Rapid 3D Recording of Archaeological Sites Found During Construction Development

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Key words: cultural heritage, documentation, archaeology, laser scanning, close range photogrammetry.

SUMMARY

Current archaeological research in Greece is greatly enhanced from urban construction development that results in new archaeological finds. Whilst these findings are very important, financial pressures from during urban development result in either being destroyed or reburied to facilitate the construction of new structures. Invariably, valuable knowledge from such sites is lost forever.

This paper discusses how modern surveying techniques can be used as foundation for preservation of cultural heritage. Specifically, the use of terrestrial laser scanning and digital photogrammetry to rapidly record detailed and definitive three-dimensional information from an early Helladic period (circa 2300BC) settlement in the southern area of Athens is discussed. The specific site has been exposed but will be completely destroyed due to a major road construction. The data capturing procedure during excavation is described and processing strategies are discussed. Finally, virtual models of the site created from the resultant data sets are shown. These can be easily disseminated to the research community and to the general public demonstrating that no archaeological site need be 'lost to posterity' due to its burial or destruction by urban development.

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1. INTRODUCTION

Archaeological research is often focused on large monuments, temples and sites because, as expected, these offer the opportunity for further excavations where significant finds are located. Whilst classical archaeology is mainly interested in important historic and architectural artefacts, current research gives emphasis in locating any material evidence that can invariably demonstrate the relevant architectural and historical period and provide information not only on the daily life of the upper class but also about the social and economical status of the lower class community.

In Greece, this trend of archaeological research has been greatly enhanced from urban construction development. This results in new finds, thus providing valuable information on the daily life of historic or pre-historic communities. Examples of these big construction developments in the metropolitan area only include the underground train in the city centre of Athens, the new airport in the area of Mesogia and the construction of a highway at the perimeter of the city. These excavations often take place in areas where there is no intention to perform any archaeological research. Nevertheless, the results of the excavations give importnat finds not only of architectural significance such as statues, but mostly remnants giving information about house designs and daily occupations for example laboratories, ceramic ovens, tools, coins. In fact, there are currently over 100 ongoing excavations around the country that are related to construction development (Zias, 2003). These extend chronologically from the Neolithic period to Byzantine and post-Byzantine era, therefore adding the time dimension to the spatial dimension of the provided historic information. Whilst these findings are very important, financial pressures from during urban development result in either being destroyed or reburied to facilitate the construction of new structures. Invariably, valuable knowledge from such sites is lost forever.

Geometric documentation is the prime concern of archaeologists when discovering new sites. The most commonly applied product continues to be the line drawing normally at 1:20 or 1:50 scales. These are made very quickly on site using direct measurements, like measuring tape or profile-meter, and are often the only form of documentation but are lacking of real geometric accuracy, unique scale, correct orientation and representation of the third dimension. When financial and time constraints are not critical, documentation is usually performed with standard surveying techniques. Using a total station the problem of measuring is moved to criteria of point selection. In this case though, very often the produced design accentuates the geometry by forced on non-measured symmetries because a large number of points are required to describe fully the shapes of found objects.

Photogrammetric survey is the method that addresses the geometric documentation of complicated monuments and sites with the production of very accurate digital products, such as digital true orthophotos, vector maps through stereo-restitution and three-dimensional models. However, in surveys of sites found during construction work where information needs to be collected quickly and fairly economically, photogrammetry is not always the most appropriate method. The remnants from sites of chronologically earlier periods have usually very low altitude characteristic features. Furthermore, the terrain of these sites can be complex due to the ongoing development of the construction, thus making it sometimes difficult to discriminate between archaeological and non-archaeological traces. Therefore, the combined use of terrestrial photography and low altitude platforms for aerial image capturing is more applicable in these cases (e.g. Georgopoulos et al, 2001). Digital image processing has simplified photogrammetric processing but this can still be laborious for providing high accuracy final products for rapid documentation purposes, especially when the automatic matching algorithms available at the existing DPW do not give satisfactory results in complex close range surfaces (Ioannidis, 2002).

The recent emergence of terrestrial laser scanning with the high spatial density of information combined with spectral response data provides a very rich visual imaging system for rapid recording. The technology has already shown promising results in archaeological site documentation (eg Cantoni et al, 2002; Barber et al, 2003). Clearly, the integration of opportunities provided by close range photogrammetry and laser scanning can offer a significant tool in site documentation. Advantages offered towards the automation of the photogrammetric process include the possibility of the laser data to supply the coordinates of signalized control points (thus completely avoiding field surveys) and provide information about the digital elevation model (DEM) for the orthophoto production.

Aiming at reduction of field work and automation of processing procedures, this paper discusses how the use of terrestrial laser scanning and digital photogrammetry can provide a measurement system that can rapidly record detailed and definitive three-dimensional information from sites that present expedient changes. The high rate and spatial density of data capture highlighted by the integrated measurement technique will ensure that construction site production down time can be minimized when sites of archaeological significance are discovered during urban development, thus providing a financial benefit to the construction industry. The essence of this system is that it should be non-contact and sites or monuments should not be interfered with or damaged in any way by the act of data collection.

A case study from a site located in a suburb of Athens in Greece is reported in this paper. Athens is a city with an exceptionally rich number of monuments and archaeological sites scattered throughout (and beneath) the city, which many of them are uncovered due to present urban construction development. An early Helladic period (circa 2300BC) settlement including a silver ore processing laboratory located in the southern area of Athens has been exposed but will be completely destroyed due to a major road construction. Details of the measurement procedures to rapidly acquire accurate and detailed three-dimensional spatial information during excavation are first presented, followed by the analysis of the data.

Results from virtual models of the site created from the combined data sets are shown to demonstrate that no archaeological site need be 'lost to posterity' due to its burial or destruction by urban development. Finally, a discussion on the products that can be disseminated to the research community and to the general public concludes this paper.

2. CASE STUDY

The inclusion of sound heritage recording is seldom a high priority to a development construction project where archaeological finds are discovered during excavations. Any effort in archival documentation is geared to urgency and financial restrictions. A case study falling in line with the above theme is the archaeological site of Labrika found during a major road construction in Attica of Greece. At the time of writing (February 2004) the site is already in the process of being completely destroyed and physically lost forever. The measurement recording procedures and the documentation results are described in the following sections.

2.1 Site Description

The site of Labrika in Koropi is located near the east coast of Athens (Figure 1). In fact, Athens was the only Greek *polis* (city-state) with the ability to dig its own wealth straight from the ground. Most of the east coast of Attica, with the port of Lavrion being the most significant mine area, was rich in siver-bearing ores which had been exploited since the Bronze Age. In 482 BC a new vein was discovered which led to a massive increase in activity. Themistocles persuaded the Athenians to spend this new revenue on building a fleet of triremes which were used to defeat the Persians at Salamis in 480 BC.

Figure 1. Location of archaeological site

The site described in this paper occupies an area of about $120m^2$ and is the most significant part of an early Helladic period (circa 2300BC) settlement, excavated in late 2003 (Nezeri, 2003). Specifically, the excavation site includes a silver ore processing laboratory located at the north-eastern part of the settlement where hundreds of silver-stones were found. The settlement however, extends further including remains of houses and other structures.

As seen at the site's topographic diagram (Figure 2), there are five small cavities located at the northwest direction of the settlement and in the perimeter of a large hole. These cavities were found during the excavation to contain silver-ore plaster. There is no indication that smelting and refining was taking place in this part of the site. The small circular shaped holes at the northern part are aligned which indicates that were possibly used for the support of a wooden structure. Although it is unclear what the use of the two big holes of diameter 1m could have been, near them a large number of silver-stones were found. This material is known to be produced when ore was moved from the mines to washing sites, where waste was removed by simple gravitational separation. Ore was separated from waste in special "washeries" and the remains of a wall shown in the figure indicate that this part of the settlement was used rather for waste deposition and not for storing purposes.

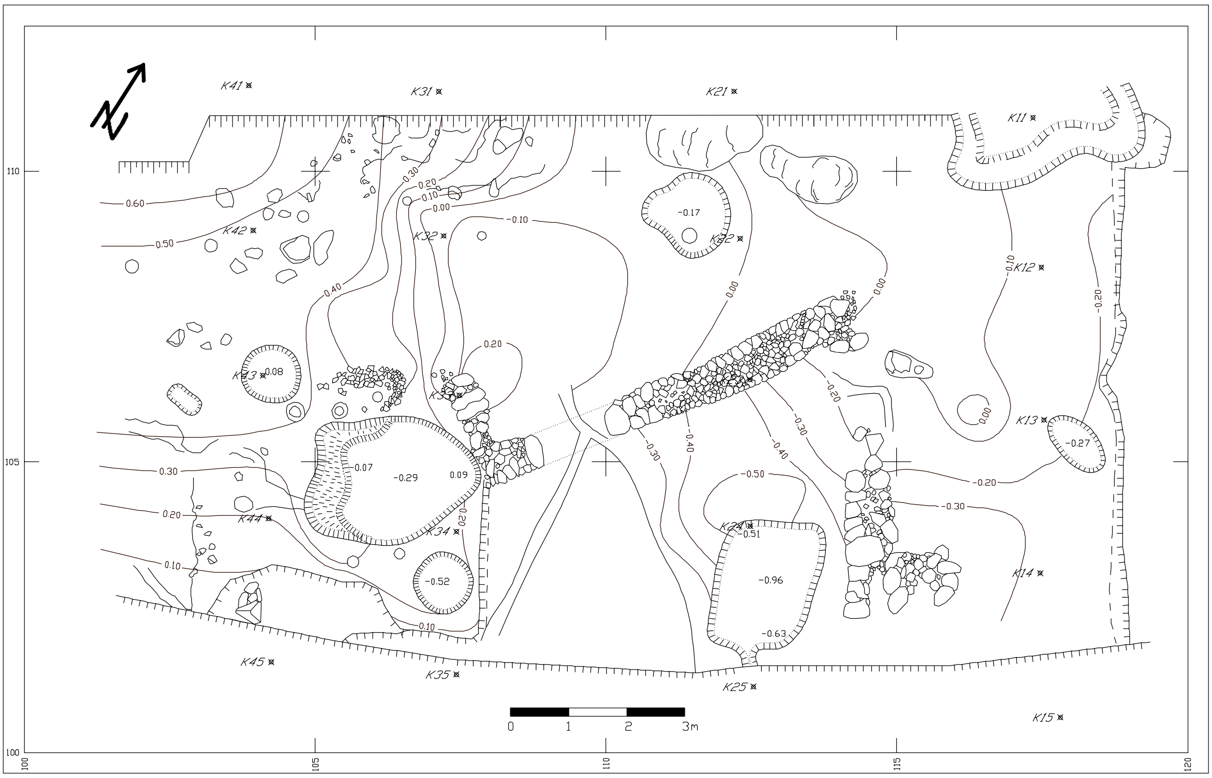


Figure 2. Topographic diagramme of the excavation site

For the geometric documentation of the site, at a scale of 1:50, three independent surveying methods were used: typical field survey, terrestrial laser scanning and photogrammetry. The field survey of the site (Figure 2) was performed with a TC307 total station at an accuracy of ±3mm.

2.2 Laser Scanner Data Acquisition

Terrestrial laser scanning technology is based on active range sensors measuring directly the distance between the sensor and points over the surveyed object. The laser scanner Cyrax 2500 was used in this project and scanning was performed from various positions so that the full coverage of the surface will be achieved with sufficient overlapping (Figure 3). The specific scanner has a recommended range of 50m. The system's horizontal and vertical field of view is 40 degrees and a maximum of 1000 scan points in each direction can be recorded in one scan. The laser dot size is 6mm over 50m and quoted standard deviations are σ = ±6mm over 50m. Laboratory testing prior to field work confirmed this accuracy.

Generally, laser scanning requires viewing the surveyed object from several viewpoints to resolve shadows and occlusions. In one day of scanning, 21 scans were recorded totalling approximately 1.5million scan points. The scan point interval was ranging from 15mm to 20mm. The number of scans was limited by the battery life of the system computer as there was no availability for externally charging the battery. No difficulties were experienced with poor surface reflection, attributed to the dry soil ground and the well reflecting stones of the walls.

The use of reflective targets distributed over the site as seen in Figure 3 allowed the easy registration of the scans during data processing. Although the laser scanning software provides direct and immediate access to the scan data by visually inspecting the point cloud in situ to identify possible problem areas in the data sets, it proved that some parts of the site were occluded and larger overlap was required for the complete merging of all scans.

Figure 3. Laser scanner facing the cavities

2.3 Photogrammetric Data Acquisition

The air-photography of the site was planned to have full stereoscopic coverage of the terrain surface and to produce orthophotos at a scale of 1:50. A bipod which can raise an analogue semi-metric camera up to a height of 9m, was used as platform to take the airphotos. The Hasselbland C/M500 camera of format 5.5x5.5 cm^2 and focal length c = 50mm (Figure 4), was used. The photos were taken from a mean height of 7m, so that a photo scale of approximately 1:140 would be achieved.

Figure 4. The bipod at the excavation area, during the field work.
Right: detail of the camera hanging system

In order to achieve a full coverage of the ground surface, especially in the interior of the holes and cavities (depth of 50cm), and to avoid shadows, the choice of large overlap between photos was selected. In total, 20 photos were taken in 4 strips (of 5 photos each), with a northeastern to southwestern direction, with an overlap of 70% along each strip. An overlap of 35% across was performed for the three strips and 55% across for the remaining two strips, mainly where the cavities exist.

The projection of each photo center was pre-marked on the ground surface, by rectangular targets of size of 10x10 cm^2. Figure 2 indicates these points which are described by code numbers from K11 up to K54. In addition, 8 predefined control points, three at the northeastern, three at the southwestern side and two in the middle of the block, were established to facilitate the photo triangulation process. The point coordinates were derived from field surveys with total station at an accuracy of 3mm. The duration of the fieldwork was 4.5 hours, requiring four people to operate the bipod.

3. PROCESSING AND ANALYSIS

3.1 Laser Scanner Data Processing

Processing of the laser data was performed using the propriety software Cyclone. The workflow for processing follows the main steps of data registration, georeferencing and meshing. From the total 21 acquired scans, 5 scans were not used because of inadequate overlapping. Figure 5 gives an example of a snapshot of the registered point cloud showing part of the excavation site. The registration of the remaining 16 scans gave an rms (root mean square) error of 3mm. This is slightly high considering that the scanned scene contained relatively large smooth surfaces. However, the overlapping points may not always be from the same surface mainly in the vicinity of edges thus producing a variety of wrong points. This is because the laser spot cannot be focused to point size and when hits an object edge, only a part of it will be reflected there (Boehler et al, 2003).

While it is not critical to perform georeferencing of the registered data in documenting archaeological sites, in this study it was required to use a common coordinate system for comparison purposes (the local reference system that had been established during the typical field survey of the excavation site). The reflective targets used during data acquisition served only for the point cloud registration and thus had not being surveyed to provide the coordinate reference system. This was deliberately chosen because in operational excavation site recording jobs where speed is the prime concern, the use of other surveying instrumentation defeats the purpose of saving time in field work. However, the coordinate transformation to the common coordinate system was performed externally.

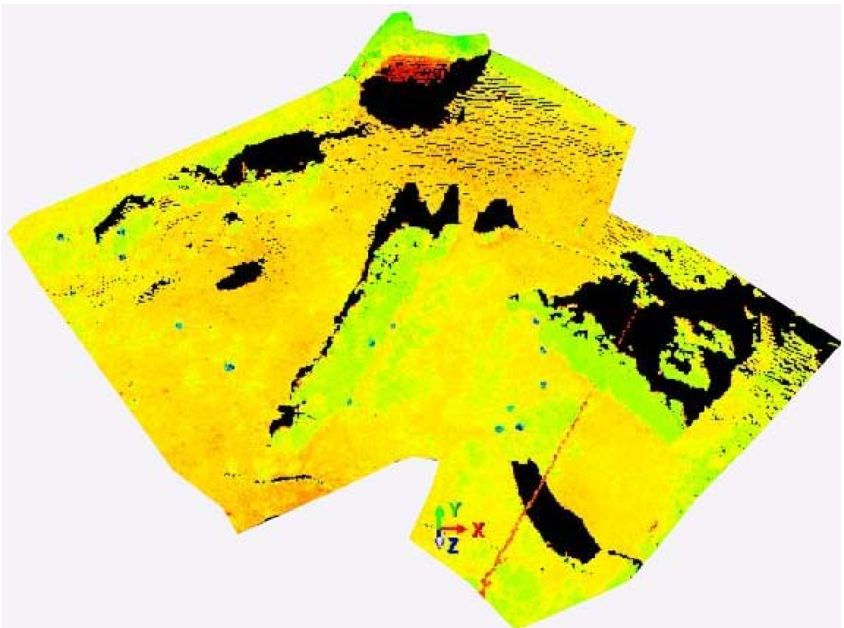


Figure 5. Snapshot of registered point cloud of the excavation site

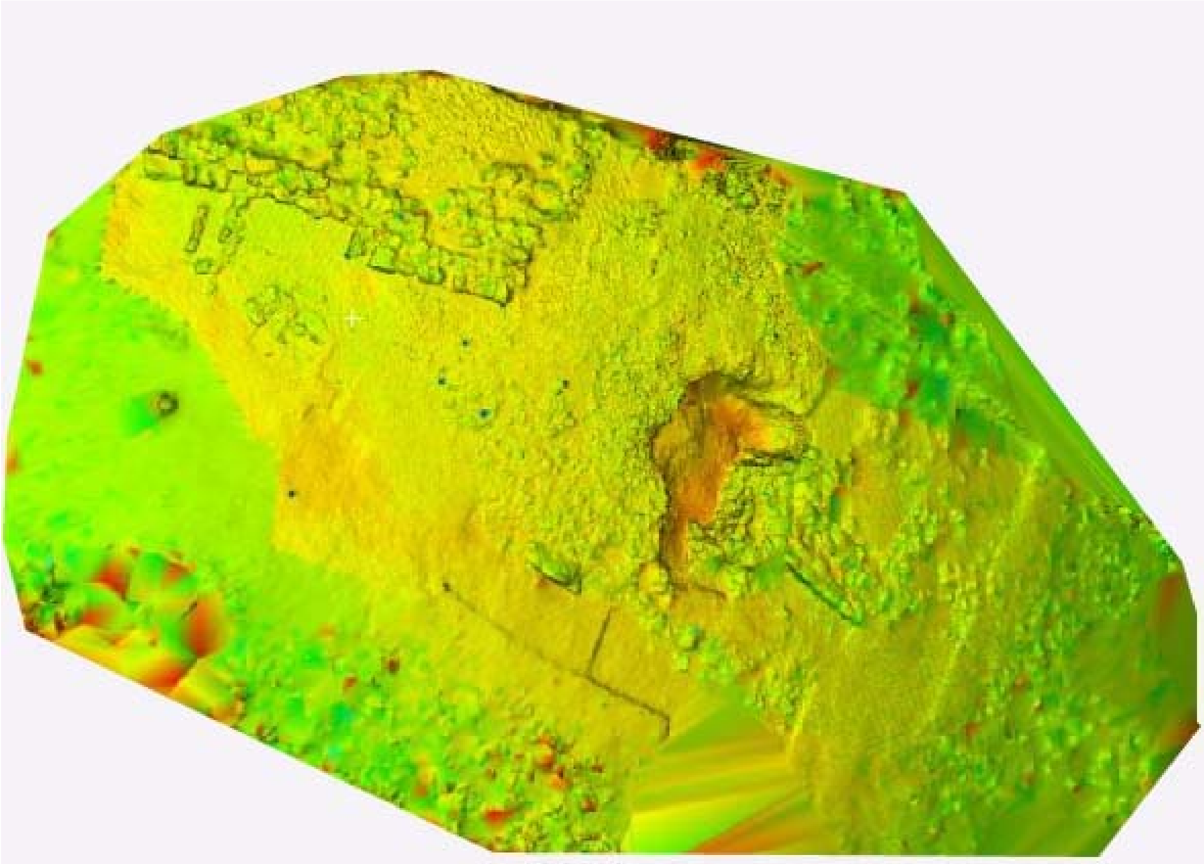
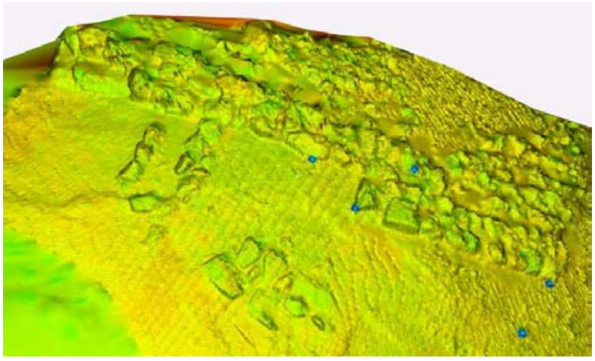
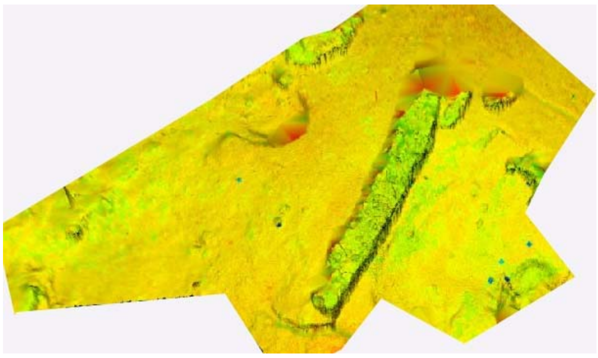


Figure 6. Snapshot of tined surface of excavation site



(a)



(b)

Figure 7. Details of tined surface

While occlusions during scanning can be a problem in the derived point clouds, the interpolation performed in the tined surface can result in a smooth surface, as seen in Figure 6. Figures 7 shows details of the tined surface where the reflective targets used for registration purposes can be easily distinguished (7a) and low altitude characteristic features can be traced (7b).

3.2 Photogrammetric Data Processing

The photogrammetric processing for the orthophoto production was performed in the SSK of Z/I Imaging digital photogrammetric workstation (DPW). The first stage comprised the aerial triangulation processing at the 20 photos block. The 28 points of known ground coordinates at the local reference system, established during the field survey (3 polygonometric stations were established at the site), were used as control points. For the triangulation process (perform at the ImageStationDigitalMensuration-ISDM module of the SSK) 24 tie points were established and their image coordinates were measured. In total, 181 image points were used. The adjustment gave σ = 25μm in image scale and errors in ground scale: rms(X/omega) = 8mm, rms(Y/phi) = 8mm, rms(Z/kappa) = 15mm and max ground residuals: V_X=1.9cm, V_Y=1.5cm and V_Z=3.5cm.

By using the estimated external orientation parameters of the images, an automatic DEM extraction at a grid of 15cm size was made and detailed manual editing followed. The orthophoto production was made with a pixel size of 5mm at the ground scale. Despite the big overlap between the airphotos, orthophotos were produced by using all the photos of the block and for the whole format of each photo. In effect, 20 orthophotos were produced, in order to have a better mosaic of the whole site without shadows and 'dead areas'. The selection of the appropriate part from each one of the orthophotos, that would be used for the compilation of the final orthophoto-mosaic, and their merging for the creation of one seamless picture was made by the software Raster Design of Autodesk. The radiometric corrections and the final colored mosaic was made by the software Adobe Photoshop 7.0 (Figure 8).

Figure 8. The final orthophoto-mosaic of the excavation site

3.3 Combined Use of Photogrammetric and Laser Scanning Data – Comparisons

While the field work for the data capture in both the photogrammetric and terrestrial laser scanning procedures can be accomplished within limited time, which is of critical importance in the documentation of archaeological finds/sites, the total time and cost needed for the production of the final products vary considerably. Also, depending on the type of method used the format and type of products are also variable. The selection of the most appropriate method depends upon the technical specifications of each project and upon the needs of the final user. For example, if the final product has to be a 3D model of the site, laser scanning is obviously the most appropriate solution (cf. Figure 6); if the final product has to be in a raster format, then photogrammetry is a must (cf. Figure 8).

There are many attempts reported in the literature for combining these two methods (e.g. Guidi et al, 2002; Caprioli & Scognamiglio, 2003; Ruether et al, 2003), aiming mainly to increase the achieved accuracy and completeness of the results and also to increase the variety of the products. This paper is focused on the combined use of the data collected by both methods, so that the required time and cost for surveying will be minimized. Also emphasis is placed in the derivation of such products that will satisfy the special needs of the archaeologists. Since these products are mainly the 2D vector diagrams and true orthophotos, it was aimed to substitute the photogrammetrically produced DEM by the laser scanning point clouds.

Further to the orthophoto-mosaic, presented in Figure 8 and derived from a photogrammetrically produced DEM (*mosaic A*), two more coloured orthophoto-mosaics of the excavation site were produced, following the same process (see chapter 3.2), in which the DEM was derived from:

i) all points that were determined from the 16 scans of the laser scanning process, without any other additional information (*mosaic B*)
ii) all the above mentioned points of laser scanning by adding the main breaklines, that were defined by the photogrammetric models (*mosaic C*).

The quality control of the two orthophoto-mosaics (*B* and *C*) revealed no mistakes in visual representation, even at the difficult areas (stones, cavities). Also, their comparison with *mosaic A* has not given any significant difference. The superimposition of each two mosaics, gave some differences at the orientation (tilts between them) of the mosaics and perhaps at their scale, as shown on Figure 9 by double exposure of the stones at the eastern part of the image. A possible explanation could be attributed to insufficient determination of the transformation parameters between the laser scanning coordinate system and the common reference system. Consequently, by field surveying of the target coordinates or by the compilation of the orthophoto-mosaic in an independent system, this problem can be avoided.

The next step was the accuracy control of the orthophoto-mosaics. Twelve check points were selected in the whole site area and 16 distances of various lengths and in various directions. The check points had known coordinates established by field survey methods at an accuracy of ±3mm.

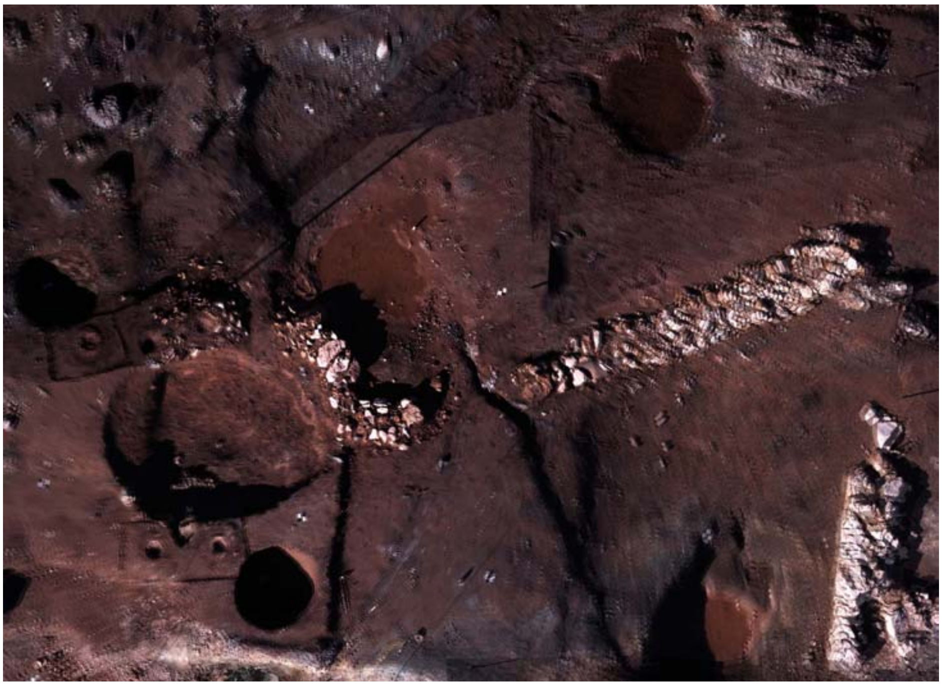


Figure 9. Overlay of the central main part of the orthophoto-*mosaics A & B*

Figure 10 shows the deviations between geodetically determined positions and the measured positions on *mosaic A* (green line), on *mosaic B* (cyan line) and on *mosaic C* (blue line), which are given for each check point. The relevant statistical information is shown on Table 1. The result of the comparisons among the three mosaics is:

$$\text{rms } \Delta X_{mosaicA\text{-}mosaicB} = 13.4 \text{ mm} \qquad \text{rms } \Delta Y_{mosaicA\text{-}mosaicB} = 10.7 \text{ mm}$$
$$\text{rms } \Delta X_{mosaicA\text{-}mosaicC} = 12.1 \text{ mm} \qquad \text{rms } \Delta Y_{mosaicA\text{-}mosaicC} = 10.8 \text{ mm}$$

Another indicator of the relative accuracy of the three mosaics, is the standard planimetric deviation from a mean value for every single point, which varies between 1÷8mm (for all points: 4.8mm).

Mosaic	Systematic Deviations S_X	Systematic Deviations S_Y	Mean Square Value
A	-5 mm	1 mm	12.8 mm
B	-2 mm	5 mm	14.4 mm
C	-3 mm	6 mm	12.6 mm

Table 1. Statistical results of the measurements of the check points

Consequently, very small systematic deviations for all the mosaics are detected, while the deviations among them are less than 1.5 cm per coordinate (accuracy of 1:50 ÷ 1:75). The improvement of the orthophotos by adding the breaklines to the DEM of the laser scanning points is almost negligible, whilst the photogrammetric work increases considerably. By using more dense point clouds an assimilation of *mosaics B* and *C* is expected.

Similar results are derived from the statistical control of selected distances. The systematic deviations are: rms $D_{mosaicA}$ = 14 mm (thus: rms $(X,Y)_{mosaicA}$ = 10 mm)
rms $D_{mosaicB}$ = 17 mm, rms $D_{mosaicC}$ = 16 mm.

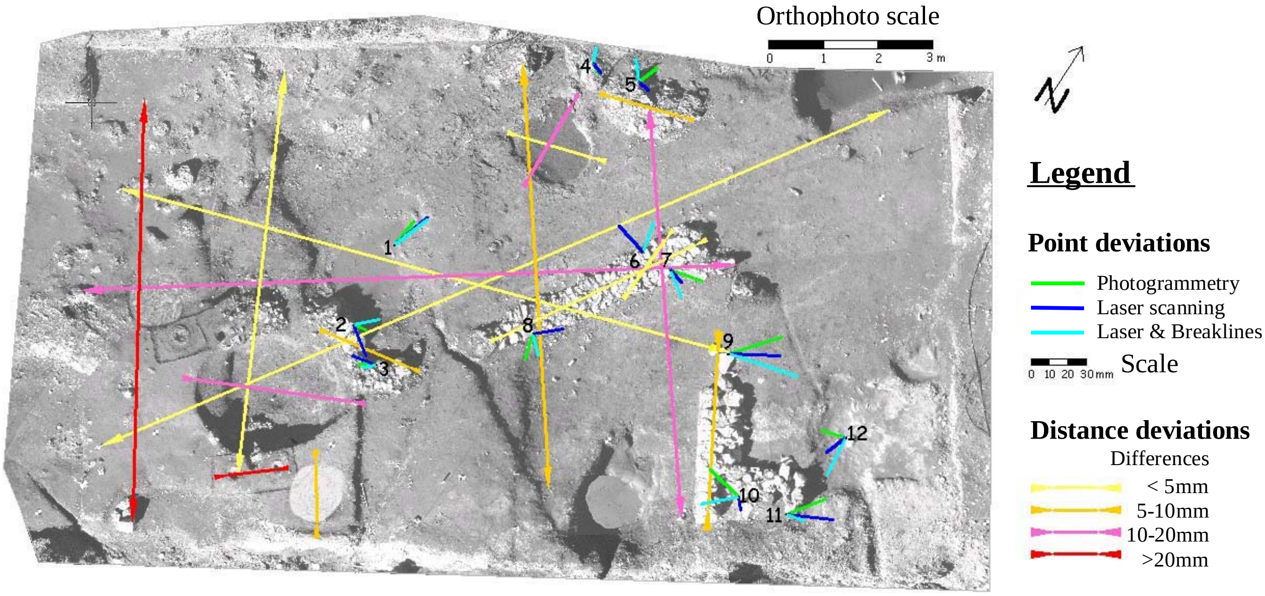


Figure 10. Accuracy check using point and distance deviations (based on orthophoto-*mosaic A*)

Figure 10 shows the location of the selected distances that were checked, while their color difference shows the size of the difference between the measurements on *mosaics A* and *B*. The distance deviations are independent of the baseline length and direction, indicating that difference in scale between the otrhophoto-mosaics does not exist.

4 CONCLUDING REMARKS

The documentation of the archaeological excavation in Lambrika constituted an interesting experience showing that a combination of photogrammetry and terrestrial laser scanning for the presentation of historic information in user defined time periods can be implemented. The effort needed to get accurate and detailed DEM models by means of photogrammetric procedures only, is considerably high for these types of object surfaces, where the automatic extraction of DEM is not applicable, and not suggested for this type of rapid documentation. Laser scanning provides dense 3D information that can be implemented for the DEM and also for the determination of the ground coordinates of pre-signalized control points. Thus, the orthophoto production is independent from geodetic field work and can be fully automated even for close range applications.

The comparison between orthophotos derived from (a) typical photogrammetric process (b) use of DEM derived from laser scanning and implemented in the orthophoto, and (c) use of DEM derived from laser scanning and photogrammetrically derived breaklines, revealed that very small systematic deviations existed and the achieved accuracy satisfies the specifications at scale of 1:50. Whilst there is no improvement in the accuracy using laser scanned data, mainly because of the large number of overlapping photos taken for this particular application, there is a significant gain in labour associated tasks.

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BIOGRAPHICAL NOTES

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