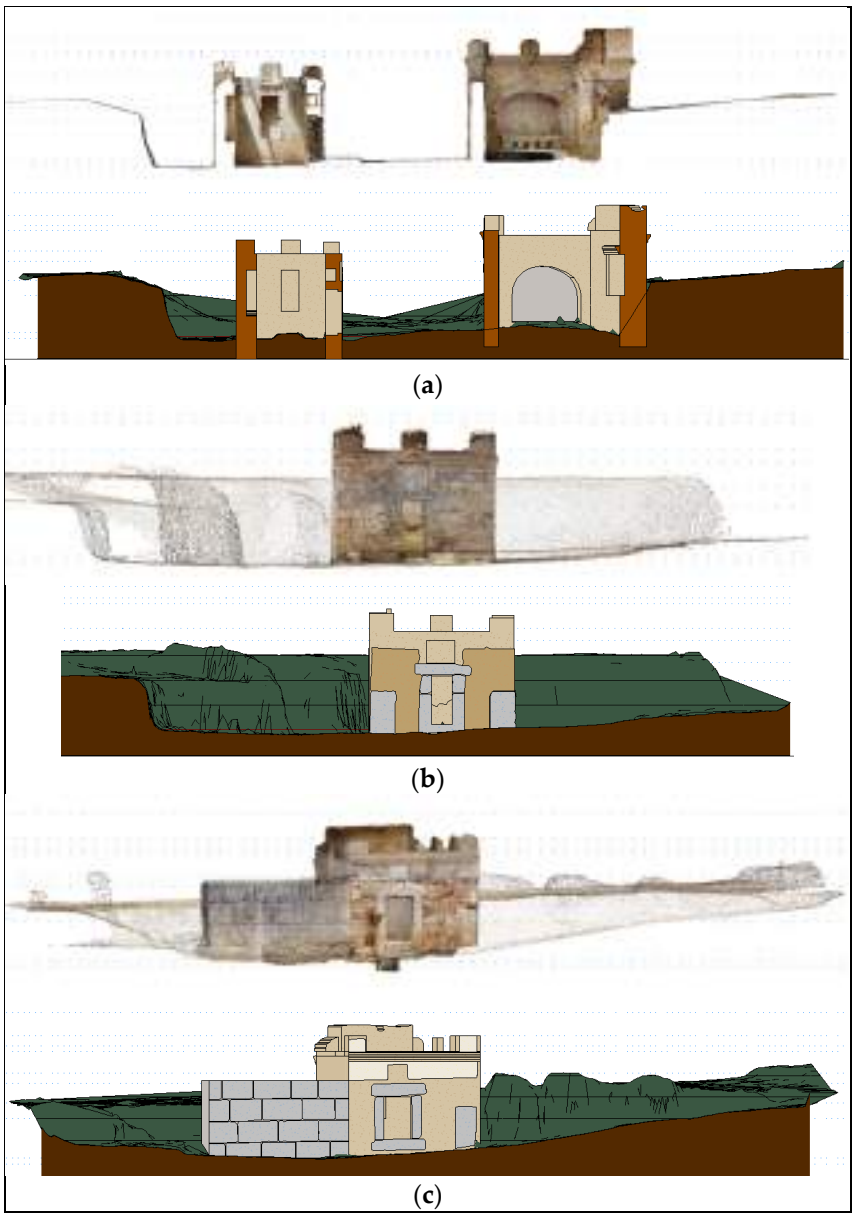



**Figure 24.** Comparative views of the survey obtained from the point clouds and the generated 3D model. We can see that the geometric accuracy of the point cloud is millimetric, while the 3D model is an approximation of the geometry of the buildings. (**a**) Longitudinal section of the point cloud (top) and of the model (bottom). (**b**) Elevation of the Voconios building. Point cloud above and model below. (**c**) Elevation of the Niger and Julios building. Point cloud above and model below.

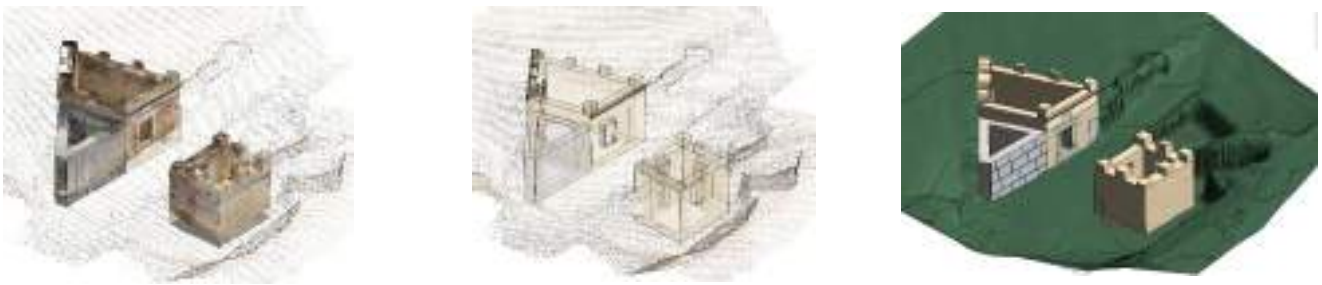
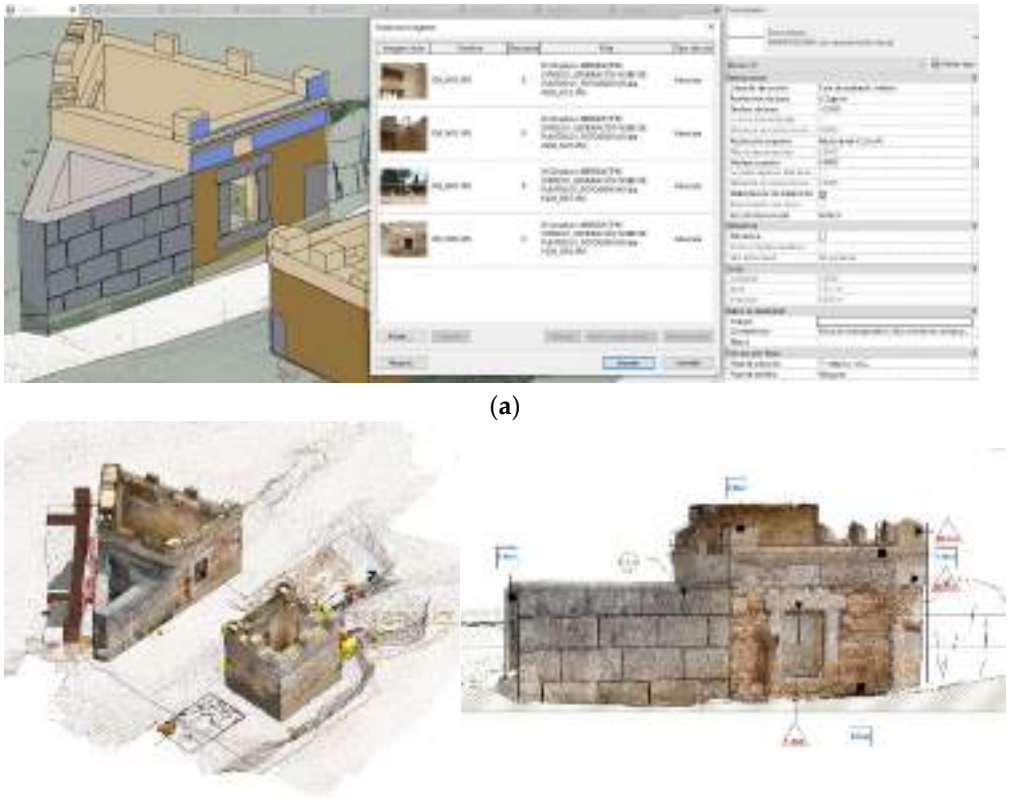


**Figure 25.** Different visualization styles of the HBIM model whereby one can obtain geometric data of heritage buildings.



(**a**)

(**b**) (**c**)

**Figure 26.** Different information that can be consulted in the model: (**a**) Material characterization; (**b**) archaeological information; (**c**) pathological information.

**Figure 27.** Screenshot of the mobile displaying the 3D model of the *Columbarios*.

The HBIM model generated has direct utility for the educational dissemination of heritage; we can underline the didactic advantages it has in terms of motivating and increasing the understanding the past on the part of the nonspecialist public. In this line of thought, we find Sabbatini, who exposed the limitations of the traditional museum when it

comes to accessing culture [61]; the COVID-19 pandemic increased these difficulties, but with the virtualisation of heritage assets we can bring them closer to every corner of the world. It should also be noted that archaeological heritage has its peculiarities, and that on many occasions there are areas, which, either because of their state of conservation or their inaccessibility, remain hidden, preventing them from being visited.

Virtual archaeology, applied to the didactics of history, is a field with a promising future, as it combines different innovative elements, with the common denominator of the use of new technologies; new technologies can be applied to education as a tool for inclusion and motivation; they can also disseminate, in an immersive and interactive way, the historical and cultural heritage of the countries of the world [62–65].

In this case, we can publish the model through an online platform such as Sketchfab, which allows each user to interact with the model, see in detail the elements that interest them, and enter explanatory notes for each relevant element.

A QR code can be scanned with a mobile phone to enter the monument and see the interior spaces that are not open to the public.

The future development of this research work could be the application of advanced techniques such as Augmented Reality and Virtual Reality (Figure 28).

**Figure 28.** QR code to scan and be able to make a virtual visit to the monument. Augmented Reality (AR) through a mobile phone. Use of Virtual Reality glasses to enter the interior of funerary buildings.

With these techniques, we can create immersive and interactive experiences through which the visitor meets culture, encountering the symbology and, as it were, the 'mind' of past societies [28,36].

This is made possible by being able to integrate a large amount of information from other sources, sites, and research into the virtual reality space, in what has come to be called "virtual heritage" or "digital heritage" [66,67].

For the future development of this work, we will use the Sketchfab application and Oculus Rift S VR glasses.

## 5. Conclusions

Nowadays, there is a trend towards optimising project development processes and improving resource management. This has a direct impact on architecture, which is currently undergoing a radical change in terms of the methods of project and building development.

In architecture, different BIM platforms, as well as technologies focused on 3D graphic surveying, were refined with the aim of streamlining architectural representation techniques. Having an accessible 3D digital model improves the planning, design, and maintenance of buildings. These collaborative working methods in recent construction projects have been fully optimised, but for heritage there is still some way to go.

With regard to the data collection and survey of buildings, this has been done by capturing photographs with a drone, this being a low-cost technology that can be within the reach of any technician and, therefore, allows us to test the effectiveness of this method

compared to the traditional one in terms of quality, time, and cost. We are aware that with the use of terrestrial photogrammetry we would increase the accuracy of the data collection; however, this technology requires equipment such as laser scanners, the use of which is restricted due to the high cost of the device.

One of the major disadvantages when using BIM platforms in heritage projects is modelling. Each element or heritage asset has its own formal and constructive singularity, since the manufacturing of the pieces is not standardised, and, furthermore, they have undergone a rheological process. This has contributed to the present-day deformations and irregular shapes. For this reason, the restrictions and automatization of BIM software tools and the lack of algorithms capable of automating the modelling of complex shapes from point clouds means that the BIM modelling process is, nowadays, almost manual and much slower than the modelling of new buildings. Using software such as Revit becomes complex, and in addition, when applying automatization to irregular elements, the result ends up being imprecise in terms of its approximation to the real element.

It would be ideal if BIM platforms were capable of automatic modelling based on the method of point clouds; however, for the time being it can only be used as a tool to support modelling.

In the present work, we suggest a 3D model with an integrated point cloud, which provides geometric data with a high accuracy; through the 3D model generated with Revit, we added qualitative data, which were previously collected and processed.

Despite the disadvantages detected, these methods continue to offer more advantages than traditional systems, as until now carrying out a reliable survey of a heritage asset was a very arduous task that did not always generate optimal results.

Generating this documentation makes the process of designing projects more efficient, so it would be interesting if most of the heritage included in archives could contain all this documentation in a 3D model.

The proposed method systematises the parametric modelling process. In addition, an HBIM library has been generated with the modelled singular elements. This gives flexibility to its parameters and allows rapid changes to be made almost immediately. All this lays a foundation so that in the future, these elements can be adapted to other models, resulting in said HBIM library gradually growing and facilitating the modelling of heritage buildings.

The lack of international HBIM libraries, the diversity of architectural periods, and insufficient international collaboration have limited the potential use of HBIM. Therefore, much remains to be done in this area, and research and development needs to be implemented to address the continuous progress of BIM platforms and their relation to architectural heritage.

Furthermore, this methodology is also an effective solution for simplifying the work of architects, restorers, archaeologists, engineers, builders, and other professionals involved in the processes of the rehabilitation, reconstruction, or maintenance of architectural heritage, because BIM platforms and tools allow for the interoperability of information and communication between the different actors involved.

In short, this system allows for greater efficiency in the development of restoration projects, and, in addition, will contribute to the dissemination and popularisation of the heritage itself, since, with the use of virtual technology, it will be possible to visit inaccessible areas of a monument from anywhere in the world. This is a way of bringing heritage and culture closer to everyone, regardless of where they live, their financial situation, etc.

The application of new technologies for the visualisation of archaeological heritage offers a wide range of possibilities that will need to be further researched and implemented. Certain archaeological sites can be recreated at different historical periods to allow people to visualise the different transformations and uses that they have undergone over the centuries.

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