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A 3D Digital Approach for the Study and Presentation of the Bisarcio Site

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Abstract
Recently, 3D-from-photos and close-range photogrammetry have established themselves as important modern technologies in archaeology. Nevertheless, three-dimensional survey has not reached its full potential in the daily work of excavation, as it has been generally restricted to exceptional and monumental cases.
The digging of the late- and post-medieval cemetery of Bisarcio, Sardinia, was an opportunity to experiment with 3D survey. After an extensive 3D survey, covering the entire excavation area and duration, 3D models have been used for the documentation and interpretation of the stratigraphy, and, to create a web-based visualization and dissemination tool.
The three interconnected steps, of documentation, interpretation, and visualization and dissemination, were used to evaluate the effectiveness of the 3D data in each step, and also to build a complete 3D workflow.
The results are promising: with the correct protocol, these procedures may be soon part of the archaeologist's daily routines.

Keywords: photogrammetry, 3D survey, digital workflow, interactive visualization, dissemination tool

Introduction

The use of 3D survey in archaeological excavation started some years ago, employing terrestrial laser scanners. However, its practical use was extremely limited, due to the cost of scanning devices, the long processing time, and the scarcity of software tools usable by the archaeological community to exploit the generated data effectively.

The game-changers for this field have been the 3D-from-photos and close-range photogrammetry technologies, that have now reached a good level of maturity and ease of use, coupled with the availability of software tools (directly usable by the archaeologists), capable of manipulating and presenting high-resolution 3D data.

Our idea is that 3D surveying will reach its full potential when it is deployed as a daily instrument:

- integrated with the standard excavation procedures, and with specific protocols,
- carried out extensively in both time and space, recording the whole work area for the entire duration of the excavation,
- providing a fully-digital documentation-study-presentation workflow.

The experimental case we are undertaking aims to present an integrated workflow, where a three-dimensional survey was carried out as a daily tool to record an excavated stratigraphic sequence in its entirety. The 3D models generated were then used to document the process and to interpret the stratigraphy. The interpreted data was finally published on the web through an interactive 3D viewer.

This test case will show how it was possible, even working in a didactical student excavation, to define procedures and protocols able to effectively use the 3D technologies to build an integrated documentation-study-presentation workflow.

The case study has covered the use of 3D surveyed data in the different phases of work:

1. the extensive day-by-day 3D survey during excavation,
2. the use of the 3D surveys for the study and interpretation of the stratigraphy,
3. the use of the 3D surveys, plus the results of the interpretation, for dissemination purposes.

It is not uncommon to find 3D-from-photos used as a surveying tools during an excavation, or to use 3D models to produce the technical documentation of a site, or to use the digital 3D representation of an excavation for dissemination and presentation purposes. Individually, these three stages and their relationship with 3D data have already been investigated in various publications (Berggren *et al.*, 2015; Olson *et al.*, 2013; Dellepiane *et al.*, 2013). The idea of this experiment, however, is to build up a fully integrated workflow, able to make comprehensive use of the data coming from the 3D survey.

In each of the steps, beside trying to optimise the procedures and protocols characteristics of that specific step, care has been taken in making sure the results of the stage were ready-to-use for the next one, trying to build-up a cost-effective workflow.

The 3D survey relied on 3D-from-photos techniques (also called Structure from Motion, or Close Range Photogrammetry (Barnes, 2011). These techniques are known for being low-cost, but they are also time-effective and versatile. It has already been demonstrated that, if applied correctly, the 3D data produced is perfectly appropriate for the use in archaeological surveying (Green *et al.*, 2014; De Reu *et al.*, 2014; Fiorini *et al.*, 2011). In most cases, the 3D surveys have been focused on specific findings or areas, or a specific time frame of the excavation. In this case study, the photogrammetric survey has been carried out extensively with respect to both space (covering the entire excavation area) and time (daily, throughout the whole excavation period).

The 3D models generated constitute a very accurate and complete recording of the archaeological context, which have then been used both in the documentation and analysis stage, and in the interpretation stage. In this way, all the contexts that has been excavated and removed during the digging operations have found a new virtual life (according to the stratigraphic method). The 3D models have been very useful for analysing the relationship between the contexts, and also between the contexts and the dating materials uncovered.

Finally, the 3D models and the results of the interpretation step have been used to set up an online visualization tool, targeted at experts, able to convey visually (and interactively) the different phases of the excavated site. With the use of the 3DHOP tool, it was possible to design and setup an interactive web-based visualization, using the high resolution 3D models generated in the survey, and connecting them to the data collected and interpreted during and after the excavation process.

Our experimentation could be considered a good opportunity to define effective protocols to use in the different steps of the excavation: the day-by-day surveying and documentation of the site, the study and interpretation phase, and in the subsequent communication and disclosure stages, especially when addressed to specialists.

Figure 1. The archaeological site of Bisarcio is located in central North Sardinia: a strategic place for Sardinian Middle Age starting from the end of the 11th century.

As the case study was a university excavation, this project was also a precious educational opportunity in which university students could understand and learn the basic principles of a new way (for our community) of surveying, archiving and managing excavation data during the excavation campaign.

The case study

The test case chosen is Bisarcio, a medieval and post-medieval site in north central Sardinia. It was a prominent place with high strategic importance for the history of the island, as it was the diocesan seat from the late eleventh century, and the village was inhabited until the first half of eighteenth century. The Sant'Antioco cathedral and the bishop-citadel ruins are, nowadays, part of a local cultural tourist route.

The archaeological excavation was carried out by the Medieval Archaeology chair of the University of Sassari, History Department, Human and Education Science. Digging operations took place in different trenches all over the site: the village, the bishop-citadel and the village cemetery. As the excavation is still an ongoing project, the results of the campaigns so far are still unpublished.

The three-dimensional survey here described was applied to the cemetery context. In this kind of environment, the archaeological process implies, after an accurate investigation, the context's removal and demolition. Generally, these contexts are rarely reconstructed for museum purposes, and it is difficult to exploit and valorise them.

Figure 2. The archaeological site of Bisarcio in an aerial image. Bottom: the Basilica and the bishop citadel. Top: beyond the street the area of the abandoned village, that covers a 4 hectare area.

Figure 3. The Sant'Antioco di Bisarcio Cathedral; a west–east oriented cathedral, and the bishop citadel area. Left: beyond the perimeter wall you can see Area 5100, at the beginning of digging operations.

Figure 4. Area 5100: in the background, southwards, the west wall of the cathedral. Right: the perimeter wall of the bishop citadel.

The cemetery (area 5100) was chosen then as the ideal case study. Area 5100 is located near the north wall of the Sant'Antioco cathedral, and the east wall surrounding the bishop's citadel. The excavation area is 10 meters square.

The tombs in the Bisarcio cemetery are characterised by simple ground trenches, without any brick structures or headstones to mark their presence. A detailed survey was necessary to produce useful documentation. Furthermore, the cemetery area was used before the medieval period, therefore, accurately recording the tombs before removing them was mandatory to understand and analyse earlier contexts.

Excavation was aimed to verify the presence of the cemetery area of the abandoned village of Bisarcio, close to the ecclesiastical building. Geomagnetic analysis

Figure 5. The excavation area seen from the south to the north, with the 10 meters square during digging operation close to the uncovered tombs.

in 2012 documented the existence of underground quadrangular structures (walls) surrounding area 5100. After a three year dig, the excavation data highlighted the highly informative potential of the stratigraphic sequence: in this part of the Bisarcio site, it was possible to record human activities over seven centuries.

The data presented in this work belongs to the excavation campaign carried out in 2014, in the trenches 1 and 2, located in the southwest part of the area 5100. So far, excavation campaigns have demonstrated the existence of four different inhabiting phases from Late/ Middle Ages to the present day. Among these various stages, two different burial phases are the most relevant for this experimentation.

The experimentation stages

Our objective has been to set up an interconnected working pipeline, in order to test not only the effectiveness of the use of 3D survey in each step of the work, but also the possible benefits of having the entire workflow based on 3D data.

We consider 3D data to be less refined than traditional documentation, but the data is highly accurate and easily adaptable. The data from 3D models is a more neutral and 'raw' representation of the state of an excavation than the classical documentation, which is more informative on its own by virtue of interpretation, but less adaptable. The adaptability of the 3D generated data facilitates the transition from one phase to another.

The day-by-day survey

The 3D survey was carried out side by side with the traditional topographical survey (Bianchini, 2008; Kavanagh *et al.*, 1996), in order to obtain a richer documentation. The main goal, in this stage, was the definition of an operating protocol (set of rules/ pipeline), able to cover the entire site but still time-effective, and usable by the students. By applying a precise working protocol, we also hoped to obtain ready-to-disseminate results.

Survey activities followed a precise strategy, designed before starting the dig. All of the contexts dug were documented in the same way, without any selection of a subset of the stratigraphic sequence.

The survey pipeline followed the same steps for each context, but each step was customised to the specific characteristics of the archaeological context to be documented:

1. automatic coded markers were positioned on the contexts surface (at least four for every layer acquired),
2. sketches and technical drawings were made in order to graphically represent context

boundaries and extension and also marker location,
3. the photographic acquisition of each layer, in terms of number of photos and area to be covered) was tailored to the specific features and characteristics of the layer to be recorded, but followed the common guidelines established at the beginning: constant lighting conditions, sharp focusing on the photos, regular coverage of the layers, no use of flash,
4. a topographic survey of the photogrammetric targets through total stations (Leica TS02) was carried out, for scaling the models and for setting up the coordinate system (in the specific case, SRS Gauss Boaga Italy 40).

The survey of each context took around 20 minutes, and the time spent every day surveying the site was around one hour and a half. The survey required two people, positioning targets, surveying them topographically through the total station, and finally taking pictures, in each case following the same procedures.

Image acquisition is a fundamental stage in the acquisition process; the quality and scientific value of the photogrammetric survey depends on this step. Particular care was taken to ensure the images were of sufficient quality to obtain a good 3D reconstruction.

In total, 33 photographic sets were acquired during excavation to document 100 contexts. In total, 2,183 images were captured, with an average of 66 photos per set. All the images were taken using a Canon PowerShot SX50, with a 12 Megapixels resolution.

Using Agisoft Photoscan software, data processing was carried out following the standard procedures for the generation of 3D models from photos as follows:

- aligning photos / building sparse point cloud
- building dense point cloud
- building mesh (3D polygonal model)
- generating texture
- building orthomosaic
- exporting results

The 3D models were scaled to the correct size and geo-referenced using the markers, topographically surveyed, and visible in 228 of the input photos (The more photos are used to specify marker position, the higher is the accuracy of marker placement; every marker was visible in at least 2 photos). Markers were also useful to improve the photo alignment procedures.

While the photographic and topographic surveys took place during the excavation, in the standard daily time-frame normally allocated to documentation, the processing of the data set (3D model creation and geo-referencing) was done afterwards and lasted two weeks, mostly of pure computation time.

At the end of the processing, we had 33 textured and geo-referenced high resolution 3D models, ranging from 500,000 to 2 million triangles.

The 3D models for documentation and interpretation

The 3D models, correctly scaled and geo-referenced (thanks to the topographical survey) were the key in achieving a higher completeness and level of detail (and, often, also of accuracy) in recording the documentation. In addition to its metric qualities, the 3D models also acted as a visual, photorealistic representation of whatever the archaeologist had to destroy and remove to access underlying strata. This visual support, although only virtual, can be used to better understand, study, and interpret data, and it is more effective than a series of photos.

It is in this sense that the three-dimensional survey offers new opportunities with respect to the traditional on-the-field documentation process. Even if the documentation and interpretation method rely on a direct observation and on the physical presence, 3D models allow for a 'virtual return' to the excavation, also to the areas that no longer exist, making possible new measurements, new observations, and revising the physical relationships between the different contexts.

Through using 3D documentation, it is also possible to make an aggregation of the different documentation media on a common, georeferenced support. This allows the different members of the on-the-field team (archaeologists, anthropologists, survey specialists), to work on the documentation and access all the media produced, from within the same environment. This is also true for the post-excavation debriefing and study, and also when the data is accessed, later on, by another team working in the same area.

The documentation methods have not changed significantly in recent years. The on-the-field workflow of the archaeologist is quite similar to what it was years ago (D'Andrea, 2006, p. 79), and the only procedures that have been formalised at a national level are related to the filling of standard forms for each finding (De Felice, 2008).

Without any standardised procedure, it is difficult to establish nation-wide scientific protocols for the stratigraphic methods, to maintain the informative potential of the stratigraphy, and also to limit the loss of information when the produced documentation is subsequently re-used.

By exploiting the three-dimensional graphics, it is possible today to rethink the entire documentation workflow, exploiting the possibilities of the three-dimensional media in preserving a more complete and visually perceivable representation of the materials removed during the excavation process.

The potential of a 3D workflow are already evident in the survey and restitution phase, as the 3D models are more suited to help in representing a series of aspects which can be difficult to perceive from the classical documentation, such as the slope and depth of a trench, or the case of a wall with height irregularities or leaning: these features can be graphically drawn, often through hachures, but are more difficult to read (Medri, 2003; Puche, 2015). As these details are more apparent in a 3D model, it is easier to trace them when creating technical drawings, resulting in a more detailed documentation.

The outlines of the contexts and of the surfaces, which are amongst the most common technical drawings used as documentation, can be traced directly on top of the 3D models, creating vectorial profiles and contours without the need of a long drawing session over the excavation, and with a higher accuracy (Medri, 2003).

Also, the traditional transverse and longitudinal sections drawings can be directly extracted from the 3D models. Given the faster generation procedure (with respect to on-the-field direct measurement), it was possible to create a more complete and rich technical documentation. As all the 3D models are geo-referenced, the creation of cumulative drawings is also easier.

A side-product of a 3D photogrammetric survey are photographic orthomosaics; in this experimentation, the availability of this type of data made the generation of plans much easier, and prospects, increasing the speed of the production of the standard two-dimensional graphic documentation. As the orthomosaics are easier to generate using 3D-from-photos tools, with respect to classic image-compositing tools, especially in case of high detailed evidence, such as tombs and walls, the survey procedure is faster.

The online visualization tool

The third step of the experimentation was to create a web-based visualization tool, again based on the 3D models and the data generated in the interpretation phase.

When creating a visualization page, it is important to define clearly the communication aim (what is the message we want to deliver) and the target public (who will use the page). It is extremely complex, if not impossible, to design effective data visualization pages that can be useful to users of all levels, and cover all aspects of a complex technical project

In this case, what we wanted to achieve was a page showing to other archaeologists the main interpretations of the excavation data. With this idea in mind, the design of the visualization followed these guidelines:

- the aim is describe the **interpretation** of the site, the visualization will not give access to the entire excavation data set, but only to a selected subset. Moreover, the pages will be structured to highlight the relationship between the contexts as they have been interpreted by the archaeologists.
- people accessing the visualization will be **experts of the field**. So, it will be possible to use non-trivial navigation and rendering options, and advanced measurement and analysis tools will have to be included.

The visualization pages have thus been structured following the timeline and the logical elements of the site, in order to highlight: 1) the different phases of use of the Bisarcio cemetery, and 2) the various tombs in each specific phase.

The main page of the web visualization shows the excavation area as a whole, making it possible for the user to explore the site. A simple info panel contains the basic information about the excavation site.

On the bottom-right of the page, the timeline panel can be used to select one of the different phases of the cemetery; each phase has its own information panel, describing the specific period.

Each period shows a different 'global' 3D model, created from a set of coeval contexts, providing a view of the state of the excavation at that specific time frame. For those phases (already excavated) which correspond to a cemetery stage, the tombs are displayed in their respective position. Each tomb may then be selected, to access a detailed visualization page, presenting the contexts related to that specific tomb.

Each tomb has its own detailed visualization page, and all have the same structure. The page shows three contexts depicting different stages in the excavation of the tomb: unexcavated, excavated, and empty. It is possible to examine each stage individually, or turn on more than one stage at the same time (to compare them and use the sectioning tool).

It is also possible to turn visible or invisible a global model of the whole area, as a semi-transparent shape,

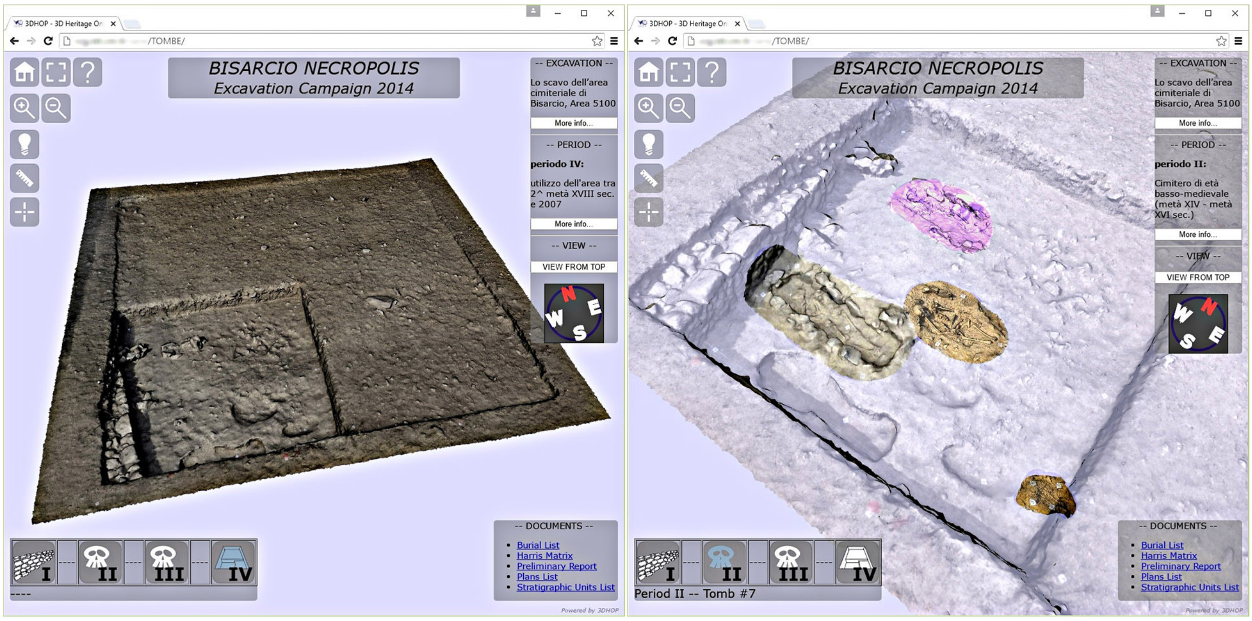

Figure 6. The 'global' visualization page of the excavation. Left: the starting view of the whole excavation area, with the timeline on the bottom-left corner. Right: once a cemetery period is selected, the tombs of that period are displayed and may be selected.

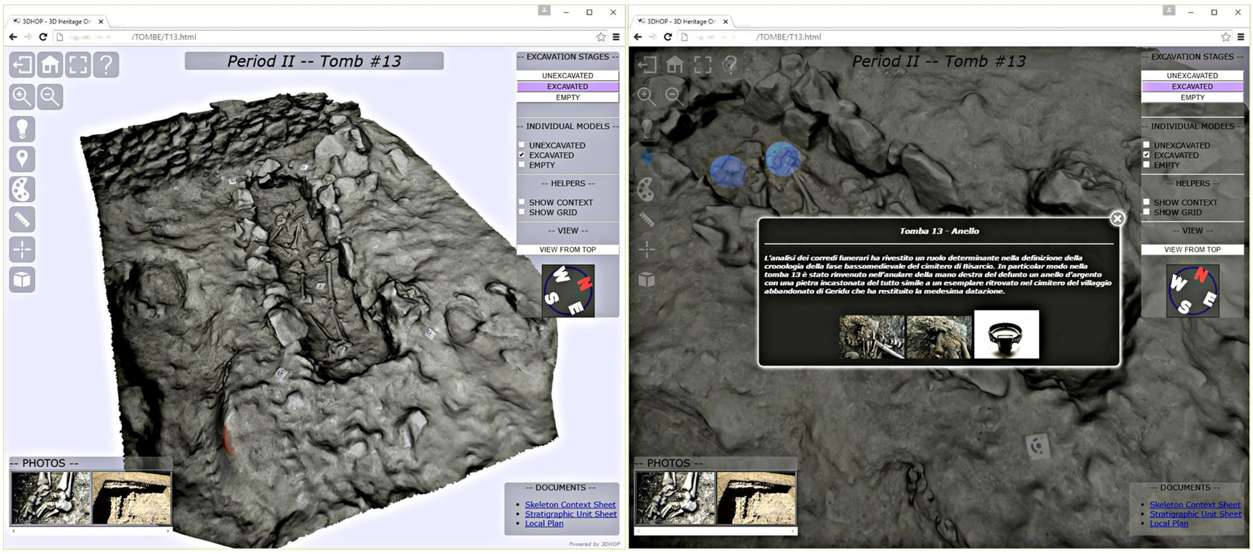

Figure 7. One of the detail pages for the tombs of phase II. Left: a view of the 'excavated' stage of the tomb. Right: the hot-spots and associated panels describing the small finds.

to better understand the spatial relationship of the tomb with the rest of the excavation. Tombs containing small finds also have hotspots. These are clickable areas on the geometry of the context, positioned according to the location of the find, which can be clicked to access a description panel detailing the find.

All the pages (the global timeline, and the single tombs) have direct links to pdf documents, images and other excavation documentation, thus providing a more structured access to the documentation corpus.

The navigation of the 3D terrain has been designed to be easy to use, but still able to reach any position on the 3D models; it is possible to zoom in/out, rotate around horizontally and move the point of view vertically, and to move around. Double-click can be used to move to a specific area, re-centring the model. The navigation of the general view and of the tombs has the same interface.

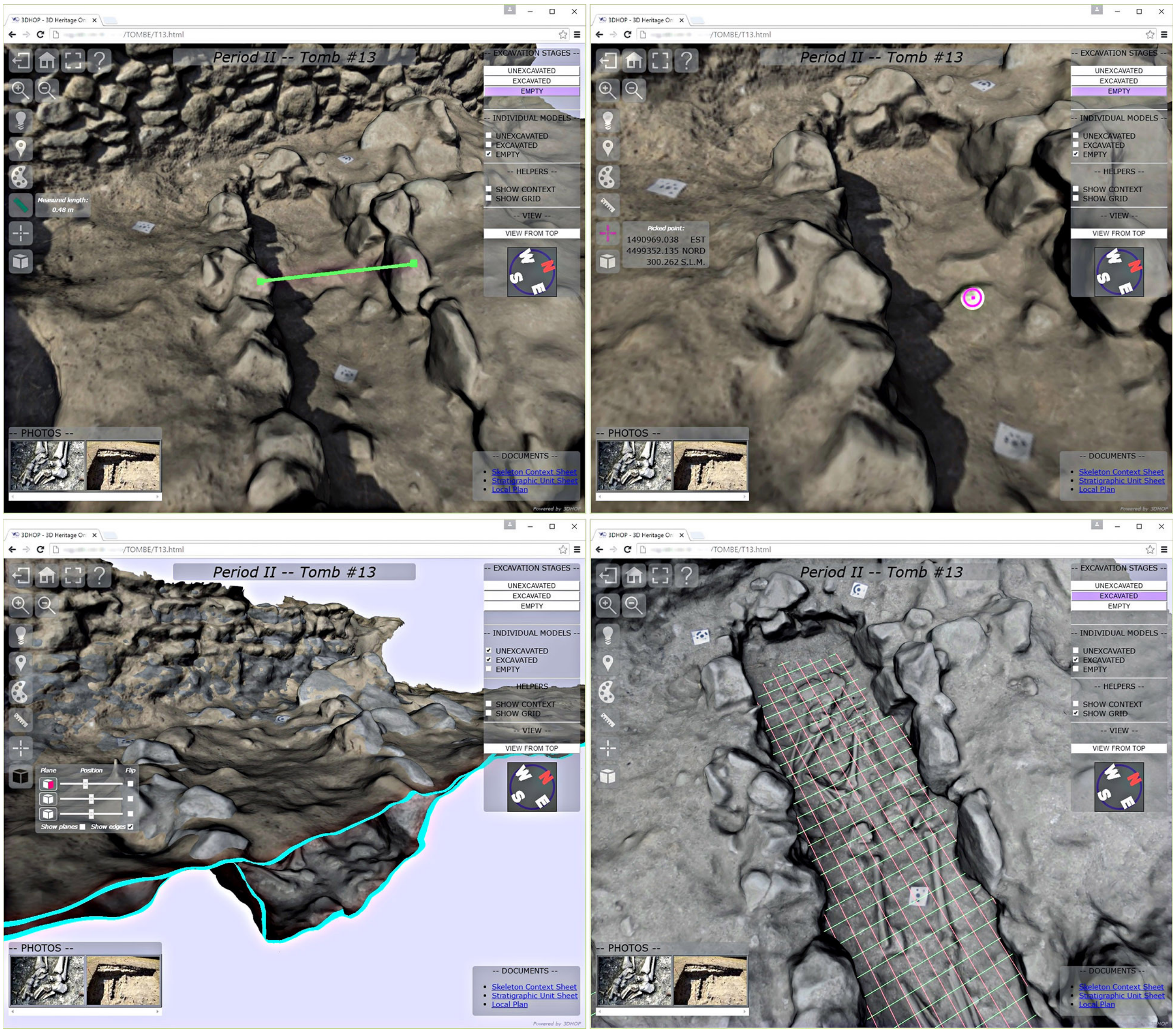

Figure 8. The various measurement and visualization tools available in the tomb detail page. Top-Left: point-to-point measurement. Top-Right: pick-point with georeferenced coordinates. Bottom-Left: interactive cut-through sectioning. Bottom-Right: reference graduated grid.

A compass helps to understand the orientation of the current view (and to reset the orientation to the north). A home button resets the view, and a 'from top' button brings the viewer orthogonal from above.

In order to better understand the shape of the ground, stones and objects, it is possible to change the lighting direction and remove the texture/colour information.

As all the 3D models are correctly scaled and geo-referenced, it is possible to use these visualization pages as a way of obtaining metric information. A point-to-point measurement tool is always available to take direct linear measurement over the shape of the excavation, and the pick-point tool returns the coordinates of any picked point (in the Gauss Boaga Italy 40 space).

In the tomb detail pages, it is also possible to use the real-time sectioning tool to 'slice' the ground along the main axis, to better understand the spatial relationship between the different surfaces composing the burial in its whole. A reference grid may also be superimposed to the 3D model, to better perceive proportions and dimensions.

The 3D web visualization uses 3DHOP, an open-source tool aimed at creating web-based interactive visualization of high-resolution 3D models (Potenziani *et al.*, 2015). The tool is based on HTML5, and runs natively inside the browsers, without the need of additional software or plug-ins.

By using a multi-resolution streaming, it was possible to put online the high-resolution 3D models of the different contexts. Data is also compressed, making the data streaming very efficient. The 3D models used ranged from 1 to 3 million triangles (considering also the models generated by merging different contexts), in most cases with a 4k texture.

This tool is designed to offer different interaction components and control functions. The idea is that these components may be configured according to the needs of a specific project, and connected to HTML components of the webpage, making possible to create complex visualization schemes.

The work on this project followed exactly this strategy: beside the design of the timeline-based exploration and of the 'global view' — 'tomb detail' page structure, most of the tools used (hotspots, measurement, sectioning) were already available in 3DHOP, and have just been configured to work according to our needs, while others (e.g. the compass and the reference grid), have been developed from scratch.

Conclusions and future work

We believe the experimentation was successful: by defining precise protocols, and with a minimal amount of resources, it was possible to obtain a complete 3D digital workflow, which allowed for an accurate and complete recording of the archaeological contexts, and has been useful both in the documentation and analysis stage, and also in the interpretation and dissemination stage.

In our opinion, three-dimensional photogrammetric survey is mature enough to integrate effectively and enrich the traditional on-field documentation, and, to some extent, overcome its limitations.

The main difference between the traditional on-field survey and the digital 3D survey resides in their respective nature. A traditional documentation survey relies on a selection of relevant features made in the field by the person in charge of the documentation. It is an *interpretation* of the data. It requires more time in the field, and produces more structured and informative results, but it is not an objective representation. On the other hand, a 3D survey provides a more objective and global recording of the state of the archaeological context: there is no selection, every detail of the context appears in the model (according to the resolution of the survey). Although 3D surveys can be quicker, in the field, and generate 3D models with a higher level of detail and realism, they will always need a step of refinement and interpretation to become a proper, usable technical documentation. By combining data coming from the two approaches, it was possible to obtain a richer and more precise documentation, and a more complete knowledge of the site.

In this case study, by using the 3D models as the base for the documentation process, it was possible to overcome some of the limitations of the traditional documentation process. The higher density of metric information had a positive impact on the accuracy and on the level of detail of the documentation. The possibility to visually revisit areas already removed from the excavation, helped in the documentation and interpretation process, as it allowed for a more thoughtful and careful study of the evidence.

Additionally, the results of a 3D survey are ready-to-use visual representations of the site, which can be easily used for dissemination to experts and non-experts alike.

A 3D photogrammetric survey also allows the capture of other kinds of usable data, like orthomosaic, which were used extensively in this experimentation to create technical documentation.

3DHOP can be considered a suitable tool to visualize on the web high resolution 3D models, and to connect them to the large amount of data collected and interpreted during and after the excavation process. It was possible to design and implement a visualization tool focused to a specific audience, still exploiting the same data produced in the previous phases of the workflow.

A possible further step in the experimentation would be to re-use the 3D models and data gathered during the excavation to build a different visualization tool, this time aimed at the general public. This would be possible, starting from the existing 3D models, and from the documentation and interpretation documents of the excavation, still using the 3DHOP tool. This would require a complete re-design of the visualization pages, to cope with the new communication aims and the different audience.

This tool would be an added value for this case study (a cemetery context), for which it is not possible to imagine or define a 'classic' museum function. This would represent another, almost direct 're-use' of the 3D survey data collected following the digital methodology, further lowering the cost/benefit ratio of this kind of survey strategy.

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