

Image-based 3D Modelling in Archaeology: Application and Evaluation

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ABSTRACT

Image-based 3D modelling tools and techniques can be used to support some stages of the archaeological process. Two application examples, for two sites of the Roman Era, are presented, illustrating the usage and usefulness of such tools for the archaeological survey. For a quadrangular pool in the Milreu Roman Villa (Faro, Portugal), the 3D models resulting from the application of two different image-based modelling tools, using the same initial set of digital photos, are compared regarding time spent and model accuracy. For the *Fonte do Ídolo* in *Bracara Augusta* (Braga, Portugal), the result of a traditional survey is compared both with a laser-based survey and an image-based survey.

Keywords

Image-based modelling, Archaeological process.

1 INTRODUCTION

As is well-known, the archaeological process comprises several steps that begin with the excavation and archaeological survey, proceed to the analysis and interpretation stage, and end with the dissemination of results. Archaeological interpretation and research depend upon accurate data collection during excavation. Traditional data collection, as stated in [DeR13a], is always a two-dimensional survey of a three-dimensional reality, which certainly introduces potential inaccuracies. An excavation is always a destruction, but the purpose of archaeological survey is, exactly, to mini-

mize the consequences of this irreversibility. Hence, a major concern of different archaeology teams in an archaeological site should always be to ensure the visual accuracy and the exactitude of the archaeological record.

The quality of the archaeological record regarding accuracy is obviously a great concern of all archaeology teams. In terms of accuracy, archaeological data acquisition using laser technology is certainly a valid decision. However, the high cost of the devices, as well as the severe conditions of some archaeological sites do not facilitate its use. Therefore, the use of image-based techniques, based on structure from motion algorithms from computer vision, to automatically perform 3D reconstruction, appears to be a valid and affordable option that has increasingly gained adherents in archaeology [Bru12a].

Although image-based modelling techniques have only lately gained some importance in archaeology, their use in heritage is not recent. Thus, the following section will be a brief retrospective of the usage of this technol-

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ogy, trying to analyse which stages of the archaeological process have most taken advantage of this practice. In the third section two examples will be presented, where image-based modelling techniques were used for archaeological data acquisition, carried out within different projects of the Archaeology Unit of the University of Minho (UAUM). The first example allows comparing the performance of two free image-based modelling packages, regarding mesh density and time necessary to produce a 3D model. The 3D reconstructions were done using the same dataset of a quadrangular pool located at the Roman Villa in Milreu (Faro, Portugal). The other example concerns the archaeological record of a monument in Braga (Portugal) known as *Fonte do Ídolo*. Three distinct data acquisition procedures were carried out: the first took place in 2005 and was performed according to the traditional methodology, the second was performed in 2008 and used a total station and a hand-held laser scanner, the latter was completed recently based on simple photos. The three methodologies are compared regarding the time used for each data acquisition and the quality of the acquired data.

The last section is reserved for the presentation of some conclusions regarding the usage of image-based modelling during different stages of the archaeological process and to point out some guidelines/ideas that might contribute to accomplish the needs of archaeologists during the entire archaeological process.

2 IMAGE-BASED MODELLING IN HERITAGE

Already in 2000, the *3D MURALE* project developed image-based 3D capture and visualisation technologies for archaeology, using as test case the ancient city of Sagalassos (Turkey) [Pol01a]. The main goal of that European IST project was to develop affordable tools that would be easy to use by archaeologists to present different types of archaeological objects with acceptable visual quality.

Later, in 2003, the EPOCH network gathered several European cultural institutions to join efforts for improving the quality and effectiveness of the use of information and communication technologies for cultural heritage [Arn07a]. Within this project and regarding image-based modelling, the Vision for Industry Communications and Services group at the Katholieke Universiteit Leuven (Belgium) developed a web-based 3D reconstruction service to be used in the cultural heritage field. This service, called *ARC 3D*, starts with the uploading of digital images of an object or scene. The automatic reconstruction process computes the camera calibration, as well as dense depth maps for the images. The reconstruction result can be later downloaded and visualized on a workstation. Also under this project, the

Visual Computing Lab at ISTI-CNR (Italy) developed an extremely useful and open-source tool, called *Mesh-Lab*, for processing and editing 3D triangular meshes [Cig08a].

More recently, the 7th Framework Programme funded the 3D-COFORM project, that brought together not only several former EPOCH partners but also other prestigious European cultural heritage organizations. The aim of this consortium was to promote and enhance the use of 3D data for long term documentation of tangible cultural heritage. To achieve this the 3D-COFORM consortium sponsored several research activities that established an important set of tools to be used in different scenarios such as archaeological and historic urban site modelling or 3D artefact acquisition. But the utility of these tools is only recognised if they are successfully used, therefore 3D-COFORM established a Virtual Centre of Competence in 3D to promote their role in cultural heritage projects [Nic10a].

As a matter of fact, there are several archaeology projects that are actively using image-based modelling techniques for architectural structures acquisition [San13a] or during the excavation process [Her12a][DeR14a][McC14a]. There are several different image-based modelling packages available, but according to the surveyed literature the more common are *123DCatch* from *Autodesk* [Bru12a][San13a][McC14a] and *PhotoScan* from *Agisoft* [Bru12a][DeR13a]. Alternatively, open source packages such as *VisualSfM* may also be used [DeR13a][McC14a].

3 USING FREE IMAGE-BASED MODELLING TOOLS

As stated in [DeR13a], the 2D representation of 3D archaeological entities generates some loss of information. Therefore, various computer vision techniques, such as structure from motion (*SfM*) and dense stereo-reconstruction algorithms, are already used for recovering 3D shape and appearance of archaeological objects in some archaeological excavations [Her12a]. Besides the advantages for the archaeological record, it enables also the use of real 3D data in the visualization process.

There are several low-cost or free computer vision based software packages that enable the generation of 3D point clouds and the representation of 3D meshes. Since some archaeology projects deal with severe budget constraints, two free software packages were selected for comparison: (1) *123DCatch* from *Autodesk* [123D] and (2) *VisualSfM* [Wu13]. While the two packages were used and compared in the case of the Roman pool in Milreu, for the reconstruction of the *Fonte do Ídolo* only *123DCatch* was used.

123DCatch is extremely straightforward and easy to use. It takes only a few simple steps to create a real-

istic 3D representation of an archaeological object. The first step is to take digital photos of the object that has to be represented. It is recommended to shoot at least one loop of about 20 sequential photos in small increments. If it is physically possible, another loop from a different angle should be taken, since this will improve the quality of the reconstructed 3D mesh. Also, to improve reconstruction results sticky targets should be placed around the object. The following step uploads the photos to the cloud, where the 3D model is created and saved into the cloud storage space. The creation of the 3D model is not dependent on any user configuration. Finally, some post-processing has to be performed on the 3D model, in order to isolate the data that is really necessary for archaeological research.

VisualSFM is an open-source graphical user interface application for 3D reconstruction using *SfM*. As in the previous software package, the first step is to take digital photos. However, unlike *123DCatch* these photos are not uploaded into the cloud, but they are added into the *VisualSFM* workspace. The next step is to perform feature detection and full pairwise image matching. At any time it is possible to add more photos and to perform a customized feature detection and image matching. After the matching stage the user is able to perform a sparse reconstruction that precedes a dense reconstruction. This dense reconstruction delivers a 3D point cloud that still has to be transformed into a 3D mesh. The 3D mesh and the final post-processed reconstructed object are obtained with *MeshLab*.

The quadrangular pool of the Roman Villa in Milreu (Faro, Portugal)

The Roman ruins of Milreu are located outside Faro, near the village of Estoi. They are considered an important archaeological site in the Algarve region. The richness of this villa is shown by its considerable amount of archaeological structures and findings [Hau02a]. The structure of interest is a quadrangular pool coated with marine themed mosaics, referred as mosaic number 2 and carefully described in [Car08a].

Before starting the photographic survey of the quadrangular pool, targets were placed around the structure. Targets are usually white circles with a black circumference of 1cm in diameter and a concentric black circle of 5mm in diameter, printed on adhesive labels. These targets are generally used to improve the reconstruction results and, in a later processing phase, for manual stitching of vertices. Figure 1 shows the distribution of some targets over the pool.

The survey was performed using a *Canon EOS 550D*, with which a loop of 24 photos was shot. The photos have enough overlapping and at least three targets are always visible. The entire 3D reconstruction process was carried out on a *ASUS K55V* with an *Intel Core*

i5-3210M (2,5GHz) processor, 4GB memory, a 64-bit operating system (*Windows 7*) and a 2GB DDR3 *nVidia GeForce GT 630M* graphics card.

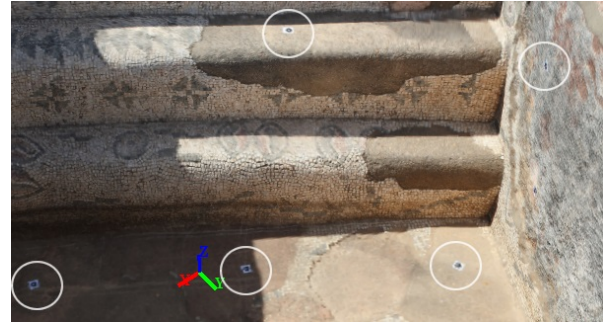


Figure 1: Distribution of the sticky targets over the surface of the quadrangular pool

Figure 2 displays the *123DCatch* user interface with the reconstruction of the quadrangular pool without any post-processing of the mesh. It took about 27 minutes to upload the 24 pictures and to compute a mesh of 229,072 vertices and 366,570 triangles. As a matter of fact, 3D model computing rather depends on the internet access upload speed, than on the computer hardware.

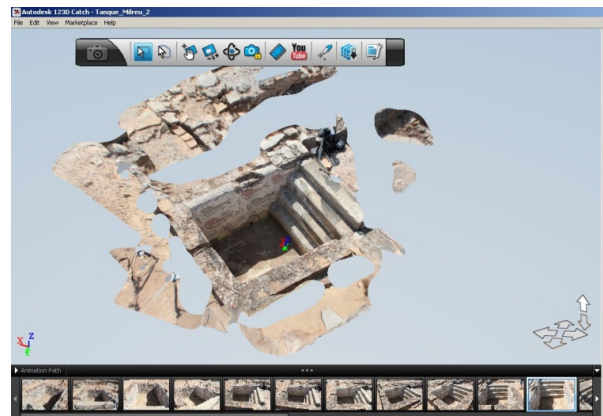


Figure 2: Pool reconstruction with *123DCatch*

The same structure was also reconstructed with *VisualSFM*, using the same images and the same hardware. After adding the photos into the *VisualSFM* workspace, the sparse reconstruction generated a point cloud with 11,304 points in 28 seconds, while the dense reconstruction generated a point cloud with 1,495,114 points in 10h 16m 10s. Both point clouds are represented in figure 3.

After the point cloud generation, *MeshLab* was used to create a 3D mesh from the point set. This comprises several steps: (1) computation of normals for the point set; (2) for a dense point cloud a point sampling will be necessary; (3) finally, points and normals are used to build a 3D surface using the Poisson Surface reconstruction algorithm. Figure 4 shows very satis-



Figure 3: Sparse (left) and dense (right) point cloud of the quadrangular Pool

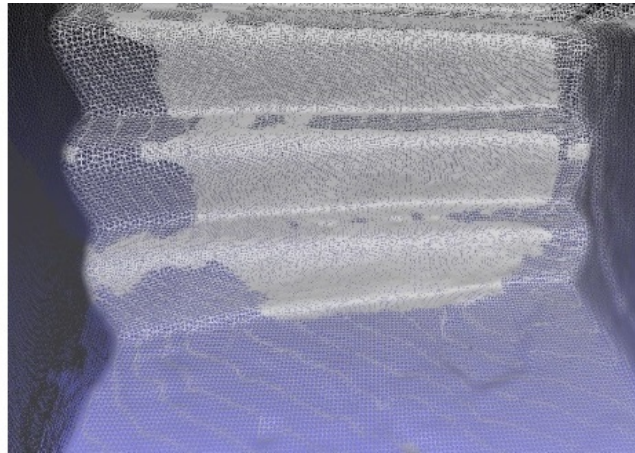


Figure 4: 3D mesh of the Pool

factory mesh reconstruction with 833,051 vertices and 1,666,062 triangles.

The *Fonte do Ídolo* of *Bracara Augusta* (Braga, Portugal)

The *Fonte do Ídolo*, in Braga, Portugal, is a roman religious structure from the I century AD which was discovered in the late XVII century and has been studied since then. The monument has a $6m \times 2.20m$ granite façade with two sculptures and several epigraphs, encompassing an overall area of about $78m^2$ ($13m \times 6m$) [Ele08a] (see figure 5).

Traditional Survey

In 2005 a major archaeological survey took place in order to properly document this archeological site. The interpretation of this site was based on the analysed and perceived reality, however this survey, which is a testimony of the site, enhanced its interpretation. The survey was performed using manual drawing, describing scrupulously both details and measures of the identified structures. This task was performed not only with the traditional tape measures, graph paper and plumb line,



Figure 5: The *Fonte do Ídolo*

but also using topographic precision equipment, such as a total station (*Nikon Total Station DTM 310*) and a level (*SOKKIA B20*), to ensure the correct georeference of the monument within the city mesh.

All structures were carefully recorded by drawing their plan over a graph paper. The chosen scale was 1:20 in order to provide a detailed and precise representation.

The façade of the monument was also recorded, with the same scale, reproducing the various figures and inscriptions present in this granite outcrop. The drawing replicates on paper the outlines of the overall structures and figures. This applied methodology enabled furthermore the establishment of the built stratigraphy unit (UE), regarding each of the detected structures. Finally, the survey was completed with a detailed and comprehensive photographic record.

The entire survey was carried out by two experienced archaeologists during two weeks. After the survey, the drawings were scanned and vectorized with a CAD system, to be later used for research and dissemination purposes (see figure 6).

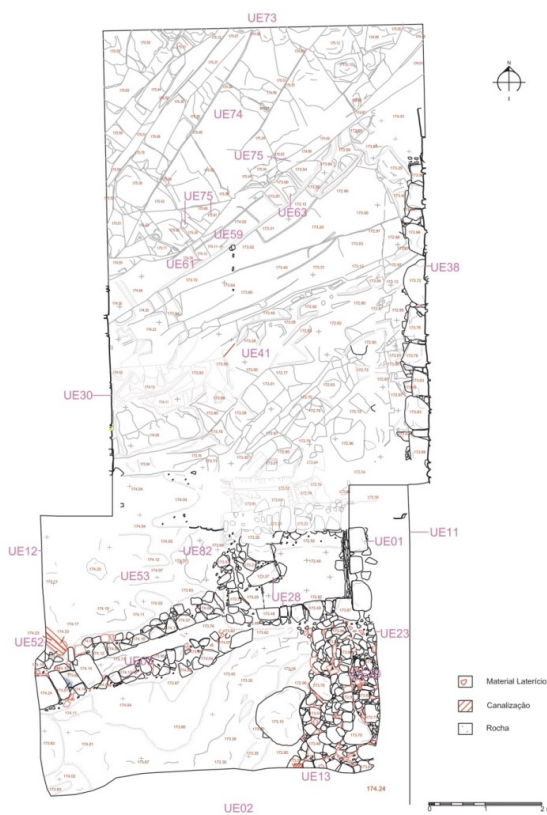


Figure 6: CAD processed traditional survey

Laser Scanner and Total Station based Survey

Another survey of the *Fonte do Ídolo* took place in 2008 and it combined data acquisition with a total station and a laser scanner. A detailed description of the 3D acquisition process and the purpose of this survey can be found in [Bar08a]. In this 3D geometric acquisition the total station (*Nikon Total Station DTM 310*) was used to get a geo-referenced, but less detailed, 3D mesh (15,621 vertices and 29,635 triangles) of the granite monolith that involves the monument, while the 3D laser scanner (*ZScanner 700* from *Z Corporation*) was used to obtain

an accurate and very detailed 3D model (1,137,721 vertices and 2,263,090 triangles) of the sculptured façade of the monument.

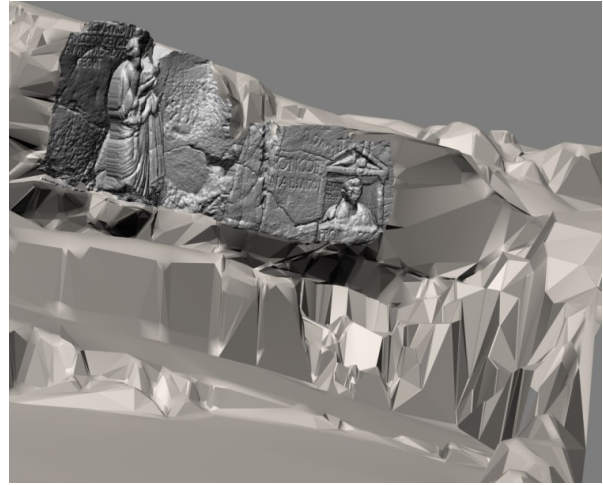


Figure 7: Combined laser and total station 3D reconstruction of the *Fonte do Ídolo*

The extremely dense point cloud had to be simplified for manipulation purposes. Therefore, to reduce the complexity of the mesh the Normal-based Simplification Algorithm (NSA) described in [Fru07a] was used, which reduced the mesh complexity to approximately 22% of its original size (500,000 triangles). After simplifying the façade of the monument, both meshes were merged to obtain the final 3D model (figure 7). Two experienced surveyors took less than a day for the overall data acquisition.

Image-based Survey

More recently, the UAUM carried out an image-based survey of the *Fonte do Ídolo* for evaluation and comparison purposes. The entire survey was performed with 49 photos recorded with a *Canon EOS 550D* and the 3D reconstruction was carried out on a *Fujitsu Celsius W520* with an *Intel Xeon CPU E3-1240 V2* (3,4GHz) processor, 16GB memory, a 64-bit operating system (*Windows 7*) and a 1GB GDDR5 *nVidia Quadro 2000D* graphics card. It was not necessary to associate sticky targets, since the site has enough and significant natural features.

The survey was carried out by an archaeologist who participated in the 2005 survey. The archaeologist was briefly instructed to take the photos from the archaeologist's point of view, but having some concern regarding the overlapping of features. After analysing the photos, some of them were excluded, because they contained problematic materials, such as glass and shiny stainless steel from the site protection structure, which could compromise the accuracy of the reconstruction. Therefore, for reconstruction purpose 34 photos were validated. The elapsed time for this initial step was approximately 30 minutes.

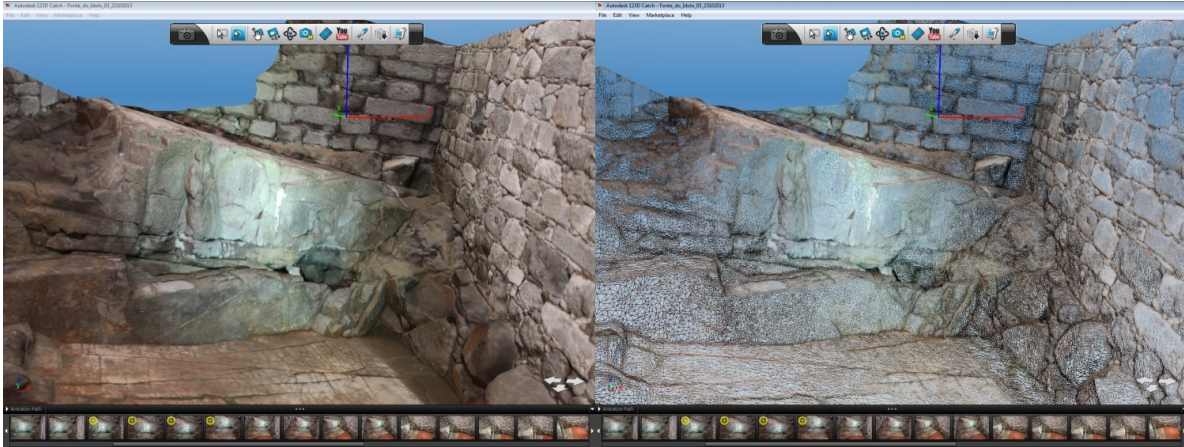


Figure 8: Image-based 3D reconstruction of the *Fonte do Ídolo*: Surface mode (left) and Wireframe mode (right)

The first 3D reconstruction was executed with a loop of 17 photos which were directly uploaded using the *123DCatch* desktop application and it took about 20 minutes to produce a textured 3D mesh of the *Fonte do Ídolo*. The obtained mesh was composed of 97,362 vertices and 193,037 triangles. A second 17 photos loop was added to the first set of photos to improve the initial mesh quality and it took about 30 minutes to achieve a significant enhancement of the mesh: 137,992 vertices and 266,883 triangles. Since there were no more photos to use, at this point the refinement of the mesh had to be carried out by stitching manually a set of vertices. Five photos with noteworthy features were carefully selected to stitch manually 3D vertices. A set of 9 vertices were determined and afterwards the scene was again submitted for processing. The final mesh was improved with 162,351 vertices and 323,131 triangles (see figure 8). The entire workflow took less than a day.

4 EVALUATION OF RESULTS

The number of 3D vertices and consequently the mesh density of Milreu's Roman pool 3D reconstruction were much higher when using *VisualSfM* combined with *MeshLab*. However, generally it takes more time to obtain the final reconstructed object, since it depends greatly on the computer hardware. Also, regarding the graphical user interface, *123DCatch* is more user friendly. In fact, besides the lower mesh density, the main disadvantages of *123DCatch* are the constant need of an internet connection (not always possible in an archaeological site) and the limited possibility to parametrize the application regarding the mesh density of the chosen archaeological object or structure. Both software packages are not able to perform surface segmentation in a simple and prompt way, which is necessary to define the stratigraphic units of the archaeological site.

In the case of the *Fonte do Ídolo*, there is a clear advantage of the image-based survey over the traditional

archaeological survey regarding the human resources that were used and the elapsed time. Also, the visual quality and the three-dimensionality of the image-based reconstruction strongly enhance the perception of the site: the different elements and structures are naturally identified even by non-experts. Moreover, there is an acceptable error regarding the measures between structures and the dimensions of the site elements. Also, the dataset obtained with the traditional survey is not well-suited for 3D visualization purposes due to its 2D nature. However, the 2D representation of archaeological data is the one the archaeologists are more familiarized with.

No doubt that the laser survey, even after its simplification with NSA, retains a better visual quality than the image-based survey regarding the façade of the *Fonte do Ídolo*. Of course, considering the overall 3D reconstruction, the image-based survey preserves a more balanced visual accuracy, partially achieved due to the textures generated during *123DCatch*'s 3D reconstruction. Also, the laser survey needs skilled labor and more human resources than the image-based data acquisition. The time required for both surveys to obtain a 3D representation of the *Fonte do Ídolo* is substantially equivalent. The laser scanner used within this survey does not seem to be the most adequate for large site surveys; however it is quite satisfactory to be used in confined regions where more detail is required, such as the sculptural and epigraphical elements of the façade.

Both non-traditional surveys produce 3D datasets that are adequate for 3D representation and visualization, used during the interpretation and research stages of the archaeological process. There are several adequate visualization systems that can be used, however, for these examples the open source *Visualization Toolkit* (VTK) from *Kitware Inc.* is used. This toolkit was preferred since it supports several visualization and modelling techniques that are useful for interpretation purposes in archaeology. In fact, using VTK it is possible to rep-

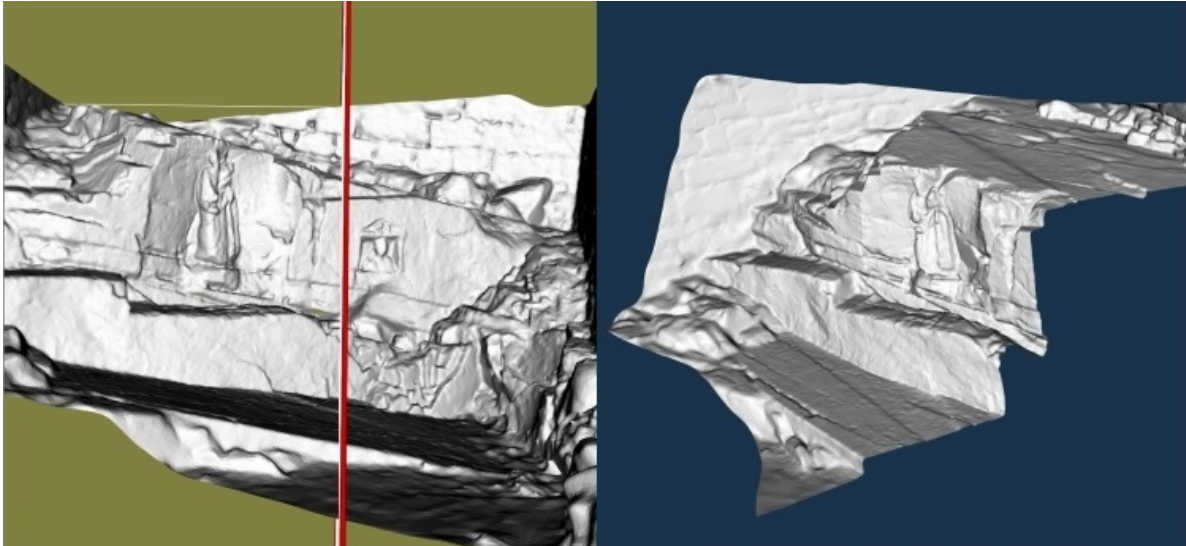


Figure 9: Arbitrary section of the *Fonte do Ídolo*

resent the archaeological site as a virtual scale model which can be freely manipulated. Figure 9 shows a 3D arbitrary plane that freely defines a section over the 3D representation of the *Fonte do Ídolo*.

Image-based 3D models are also acceptable for dissemination purposes, which is one of the last stages of the archaeological process. The 3D representation of the *Fonte do Ídolo* was processed with the *Instant Reality* framework developed at *Fraunhofer IGD-VCST* [Inst14], which offers various components that, on the one hand, simplify the geometry of a 3D model and, on the other hand, convert the input file into a X3D file. In this way, it is straightforward to use the X3DOM framework to make the model available on the Web (see figure 10) and to manipulate the 3D content. A clear advantage of using this framework is that web-browsers which support X3DOM do not require to install a plugin to visualize 3D models.

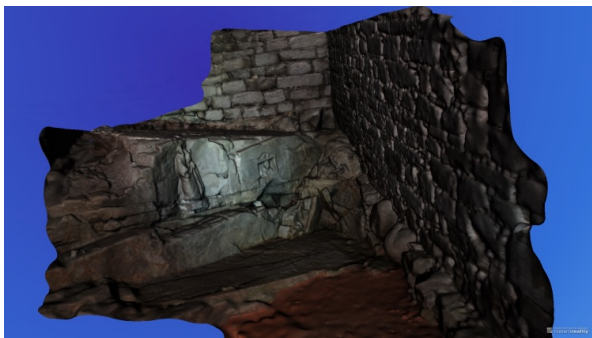


Figure 10: X3D file of the *Fonte do Ídolo*

If the aim is only to visualize the 3D model on the Web, another dissemination possibility is to publish the 3D reconstruction on *Sketchfab* [SFab14]. *Sketchfab* is a free instant in-browser viewer that does not require a

plugin and which can be embedded on a web-page (see figure 11).



Figure 11: The *Fonte do Ídolo* integrated on *Sketchfab*

5 CONCLUDING REMARKS

Regarding the 3D reconstruction of the quadrangular pool at the Roman Villa in Milreu using two different image-based modelling packages, it is clear that both are valid options. However, in spite of the higher mesh density of the *VisualSfM* and *MeshLab* reconstruction, it is preferable to use *123DCatch* because of the (1) user-friendlier graphical interface, the (2) ellapsed reconstruction time and the (3) very acceptable visual quality.

The distinct methodologies for archaeological survey carried out at the Fonte do Idolo illustrate that using image-based modelling for surveying an archaeological site is adequate. It generates a 3D model with the necessary visual accuracy and quality for the archaeological record and for interpretation and dissemination purposes. However, this does not mean (at least for now) that the traditional archaeological survey can be completely substituted by an image-based archaeological survey. In fact, for sites where it is necessary to

record shiny materials, such as glass or metal, the 3D reconstruction might experience some difficulties.

The segmentation of an image-based reconstruction still remains an unwanted constraint for archaeology. In fact, a major purpose for future work is to develop a segmentation tool, based on VTK, to define the stratigraphic units that are indispensable for archaeological analysis and interpretation, and a volumetric reconstruction module to represent the volumes defined by the stratigraphic units.

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