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DYNAMIC MANAGEMENT OF SURVEY DATA AND ARCHAEOLOGICAL EXCAVATION. THE CASE STUDY OF THE AMPHITHEATRE OF VOLTERRA

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Abstract

The work presented in this article demonstrates how combining different expeditious techniques can better describe the studied subject, in addition to creating a rich database of colorimetric information and metrics. Data that were foundational for the prototypical construction of the VR mobile application were also able to manage the details of the excavation. The discovery of the amphitheatre in Volterra is the case study that was used for this research. This research is divided into three phases: (i) identification of the case study; (ii) analysis and comparison of the survey systems used; (iii) the design and development of a mobile app to manage the information in a virtual environment.

Keywords

Amphitheater, archeology, reverse modelling, terrestrial laser scanner, photogrammetry

1. *Introduction*

The present article aims to describe how different techniques of expeditious surveys can be interconnected to provide a more detailed description of the studied subject. Some digital survey techniques, i.e. terrestrial laser scanning (TLS), topography and the Structure-from-Motion (SfM) technique (Bertocci, 2014), can be simultaneously used and interconnected with one another, in order to compile an exhaustive database, rich in colorimetric and metric information. However, these methods can also sometimes display peculiarities, or errors, depending on the technique utilised. The study was continued by comparing the results produced by the SfM with those arising from TLS. The analysis of the standard deviations confirmed a possible mass use of SfM, therefore lowering the analysis costs while maintaining a high level of precision of the structures detected.

The data collected during this experimentation have found use in the realization of virtual application mobile capable to connect to a MySQL server and record information such as drawings and texts in three-dimensional space.

The case study used for this analysis is the the discovery of the amphitheatre in Volterra. An excavation campaign was undertaken between October and November 2015, which allowed us to reveal the supporting walls of the structure, unveiling the presence of the three orders and a depth of about ten meters.

2. *The discovery of the amphitheater in Volterra*

On 8th July 2015, during the archaeological excavation, a wide section of wall was rediscovered. It was a 40-metre-long curved wall, which was hypothesised to be part of a structure for performances, perhaps an Amphitheatre (Fig. 1-2). In October 2015, thanks to the funding from the Volterra Savings Bank, it was possible to start the first excavation campaign, which confirmed the hypothesis that this structure was actually a forgotten Roman amphitheatre consisting of three floors, that were interred deep in the ground (Fig. 3-4). The rediscovered wall belonged to just one part of one section of the amphitheatre. The aim of our sample, which lasted 6 weeks, was primarily to confirm the existence of the monument itself and understand its dimensions. As winter was drawing near, the decision was made to analyse only the surface of one section of the monument and clear it from the thick layers of colluviums that were deposited throughout the centuries, in order to measure the actual dimensions of the amphitheatre. In reality,

Fig. 1: The discovery of 40-metre-long curved wall tipically of a structure for performances, an Amphitheatre

Fig. 2: The positioning of the first discoveries on aerial photo of the area

Fig. 3: The portion of the cavea of'amphitheater with headlines the carceres of the first two orders delimited by the first and second praecinctio

Fig. 4: Entrance to the cryptoporticus buried and Pillar on the left that marks the entrance to the third order with next elements in the collapse of the arch above

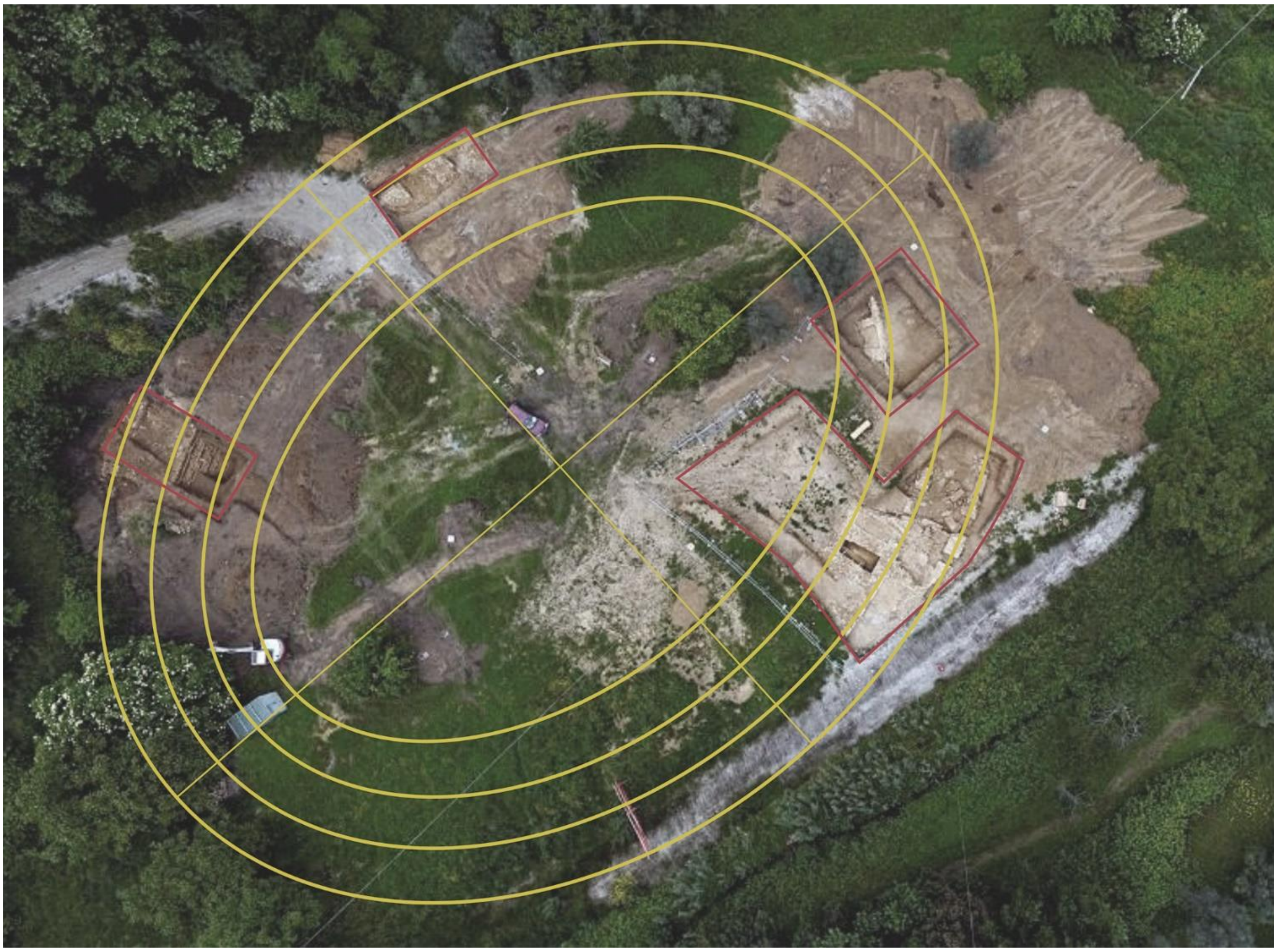

Fig. 5: Hypothetical reconstruction of the dimensions of the Amphitheater

however, no part of the amphitheatre has been completely explored. The sample provided the documental certainty that the structure discovered was in fact an amphitheatre comprised of three floors, which would have had steps, but in this section none were found. The cavea was vast and structured in three floors, prima, secunda and summa cavea (or Maenianum primum, secundum and summum), separated by the praecinctiones (which can be described as thick concentric support walls) up to the lower wall, or Podium wall, which separated the cavea area from the arena. The arena is located at a height which we imagine to be two metres below where we reached – therefore it should be circa 6 metres from the height of ground level, where the excavation started. Architecturally, the amphitheatre could likely have a mixed structure, which would show strong similarities to the Vallebuona theatre, inserted (where possible) into the slope of a hill, with other parts built on substructures - as research carried out in one of its carceres (chariot pit) seemed to prove.

Unfortunately, the steps appear partly collapsed or even removed completely in the section we are unearthing, but we hope that in the uphill section of the small valley the structures will be better preserved, due to them being interred even deeper into the ground in that area.

During the first survey, it was not possible to examine the ruins, therefore currently nothing can be said about the actual conservation state of the structure or on the overall strength of the interment. The non-invasive geo-diagnostic surveys, carried out during winter in the area by the Livorno's SOING company (project partner of the Italian Superintendency of Cultural Heritage), suggested the hypothesis of a structure even vaster than what was previously estimated. For this reason, the decision was made to carry out more samples during spring to measure the exact perimeter of the structure.

Fig. 6: During last excavation of may 2016, in addition to cutting into the rock, it has brought to light a sector of'last order of the cavea with part of the last two praecinctiones. In addition, the penultimate Praecinctio retains part of the tiers of seats

In May 2016 we were able to start a new brief survey campaign, funded by the Italian Ministry of Cultural Heritage, in order to acquire useful data on the actual dimensions of the monument, the strength of the interment and its conservation state. During both survey campaigns we worked in cooperation with the experts of the DiCCA Department of the University of Genoa, who dealt with the surveying stage and the graphic restitution of the monument.

Thanks to this second survey campaign, further data was gathered confirming and integrating the previous data from October 2015. The amphitheatre, with three floors of steps, is located in the valley near the renowned Porta Diana, probably along an ancient Etruscan road, as proven by the Cardo of the Roman colony. The total dimensions of the monument are wider than previously hypothesised – they seem to be around 82 m x 64 m. (Fig. 5) Thanks to the 4 new samples carried out during the last surveys it was possible to reconstruct the plan of the entire monument. A particularly interesting discovery was a section of steps belonging to the second floor found in the last excavated area (Fig. 6).

Up to now the state of the monument appears to be moderately good, bearing in mind that during this first survey campaign we only removed the layers covering the monument. The walls are in a relatively good state, whereas the elements made in Panchina stone are already undergoing constant maintenance (Sorge, 2016).

3. *Data acquisition and managent*

Thanks to the continuous development of surveying techniques, nowadays, a wide amount of information can be acquired in a short period of time. This information often derives from various surveying procedures interacting with one another to enrich the database, which is pivotal to the study of the surveyed subject. These methods are important for data interpretation, conservation and storage as well as the exploitation of the subject through interacting systems of visualisation (Russo, Remondino, & Guidi, 2011).

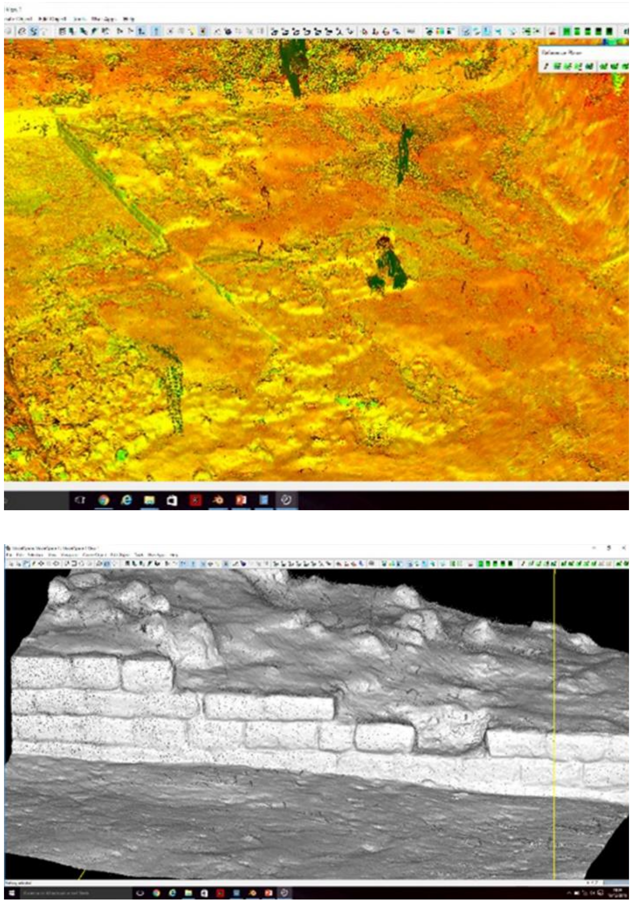

Fig. 7: Working screenshots of the cloud of points acquired with laser scanner

Some of the most recent techniques of digital surveying were used in the excavation of the Amphitheatre to record all the information gathered during the removal of each stratigraphic unit. Building a topographic network guaranteed utmost accuracy in defining the main reference system, while the TLS survey and the SfM technique (Russo et al., 2011) enabled the acquisition of information on the three-dimensional development of the rediscovered

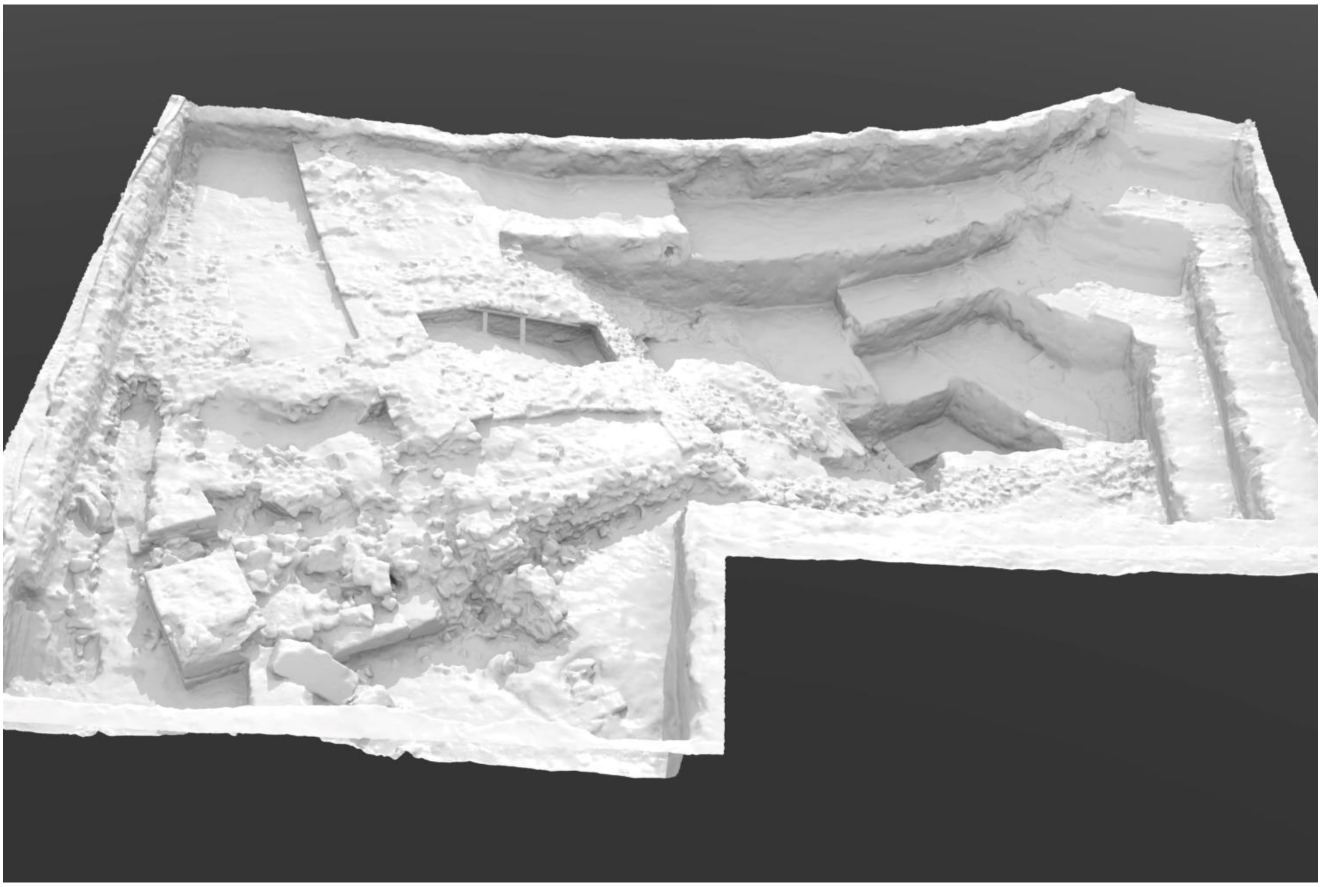

Fig. 8: Three-dimensional model composed of approximately 6 million polygons deriving from the points cloud acquired with laser scanner

structures through photographic images. Particular focus was placed on identifying the maximum admissible error in order to guarantee a reliable restitution of the acquired data for archaeological documentation. Due to the consistency of the material (sandy ground and ashlar walls) and the dimensions of the retrieved structures, the maximum error allowed for the present study was 1,5 cm. In this way, it was possible to operate with an expeditious approach and maintain a high level of detail.

Many scientific contributions were written on the topic of TLS techniques (together or substituted with photogrammetric surveying systems). A large amount of research has been conducted to investigate the potential and limits connected with the alternative or integrated use of these two techniques (Beraldin, 2004) (Boehler & Marbs, 2004). The application of these systems in the field of Cultural Heritage to survey objects (Boehler & Marbs, 2004) (Grussenmeyer, Landes, Voegtle, & Ringle, 2008) highlights how dimensions, geometric complexity and superficial coloration are fundamental parameters in carrying out a survey and underlines the fact that currently, no one survey technique can be applied to every situation. Therefore, the combined and integrated use of these techniques is essential for the quality of the final result.

In the present study, due to the combination of these two techniques and the comparison of the results, it was possible to create three-dimensional models with a high level of metrical precision thanks to the use of high-definition texture for the restitution of the object's visual appearance. The 3D models reconstructed with this method were then used to gather all the necessary information to examine what was recovered. From the conducted analysis it was noted that due to the morphological and material characteristics of the site, the execution of SfM surveys resulted in a high level of precision, drastically less time in carrying out the survey, and was less invasive on the excavation process.

The surveying techniques were compared by examining a number of samples from some portions of the excavation site. Both the metric data deriving from the restitution of the utilised techniques and the level of chromatic quality were analysed. For the TLS system, a Z+F Imager

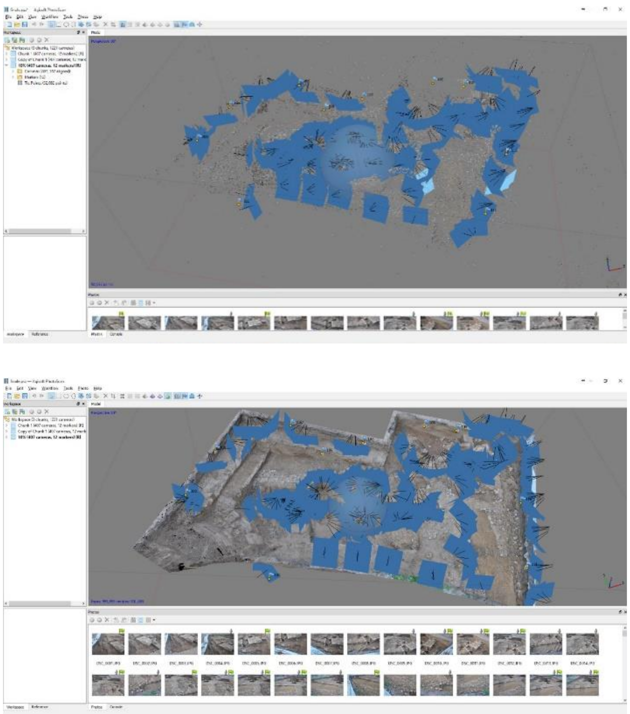

Fig. 9: Screens of the three-dimensional model processing within the software PhotoScan

5006h phase-shift laser was used, which can scan structures in a range of 79 metres with an accuracy of 2 mm. Even if this equipment guarantees high precision, it does not, however, have a recording system for chromatic data, which would offer a differentiation of the structures by visualising the information, in greyscale, on the material's reflectance value. Just by applying specific motorised cameras or substituting its head with nodal-point equipment (photographic arm and reflex camera), it is possible to colour the point cloud. However, this requires more time both in the acquisition and in the post-processing stage.

The TLS survey campaign to compare the survey techniques was conducted at the end of the first sample, producing a database of point clouds that were connected with one another through homologous points (targets), also topographically detected. Through the acquisition of 14 laser locations, it was possible to record a point cloud of 288'305'559 points, that was reduced to 57'403'050 points (after having selected the area of interest on the site) (Fig. 7). In the next step a 3D-mesh model was created starting from the point cloud and maintaining an accuracy level of 1 cm. This value of 1 cm accuracy was important in understanding the wall structure and it was also a lower value than the error value that had been previously defined. During these stage uniform sampling operations were carried out with a 1 cm range. This led to the definition of a point cloud of 6'447'315 points; the creation of the mesh surface; cleaning and restoration of the imperfections; punctual

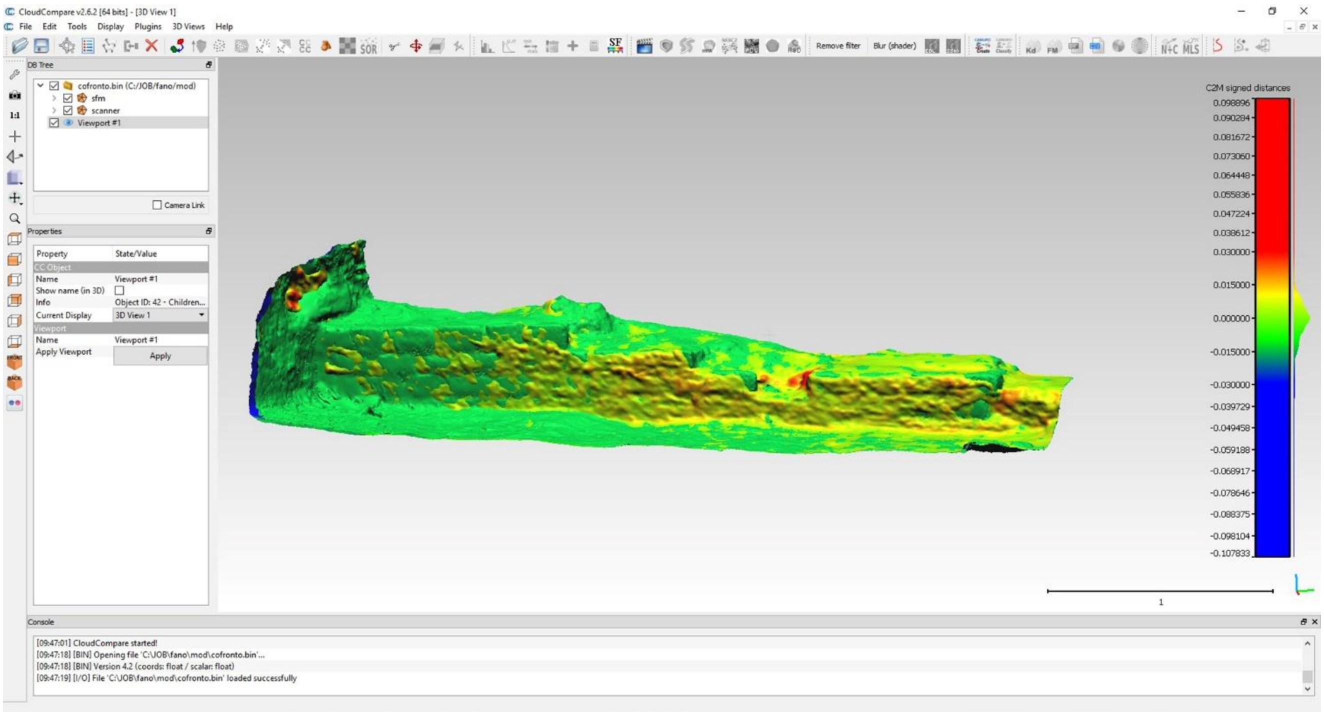

Fig. 10: Particular of the excavation reconstructed in 3D.

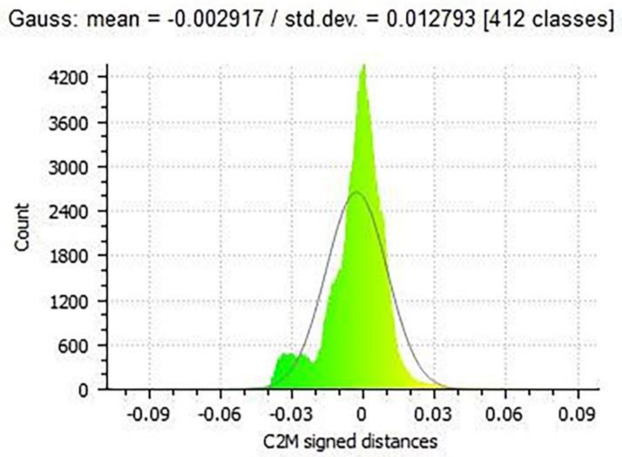

Fig. 11: Screens of the three-dimensional model processing within the software PhotoScan

Fig. 12: The coloring of the 3D model developed by the clouds of points of the laser scanner through the algorithms of texturing of PhotoScan

decimation of a number of less relevant areas (flat ground surfaces and vertical sections of the excavation site). The final result was a three-dimensional model of 12'058'625 triangles (Fig.8).

At the same time, a photographic survey was carried out with a Nikon D5000 reflex camera using a18-105 lens. The acquired images (all shot with the same focal aperture) were used to reconstruct the three-dimensional model with the SfM technique. For this elaboration the Photoscan 1.2.2 software was used. Through simple steps (image alignment; construction of a sparse cloud, a dense cloud, a 3D model and texture), this software produced a 3D model applying the texture of the colour (Fig. 9). To correctly compare this technique with the TLS technique, for the orientation and dimensions of the reconstructed model, the same targets were used.
The comparison of the two three-dimensional models was executed within the open-source software CloudCompare 2.6.2, where it was possible to visualise, using colour-code map, the overlapping of the two different models (Fig. 10) and to gather the mean-distance value of 0.002917 m and the standard-deviation value of 0.012793 m (Fig. 11). These values were lower than what was expected at the beginning of the process.
On the basis of these results, choices could have made about future surveys, and also restitution through the use of TLS techniques. Firstly, the 3D laser scanner was imported into Photoscan (substituting the model made up of images) to be then put through the texturing process (Fig. 12). The result was an extremely precise model with an applied texture of 15’000 pixels. This texture was calculated through algorithms for correcting chromatic range, thus being more accurate from a colorimetric point of view. Another important consequence of comparing the models was that the following surveys were based mainly on the SfM technique with topographic support. The accuracy and precision of the collected data guaranteed an efficient execution of the survey operations, being faster and less expensive in comparison to the operations using solely the TLS technique, which was however utilised in the final stage for the registration of the conducted samples.

4. *The Dynamic Representation Mobile Data of Excavation*

The continual development of new technologies, capable of acquiring information with a very high level of detail, has brought a strong acceleration in the field of computer graphics for viewing and sharing data. Systems with increasingly high performance allow accessible, information rich databases and three-dimensional models navigable via web and smartphone. This is useful in many fields, such as restoration, documentation and exploitation. These systems could also be considered a fundamental instrument in the understanding and management of cultural assets.

In the field of archaeology, numerous studies have addressed this issue by focusing on the need to record the progress of the steps of an excavation at regular intervals, allowing for validation of scientific results (Grabner, Wozelka, Mirchandani, & Schindler, 2003). Archaeological excavation is not only a fundamental instrument of investigation but, above all, is the moment in which any non-collected information is destroyed with the removal of the layers of earth (Bezzi,

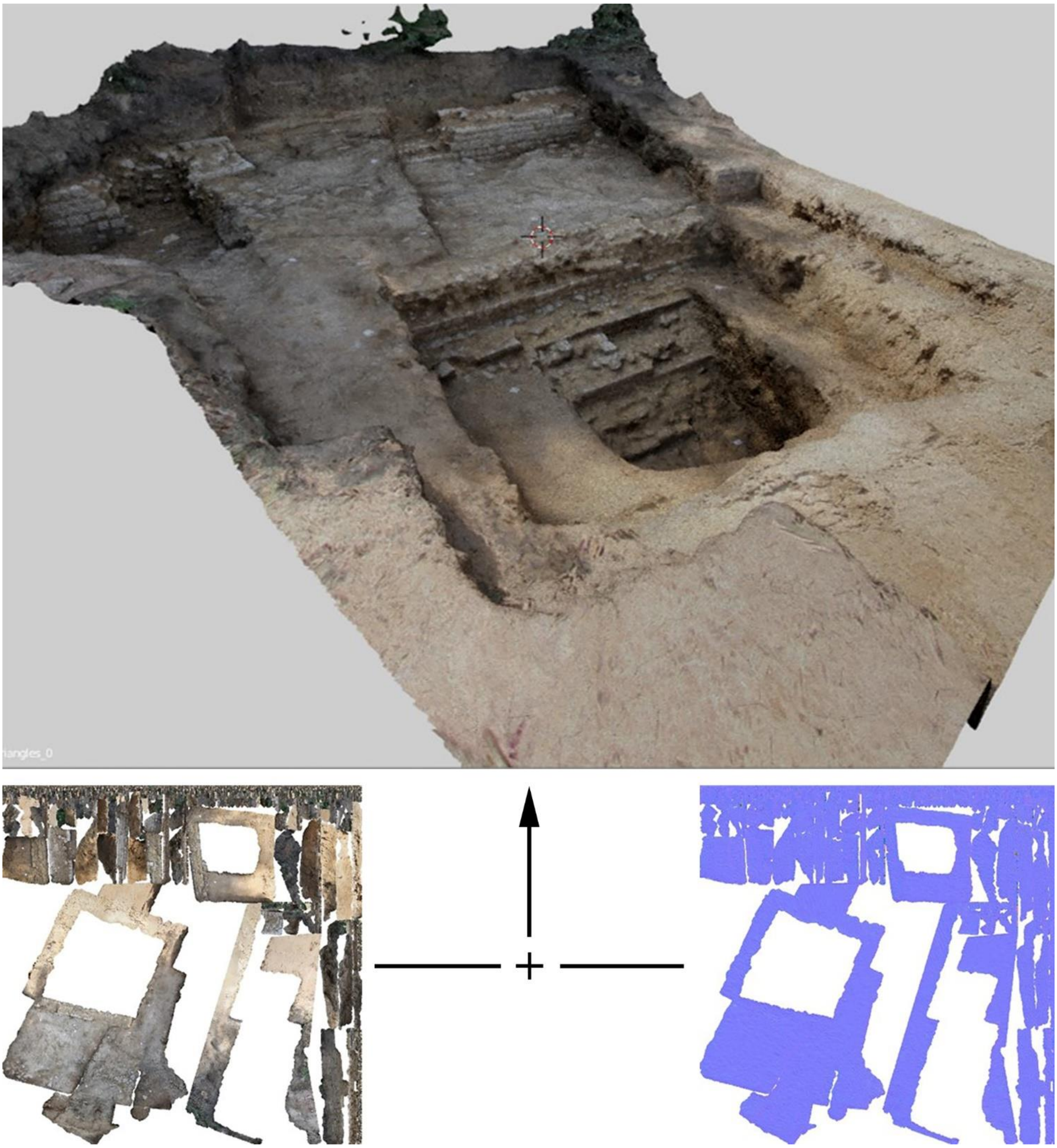

Fig. 13: Models simplified and implemented with textures of a normal map to increase the detail of the surfaces.

Bezzi, & Benjamin, 2011). If not registered, potentially crucial information for understanding the historical evolution of the site can no longer be considered or analysed by other scientists or experts from different disciplines.

New research projects can be developed with the use of the commercial platforms and open source tools, such as three-dimensional models, images, texts and sounds for viewing and interacting with the collected data. Studies such as Archeoguide (Vlahakis et al., 2002) were able to create guided tours in augmented reality with head-mounted displays. Other projects, such as Virtual Rome, reconstruct the landscape of modern day Rome and that of Rome in the second century A.D. within common web browsers through a three-dimensional online reproduction, including multimedia insights (Pescarin, Palombini, Calori, & Negri, 2009).

Today, the platform 3D Heritage Online Presenter (3DHOP), developed by Visual Computing Laboratory of the Department Isti-CNR of Pisa, proves to be a promising project for visualising digitized media assets on the web web (Potenziani et al., 2015). The use of multiresolution encoding efficiently streams high-resolution 3D models, such as the sampled models usually employed in CH applications. In addition, it provides a series of ready-to-use templates and examples tailored for the presentation of CH artefacts, and it interconnects the 3D visualization with the rest of the webpage DOM, making it possible to create integrated presentations schemes (3D and multimedia).

The research presented in this article examines the potential of mobile systems and interactive applications in offering interaction with cultural heritage, and making perceptible details and annotations in a well investigated three-dimensional space. Considering this the basis of the research, this project created a mobile application for virtual reality (VR)[1].

The VR is an instrument capable of representing a world of three-dimensional, high-resolution objects that can interact with the end user, leaving them freedom to act and to choose their own point of view. The sensation of immersion and presence in the reconstructed environment make possible to interact naturally with synthetic environments in their own space-time (Varani, 2004).

The application was realised through the programming platform Unity 3D, which is capable of managing three-dimensional models, images, texts and scripts in C#, and is indispensable for controlling and operating the actions associated with the buttons. The layout studied sees the creation of an interface capable of interacting with virtual space through navigation sliders for the displacement and rotation of the viewpoint. User interaction in ensured due to the possibility of adding and viewing information in the 3D space. Data that are not stored locally, but are sent through the appropriate script for connection to a central server in a MySQL database, make them accessible in anywhere and by multiple users in real-time. The main objective of this research is to create the ability to navigate in the three-dimensional space framed by the camera and enter points of interest characterized by a title, a brief description and graphical information.

The three-dimensional models - products capable of making multimedia vision more realistic - are built with the techniques previously explained, and are a construction of points, edges and surfaces with applied texture and contain highly detailed information. At the same time however, it is these highly detailed models that can create problems being displayed on both the web and on mobile media (Minto & Remondino, 2014). In order to overcome this problem, models have been simplified and implemented with textures of a normal map to increase the detail of the surfaces (Fig. 13).

An 'add' button for the graphic layout of the application was then included, capable of operating the appropriate script C# for the insertion of the data required to populate the database. This process allows for the identification of the spatial coordinates of the camera, which in a sequential manner allows for the definition of the title, the description and of an image from the identified point that is being viewed. A suitable drawing tool, capable of leaving a red sign or drawing on the image acquired from the point of view, allowed the addition of the note chart function (Fig. 14). The interaction between the user and the software occurs by exploiting the function of invisible rays - raycasts - that following the movement of the fingers on the monitor, identifies objects and/or points in the scene. For fast execution of raycast, the drawing tool allows to simulate the continuity of the drawn line.

5. Conclusion

Currently informatics has interactive technologies that have the ability to make a difference in drafting a restoration project or be the key to success in interventions of exploitation and dissemination.

The diffusion of knowledge of cultural heritage is the first step toward its conservation, and today virtual reality appears to be an effective instrument to achieve this purpose. To

[1] The term virtual reality was coined in 1988 by expert in Informatics Jaron Lanier who, during an interview, defined the Virtual Reality (VR) as, "the use of computerized clothing to synthesize shared reality. It recreates our relationship with the physical world in a new plane, no more, no less. It doesn't affect the subjective world; it doesn't have anything to do directly with what's going on inside your brain. It only has to do with the sense your organs perceive" (Kelly, 1989).

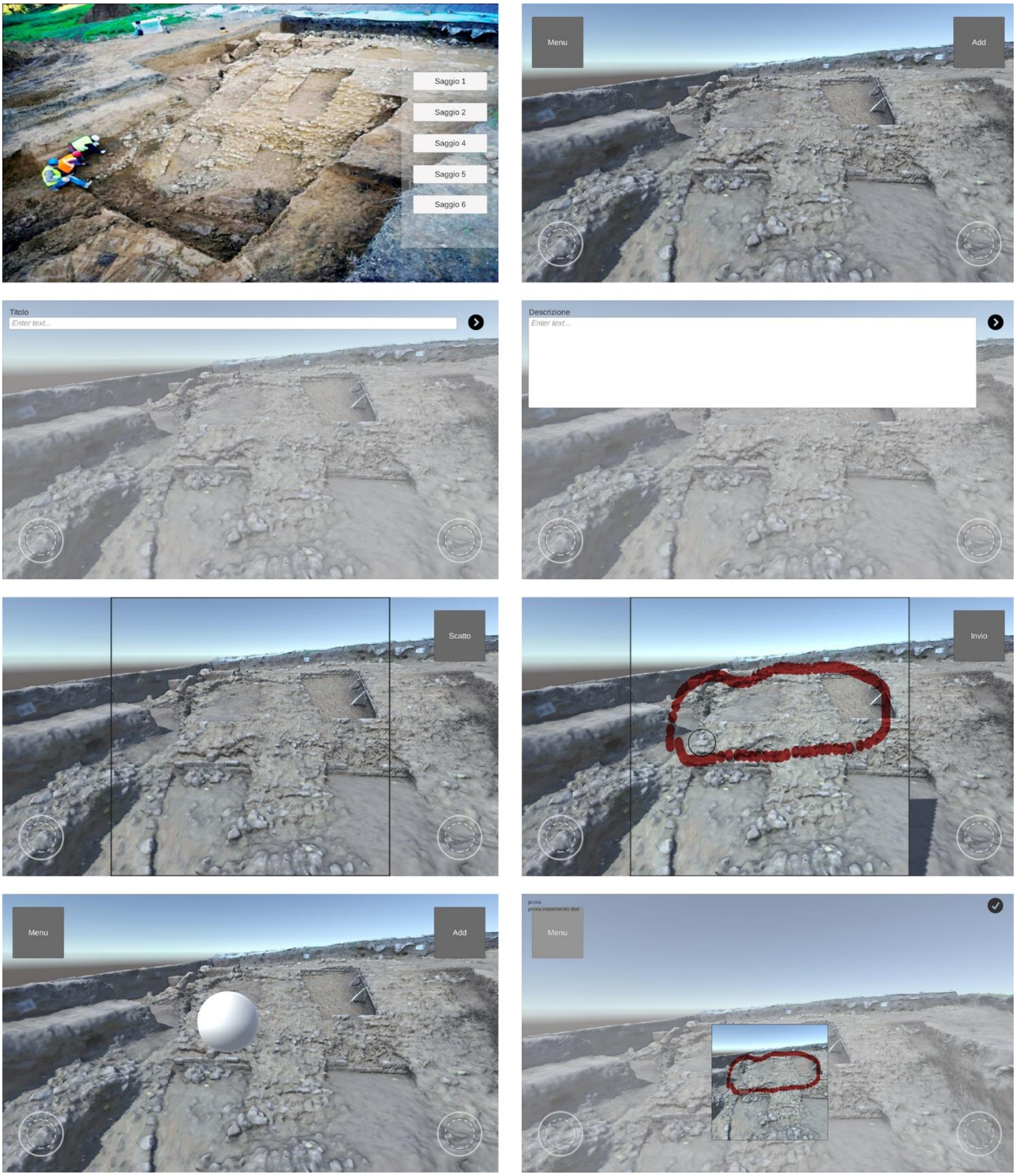

Fig. 14: Screenshots of the application's operation. From top to bottom and from left to right: menu for selection of the excavation; VR view of the excavation; entering the POI title; inserting of the descriptcreaion; frame for shooting; drawing; save and creation of the sphere for the link to information stored on the DB; visualization of the data entered.

be able to experience the countless possibilities of texts to read and the expressive richness of every small and apparently insignificant detail can only bring an increasing number of people to awareness of its importance. The knowledge and the experience of a cultural or historical artefact is the basis for the recognition of its value and therefore influences the choice of its conservation. Consequently, the latter can become an authentic and shared need, which will render the experience richer and more intense. From this perspective, virtual reality allows the implementation of processes of knowledge, even in the absence of a specific technical preparation; and those who build the project can drive the experience on more than one level, from that of a generic user to that of a specialist. If data is used for enhancement, it is not a question of making reality or the job spectacular, but of offering a potentially vast audience the opportunity to experience the same emotion of an operator on the job.

Virtual reality technology can be a valuable tool that allows carrying out different cultural tasks, from conservation to exploitation. Although traditional means of communication can and should continue to offer their contribution to education and awareness, VR also could be used in these areas as a more immediate and effective didactic tool. In fact, in addition to constituting valid instruments for study and depth for experts, it is evident that similar projects that VR contributes to the fulfilment of the educational function of cultural heritage.

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