Advantages and disadvantages of digital approach in archaeological fieldwork

Bianchini C., Borgogni F. and Ippolito A.

Abstract

Graphics and photographs have always played a fundamental role in archaeological documentation and data interpretation. Both may be affected by subjective interpretation. In the last decades the digital approach has helped to speed up fieldwork and provide enough information for GIS platforms. Since the 1990ies researches have applied digital numeric models to the representation of phenomena also in disciplines like archaeology. Nowadays this approach has become common practice. Nevertheless exploiting increasing amounts of data often implies more complex procedures for investigation and categorization. The whole process depends on the quality of models adopted to gather, order out and process this information. It is aided by 3D numeric models that are becoming widely available for automatic 3D acquisition, digitalization and real time browsing. Digital gathering of fieldwork should consider the need of collecting maximum information in the shortest time and budgetary constraints.

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Advantages and Disadvantages of Digital Approach in Archaeological Fieldwork

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Abstract

Graphs and photographs have always played a fundamental role in archaeological documentation and data interpretation. Both may be affected by subjective interpretation. In the last decades the digital approach has helped to speed up fieldwork and provide enough information for GIS platforms.

Since the 1990s researches have applied digital numeric models to the representation of phenomena also in disciplines like archaeology. Nowadays this approach has become common practice. Nevertheless exploiting increasing amounts of data often implies more complex procedures for investigation and categorization.

The whole process depends on the quality of models adopted to gather, order and process this information. It is aided by 3D numeric models that are becoming widely available for automatic 3D acquisition, digitalization and real time browsing. Digital gathering of fieldwork should consider the need of collecting formation in the shortest time and budgetary constraint shortest time and budgetary constraints.

budgetary constrains. Digital gathering of fieldwork should consider the need of collecting maximum information in the shortest time and budgetary constraints.

Keywords: Survey, Archaeological Fieldwork, Documentation, Low Cost Technologies.

1. Introduction

The cognitive process in archaeology aims at reaching the most precise and complete understanding of the object of research. The methodologies that exploit the potentialities of digital instruments for non-contact surveying have lately increased their relevance actually becoming part and parcel of an integrated workflow somehow combining tradition and high-tech. The study of an archaeological site or element often engages also different expertise and professionals (archaeologists, architects, historians, engineers, ICT experts, etc.): this fact entails the setup of a common working protocol already at the excavation stage for both data capturing and modeling. This goal can be achieved through a double effort: on the one hand, experts in digital technologies and techniques will have to better respond to the needs connected with the archaeological research; on the other, instead, scholars will have to become better acquainted with capturing/modeling technology in order to master its potentials. In this paper we shall describe the procedure worked out by our research group taking into account both the main techniques used for 3D capturing and the methods for their optimization when applied to archaeology. In particular we shall describe and compare models obtained with active (laser scanner), passive (photomodeling) 3D no contact capturing systems and traditional direct surveying methods.

The survey and the methodological comparison presented in the following paragraphs refer to an excavation campaign developed in 2011 in the necropolis of Crustumerium, an ancient city situated a few kilometers north of Rome. The work has entailed the documentation of the various excavation stages of one of the tombs as well as of some findings.

2. The necropolis at crustumerium

The majority of ancient Roman authors describe Crustumerium as a Latin city. It occupied an area of approximately sixty hectares along the present via Marcigliana, north of Rome. The site was strategically very important being on the main commercial road which connected Etruria with Campania: this particular location made the city flourish in archaic times and, most probably, it also represented one of the reason why the neighboring cities of Veio and Rome were so much interested in maintaining relations with Crustumerium. Rome expanded and in 500-499 B.C. finally conquered Crustumerium which kept its strategic its strategic relevance until 369 B.C. when, after the destruction of Veio, the Romans were no longer interested in controlling roads in the area. Thus the ancient city gradually fell into the state of semi-abandonment and disappeared completely during the V

1 Experiments with large objects have been purposefully excluded because of the sheer bulk of information would make it difficult to carry out elaborations.
century A.D. The ancient site of Crustumerium was then discovered in 1976 thanks to the research of the CBR conducted by the archaeologists Lorenzo and Stefania Quilici who produced the first survey documentation concerning this ancient settlement (Fig. 1).

The site is so vast that, at least so far, an exhaustive study of the internal structure of the city is still lacking, being its necropolis the only well analyzed part. The finds collected to date have allowed the researchers to differentiate and define various funeral typologies related to different historical periods.

Our research was focused on one of the tombs excavated in July 2011 (n. 310), a rectangular well of 106x231 cm. approximately 84 cm. deep, with a lateral loculus (80x260 cm., 63 cm. high) closed with tufo tiles placed vertically in which the archaeologists discovered the skeleton of a woman with a complete funeral dowry.

3. Problems inherent in data acquisition

Excavations inside a necropolis imply the re-opening of structures which had been conceived and built to remain closed forever and that, in addition, are presently located under layers of materials deposited through the centuries. It is paramount then that any archaeological investigation must be regarded as a highly invasive, destructive and above all irreversible process and that documentation is the only means to keep track of the original status of the site. Furthermore, the necropolis of Crustumerium contains various types of funeral structures differing in shape and size. The common features are big stone slabs – horizontal and vertical – designed with the function of sealing the corpse inside his or her own burial recess (Fig. 2). The documentation of these sealing slabs (which inevitably need to be removed in order to bring to light the dowry and the skeleton) represents one of the main problems to be addressed. Too often, in fact, they have been too hastily documented or simply destroyed without considering the relevance of these burial structures. Nowadays the stratigraphic approach allows the accurate documentation of each excavation phase and of all structures belonging to the different layers encountered by the researchers. In this framework, the burial site has been specifically studied to test out different fieldwork documentation methodologies (both traditional and high-tech) in order to assess advantages and disadvantages in terms of accuracy, cost, time, etc. Even if the traditional approach (direct survey, hand sketching, etc.) still appears somehow irreplaceable, nevertheless we have concentrated especially on 3D capturing techniques comparing procedures and results coming from 3D scanning and photomodeling.

One particular parameter has been closely monitored during our work developed together with the team of archaeologists: the user-friendliness of the system. Any technical development, in fact, will turn to be effective only if the main user group is likely to adopt it: in our case it means that 3D capturing/modeling will deploy its real potential in the archaeological field only if archaeologists will feel confident enough of using it widely. Not only the cost of the equipment can be seen as a great obstacle but also a general suspiciousness towards technology and a lack of confidence in handling digital instruments both
texturizing the 3D model with the images acquired by the scanner or captured by the camera (fig. 3).

4. Data acquisition

4.1 Direct surveying

As already mentioned in the previous paragraphs, the integrated approach used in Crustumerium relies on a close cooperation between archaeologists and experts in digital capturing/modeling technologies. Besides, we all intended to compare data and procedures commonly used by different teams in order to assess benefits and drawbacks. For this reason, different teams worked on the same site each acquiring information according to their ‘standard’ protocol. In this framework, archaeologists have collected data using their traditional procedures: observation of the object, understanding of the context in which it is immersed, direct measure of a limited number of significant points. The information has then been stored in the shape of two-dimensional drawings (plans and sections) and photographs. Both these, together with other studies and analyses (historical, sociological, etc.), would lead to hypothesis about the traditions of the ancient civilization of the inhabitants of Crustumerium as well as to place the archaeological finds in their proper historical and geographical context. It’s paramount that in this case there is a direct relationship between the level of acquaintance of the surveyor towards the site and the quality of the survey itself as any bit of information reported on a piece of paper depends inevitably and directly on the skill, experience and will to communicate specific aspects of the object. In other words, the information collected are the result of a direct choice of the surveyor. Besides, two more crucial aspects must be considered about traditional surveying methodologies: firstly, it is not always possible to use direct surveying procedures without altering or damaging the find or the context; secondly, as we shall demonstrate in the following lines, the direct approach not always represents the best combination of time, cost and information for documenting the various steps of an excavation campaign (fig. 4).

4.2 Non contact surveying

Long Range Laser Scanner

Long Range Laser Scanner in surveying tombs buried underground one runs the risk of encountering problems while trying to apply the procedures – like those of the ground undercut or the positioning of the target which lies at a certain depth and has restricted dimensions. These have to be solved in order to proceed with the step of registering between separate scans. As far as the undercut are concerned, if proper considerations are not taken into account before initiating the survey, one runs the risk of not obtaining complete data or that of getting a plethora of information. As to the problem of targets, the choice was made to avoid applying them to directly on surveyed surfaces for two fundamental reasons: one, in order not to alter the surveying data and simulate as closely as possible...
the conditions of the fieldwork: two, the necessity to excavate would not allow to keep the objects in their fixed places inside the tomb for the whole time of carrying out the excavations. These preliminary considerations guided an optimized positioning of targets during the surveying of all excavation stages of tomb n. 310. In order to proceed as expeditiously as possible with the digging, four targets were fixed on four wooden poles, driven into the ground around the area to be studied and positioned in such a way that they were visible from all places without disturbing the archaeologists’ work. What is more, in order to scan the inside of the tomb, independently from its depth, a tubular scaffolding - easy to dismantle - was erected and used to fix four more targets above the excavation site.

Ten different excavation stages have been documented. For each of them two separate scans were performed in such a way as to fill out various undercuttings with a 2x2 mm. spacing. As long as the excavations was not too deep, the scanner was placed on its tripod. When the excavation got deeper, it was placed directly on the ground around the edges of the hole. In this way the lower shadow zone was limited\(^4\) and the scanning provided more data. The Cartesian coordinates and respective RGB and reflectivity data characterize each point of every acquired cloud.\(^3\) Thanks to the overlapping of clouds it was possible to unequivocally represent the real development and succession of the ten excavation layers adding somehow a fourth-dimensional character (time) to the conventional two and three-dimensional representations. The stage of registering point clouds follows the acquisition phase: it aligns the local coordinate systems of the different scans to an uni-vocal and homogeneous Cartesian system of reference generally using tie points. This operation creates the numeric model, that is to say the general point cloud composed by all the aligned ‘sub-clouds’. Leica Cyclone 6.0, the software used at this stage, ensured also a real-time control of the level of uncertainty of the procedure thanks to semi-automatic tools for registering clouds. In this framework, we chose to consider the average error of collimation for targets (about 2 mm.) as a reference for the general uncertainty value of the data acquired with the laser scanner and, more generally, the benchmark value also for comparing different methodologies. All the analyzed stages of the excavation have been thus captured as independent scans leading to independent numeric models. For this reason, after optimizing the clouds with Meshlab 1.3.0 software (i.e. eliminating redundancies), they have been put together in a single 3D space actually reconstructing the exact timeline that had generated the capturing. 4 Things that are no visible from a definite positioning of the instrument cannot be surveyed. In order to have complete data, it is necessary to carry our a further series of scans that will

\(^3\) Things that are no visible from a definite positioning of the instrument cannot be surveyed. In order to have complete data, it is necessary to carry out a further series of scans that will include places hidden from sight and will simultaneously guarantee the overlapping satisfactory for assembling the parts. The lower shadow zone is the area ‘unsurveyable’ for technical mechanical reasons and extends at the angle of 90 degrees.

\(^4\) The value of reflectivity indicates the amount of light that a given surface can reflect.
include places hidden from sight and will simultaneously guarantee the overlapping satisfactory for assembling the parts. The lower shadow zone is the area ‘unsurveyable’ for technical reasons and extends at the angle of 90 degrees.

Exploiting Poisson’s interpolation algorithm\(^6\) for extracting mesh surfaces from a point cloud, it was possible to build polygonal three dimensional models made up of triangular surfaces which had to be partially corrected manually to eliminate again redundancies and to keep only the portion of the model significant for our purposes. Chromatic surface characterization is yet another datum necessary to compare the ‘scanned’ 3D model with the image-based one. For this specific reason we used a special function developed within MeshLab that transfers the RGB value from the point cloud directly to the vertexes of the mesh surface and then to the textured model.

The application of this particular technology to the surveying of tomb 310 pointed out some specific issues:

- natural illumination of the site with shadows changing through the different phases of the day; the context which, though cooperative towards our experimentation, could not be too modified to accomplish our needs;
- the surveyed object, which could not be moved or turned because of its particular structure. Finally, the use of low cost instruments for non-contact surveying (compact commercial camera with 12 Megapixels) called for an optimization of the survey project in terms of number and framing of photographs to be taken. On the other hand, as our activity aimed at comparing various different surveying methodologies, it has been necessary to provide a photographic documentation of the same excavation stages already documented through laser scanning.

A preliminary recognition of the actual equipment potentials of our team in hardware/software terms, we decided to take a set of pictures that would not exceed the total of 30 units, a number that would anyway guarantee a satisfactory overlapping of images without overloading the calculation system.

Twelve photographs taken around the excavation site together with 18 close up shots formed the whole dataset yielding to a perfect balance between the general pictures and the detailed ones. Unfortunately, because of the uneven geometry of the structure and some operational limits of the laser scanner, certain well-hidden parts of the object could not be surveyed at all. In this case the point cloud has been obtained only by correlating homologous points on two photographs.\(^7\) After cleaning the datum with Poisson’s interpolation algorithm to get rid of redundant information, it was possible to build a three dimensional polygonal model. The result of this process underwent an optimization leading to the transfer of chromatic values of the initial point cloud to the vertexes of the mesh surfaces and finally to the 3D textured model.

**Comparison**

The first evaluation concerned a methodological comparison of non-contact surveying methodologies.

When working on any excavation site, especially such as that of Crustumerium gone through a series of clandestine excavations, it is very important to extract the various finds as fast as possible. Keeping an excavation site open too long also means risking all kinds of problems connected with weather conditions. While conducting our survey, in fact, an unexpected night rain filled all the tombs with water seriously compromising the fieldwork. Not only did the unfortunate accident affect negatively the rhythm and the pace of our work (the whole area had to be dried) but it also threatened the state of conservation of the finds, which had already been partly uncovered. Such events, rare as they are, bring to light the need of procedures that guarantee the fastest collection and documentation of the finds without reducing excavation standards. In our experience, time proves to be one of the main parameters that distinguishes the two approaches analyzed: data into points in space characterized by Cartesian coordinates XYZ and the chromatic ones – RGB. Such an operation is necessary in order to find the position in the very centre of the projection or of the camera in relation to the scene at the moment of acquiring the image. It determines the precision and number of points gathered later.

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\(^6\) For further reading on this particular algorithm, see texts in the bibliography.

\(^7\) The automatic correlation of homologous points is the stage in which the photomodelling process is articulated. It follows the acquisition of photo images precedes the construction of the numeric model. At this stage homologous points in the photograms are transformed automatically
acquisition with the laser scanner, though extremely fast, imposes nevertheless some operational constraints related with the positioning of the instrument that can be quite time consuming. Moving the scanner around the tomb has been in fact not so easy: the scanner itself weighs approximately 18.5 kg and any shift generally involves also its tripod, the batteries and the laptop that controls the instrument. On the contrary, the procedure based on the photographic data acquisition is much easier: the only instrument necessary is in fact a camera (much more convenient to carry around), no particular positioning is required before each picture, the overall time necessary to complete the work is that needed to target and shot each photograph. Here is a comparison of the two methodologies in terms of the time used for the acquisition phase: TOF laser scanner Number of scans: 2 Average time of a single scan: approx. 45 mins. (taking into account the necessity to move the instrument around as well as targets’ acquisition) Average total time necessary for the acquisition of a single excavation stage: 90 mins. Photomodelling Number of photographs: 30 Average time per single photograph: app. 20 sec. Average total time for a photographic set: 10 mins.

The differences between the two approaches are quite evident: by saving up about 80 minutes for each stage of the excavation means that for the 10 stages the reduction would be of about 13 hours. It must be stressed, however, that the point cloud acquired by the 3D laser scanner can be navigated and controlled directly on-the-go, while this important feature is precluded when gathering data from photographs. In this second case, though, it is possible to take in only 10 minutes the 30 photographs necessary to guarantee a complete modelling and a point cloud comparable to that produced with the laser scanner. Another parameter of the comparison of the two non-contact surveying methodologies is the cost of the surveying campaign. From this standpoint, photomodelling proves to be much cheaper than 3D scanning especially for the cost of the equipment itself and its deploying on site. The comparison of the two methodologies has unequivocally demonstrated that photomodelling, at least in the capturing phase, is much more advantageous than the TOF laser scanner.

5. Data elaboration

The assessment of the level of uncertainty of the captured data represents one of the most significant parameters related with survey. When using the technique of photomodelling, though, it is impossible to assess this datum during the capturing phase. Any comparison between the data obtained with this methodology and those acquired by laser scanning requires some preliminary operations so to make the two clouds compatible: in particular, the image-based cloud needs to be conveniently scaled as the raw numeric model is dimensionless. Following this crucial step, we started to compare systematically the 3D models of each excavation stage (laser scanning and image-based) analyzing homologous elements. This operation turned to be particularly tricky: the acknowledgement of homologous elements in both models (i.e. a line or an edge) implies the tracing of a number of corresponding points in the two clouds, often very different in shape and color.

Once the image-based models were properly scaled, there followed an alignment phase performed by means of rigid roto-translations which helped to find the best fitting position between the scanner and the image-based models. The procedure was carried out with the Geomagic Studio 10 software: after a manual pre-alignment, we used an automatic procedure to reach the best positioning always controlling the average error. Just before performing the models comparison, they have been optimized by cleaning out edges, that is to say regularizing the contours of homologous surfaces. Finally, we went through the assessment of deviations: point by point we pointed out their distance in the two different models (the minimum distance segment) assuming the 3D scanner model as a reference. The following tables summarize the models comparison referring to the initial, intermediate and the final excavation stages of tomb n. 310.

6. Conclusions

Analysis of the values obtained by comparing 3D models built with the data from the 3D TOF laser scanner and from the photomodelling brings forward a number of particularly interesting issues. Some characteristics intrinsic to each technology fundamentally influence the final result in terms of chromatic output and uncertainty level of the model obtained. Texture mapping for both models – the model obtained from the scanner and the image-based one, are both carried out by transferring RGB values of the initial cloud directly onto the vertexes of the final mesh surface. In principle, a very dense point cloud yields a mesh surface rich in geometry (high number of vertexes and edges) and thus an excellent chromatic result and high level of detail in the shift from the cloud to the surface. The test carried out on real conditions (survey of tomb n.310) has revealed quite a different situation. The scanner used for documenting the excavation did collect a high number of points which could be used to construct a particularly detailed 3D model, but the acquired color datum was almost useless for the following main reasons:

- the resolution of the 3D scanner camera (1024x1024 pixel) did not guarantee a convenient level of detail;
- the way the scanner acquires images: the internal mirror drives in fact light onto the CCD sensor often generating many undesired reflection effects;

ScanStation has the maximum acquisition velocity of 50,000 points per second.

In the new models the problem of the weight of the instrument has been at least partially solved and the user can control the scanner directly on the instrument thanks to an integrated display.

Just as reference, in the time the laser scanner worked on the tomb n. 310, 4 other tombs on the excavation site and a funeral memorial stone discovered in the area were successfully surveyed.

11 The value of the average error is in inverse proportion to the precision level of the alignment operation
<table>
<thead>
<tr>
<th></th>
<th>Scanner laser 3D data</th>
<th>Data from photographs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of scans</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Number of photograms</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Exported dimension file point cloud</td>
<td>55.222 Kb</td>
<td>25.226 Kb</td>
</tr>
<tr>
<td>Initial number of points</td>
<td>1,570,721</td>
<td>371,444</td>
</tr>
<tr>
<td>Number of points after cleaning excessive data (.ply)</td>
<td>947,928</td>
<td>208,874</td>
</tr>
<tr>
<td>Mesh model obtained through Poisson’s interpolation</td>
<td>659,374 faces</td>
<td>310,741 faces</td>
</tr>
<tr>
<td>Final dimension model (.ply)</td>
<td>16,488 Kb</td>
<td>7,962 Kb</td>
</tr>
</tbody>
</table>

**Excavation stage 1**

| Scale factor calculation – distance of model from scanner (m) / distance from model da photographs (m) | Average value in the data obtained: 1.57 |
| Data registration                                                                                     | Manual pre-alignment by signalling of four homologous points |
|                                                                                                       | Automatic alignment with error calculation |
| Deviation calculation                                                                                  | Maximum Distance positive: +0.021 m |
|                                                                                                       | Maximum Distance negative: -0.017 m |
|                                                                                                       | Average Distance: 0.000 m |
|                                                                                                       | Average Distance positive: +0.004 m |
|                                                                                                       | Average Distance negative: -0.004 m |
|                                                                                                       | Standard Deviation: 0.005 m |

**TABLE 1: EXCAVATION STAGES 1. COMPARISON BETWEEN SCANNER LASER 3D AND SURVEYING FROM PHOTOGRAPHS, DATA ACQUISITION AND DATA ELABORATION.**

- The time needed for scanning produces a set of images with different exposition and shadows and finally a chromatically non-homogeneous point cloud.

3D models obtained from photomodelling, instead, although less dense in terms of vertices and edges, are chromatically uniform enough to enrich with information a geometry which is less detailed.12

Another issue refers to the geometric detail level of the 3D model. While the scanner guarantees a high geometric accuracy for acquired data being not influenced by the brightness or glare of the object, photomodelling is instead deeply affected by the ‘visible’ aspect of the object that needs to be sufficiently well lighted to be adequately photographed. From this specific standpoint, the laser scanner yields more homogeneous data than photomodelling where, on the contrary, there is a strong lack of homogeneity caused by differences in lighting.13

Other aspects connected with any surveying campaign are cost and time. There is no doubt that the photomodelling technology is zero cost in comparison with the price of a 3D laser scanner but also in comparison with the instruments used in photometry and topography. The budget would most likely be comparable instead to that of a direct surveying campaign, practically affordable by anyone. Moreover, these image-based technologies can perform surveys 10-20 times faster than those carried out with a 3D laser scanner. Worth considering is also the transport and positioning of the instruments where cameras’ operativity show no constraints while 3D laser scanners might seriously be limited.14 We cannot affirm that photomodelling can always substitute the use of 3D scanners: in our specific case, though, where archaeologist had to document the excavation as soon as possible in order to describe exhaustively the state of the excavation, it has proved very productive and accurate. Even if an uncertainty value of ±3-4 cm was considered acceptable by archaeologists, the image-based technique yielded models with uncertainty level of ±0.5-0.4 cm, and with a great save of time. In our opinion, therefore, we think that this 'zero-cost capturing technology will deeply revolutionize the archaeological documentation in the very close future. It proved to be a valid alternative to the graphic documentation on the spot, a powerful instrument for 3D capturing as well as scanners, an indispensable equipment of all future researchers.

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12 In some 3D models based on photographs, chromatic values were changed because of different exposition to light of the object surveyed. This is the case of a part of the loculus and the parts that were in shadow.

13 Some of the zones particularly dark like e.g. the bottom of the recess and the so-called ‘sky’ have a very low detail level in comparison to the rest of the tomb.

14 These considerations are connected to the typologies of the 3D laser scanner used in the experiment described. They cannot be, therefore, regarded as valid for all laser scanners available on the market.
<table>
<thead>
<tr>
<th>Number of scans</th>
<th>Scanner laser 3D data</th>
<th>Data from photographs</th>
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<td>7.962 Kb</td>
</tr>
</tbody>
</table>

**Excavation stage 5**

Scale factor calculation = distance of model from scanner (m) / distance of model from photographs (m)

<table>
<thead>
<tr>
<th>Data registration</th>
<th>Average value in the data obtained: 1.42</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual pre-alignment by signalling four homologous points</td>
<td></td>
</tr>
<tr>
<td>Automatic alignment with error calculation</td>
<td></td>
</tr>
<tr>
<td>Average error = 0.008 m</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Deviation calculation</th>
<th>Maximum Distance positive: +0.029 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Distance negative: -0.052 m</td>
<td></td>
</tr>
<tr>
<td>Average Distance: 0.003 m</td>
<td></td>
</tr>
<tr>
<td>Average Distance positive: +0.006 m</td>
<td></td>
</tr>
<tr>
<td>Average Distance negative: -0.006 m</td>
<td></td>
</tr>
<tr>
<td>Standard Deviation: 0.006 m</td>
<td></td>
</tr>
</tbody>
</table>

**Table 2: Excavation stages 5. Comparison between scanner laser 3D and surveying from photographs, data acquisition and data elaboration.**

<table>
<thead>
<tr>
<th>Number of scans</th>
<th>1</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of photograms</td>
<td>-</td>
<td>10</td>
</tr>
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<td>Exported dimension file point cloud</td>
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<tr>
<td>Final dimension model (.ply)</td>
<td>16.488 Kb</td>
<td>7.962 Kb</td>
</tr>
</tbody>
</table>

**Excavation stage 10**

Scale factor calculation = distance of model from scanner (m) / distance of model from photographs (m)

<table>
<thead>
<tr>
<th>Data registration</th>
<th>Average value obtained: 0.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual pre-alignment by signalling four homologous points</td>
<td></td>
</tr>
<tr>
<td>Automatic alignment with error calculation</td>
<td></td>
</tr>
<tr>
<td>Average error = 0.002 m</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Calcolo delle deviazioni</th>
<th>Maximum Distance positive: +0.015 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Distance negative: -0.018 m</td>
<td></td>
</tr>
<tr>
<td>Average Distance: -0.000 m</td>
<td></td>
</tr>
<tr>
<td>Average Distance positive: +0.002 m</td>
<td></td>
</tr>
<tr>
<td>Average Distance negative: -0.002 m</td>
<td></td>
</tr>
<tr>
<td>Standard Deviation: 0.003</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3: Excavation stages 10. Comparison between scanner laser 3D and surveying from photographs, data acquisition and data elaboration.**
**Figure 7:** Excavation Stages 1.
Point cloud from 3D laser scanner: original point cloud. Mesh model from 3D laser scanner: mesh model geometry and mesh model with photographic characterization. Point cloud from photomodelling: initial point cloud. Mesh model from photomodelling: mesh model geometry and mesh model with photographic characterization. Model alignment: automatic operation of alignment and average error calculation. Deviation calculation: by calculating deviations it is possible to quantify the gap between two models. The image presents chromatic values referring to the so called deviation scale. The maximum values are in red and intensive blue.

**Figure 8:** Excavation Stage 5.
Point cloud from 3D laser scanner: initial point cloud. Mesh model from 3D laser scanner: mesh model geometry and mesh model with photographic characterization. Point cloud from photomodelling: initial point cloud. Mesh model from photomodelling: mesh model geometry and mesh model with photographic characterization. Point cloud from photomodelling: initial point cloud. Mesh model from photomodelling: mesh model geometry and mesh model with photographic characterization. Model alignment: automatic alignment operation and average error calculation. Deviation calculation: by calculating deviations it is possible to quantify the gap between two models. The image presents chromatic values referring to the so called deviation scale. The maximum values are in red and intensive blue.

**Figure 9:** Excavation Stage 10.
Point cloud from 3D laser scanner: initial point cloud. Mesh model from 3D laser scanner: mesh model geometry and mesh model with photographic characterization. Point cloud from photomodelling: initial point cloud. Mesh model from photomodelling: mesh model geometry and mesh model with photographic characterization. Point cloud from photomodelling: initial point cloud. Mesh model from photomodelling: mesh model geometry and mesh model with photographic characterization. Model alignment: automatic alignment operation and average error calculation. Deviation calculation: by calculating deviations it is possible to quantify the gap between two models. The image presents chromatic values referring to the so called deviation scale. The maximum values are in red and intensive blue.
FIGURE 10: EXCAVATION STRATIGRAPHY RECONSTRUCTION. Placing the various stages of the excavation into a unified Cartesian system of reference makes it possible to reconstruct in 3D the stratigraphy of the documented excavation.

FIGURE 11: BASE ELABORATION MINING. By intersecting models with reference plans it is possible to obtain also two dimensional representations and compare them with elaboration worked out by direct surveying.

References


