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# THREE-DIMENSIONAL STRATIGRAPHY RECONSTRUCTION AND GIS – POSTPROCESSING ISSUES IN ARCHAEOLOGICAL FIELD 3D DOCUMENTATION

**Abstract:** This paper aims to present the results of experiments which allowed us to propose up-to-date method of 3D visual representation of explored archaeological layers. Considering the destructive nature of excavations, the correct documentation of an exploration, which offers an insight both into the decision-making process taking place on site, and into the most faithful representation of the examined material, presents a fundamental challenge for a field archaeologist. The aim of the experiments presented here was to test three methods of creating 3D models of successive archaeological layers (contexts) recorded during an exploration. The presented findings show that the method of editing point clouds using open-source software prior to importing the model of the reconstruction of the explored layer into GIS software, is the best solution from the point of view of both the effort and time required, and it can definitely be suggested as the standard procedure of creating the graphical bases for an archaeological database.

**Key words:** 3D GIS; fieldwork archaeology; stratigraphy

## Introduction

Archaeologists are constantly confronted by the demand to improve the standards of field documentation during excavations, which follows from their destructive and irreversible nature. In the face of an ongoing scientific discourse on whether there is a need to conduct invasive investigations in the first place (Barker 1986, 73- 99; King 2006), archaeologists who believe it is necessary to conduct field work both keep improving the methods of documentation, and reach for an ever-broader spectrum of technological solutions offered by related disciplines (Forte 2014, 1; Roosevelt *et al.* 2015, 325). Technological progress and closer cooperation between archaeologists and specialists in other fields of science have considerably expanded the arsenal of currently available methods of documentation. Alongside classic solutions, new specialist methods have emerged, which are used more and more frequently during excavation works. They include traditional geodetic surveys using a total station, as well as newer ones, using GNSS RTK technology, close- and long-range photogrammetry, as well as laser scanning (terrestrial, aerial and mobile) and GIS (Geographical Information System) application (Zubrow 2010, 1). Contemporary archaeologists are also no strangers to collaborating with computer graphics and IT specialists to create VR – Virtual Reality (Hermon 2007; Hermon and Kalisperis 2011; Tsiafaki and Michailiodou 2015, 40), as well as AR – Augmented Reality (Fernández-Palacios *et al.* 2012; Deliyiannis and Papaioannou 2014).

With the digitalisation of archaeological documentation, a need has emerged to find a method, form and space for collecting the ever-growing archaeological databases. One of the most complicated problems is the method of recording and visualising archaeological stratigraphic layers. Although in the case of sites with a simple stratigraphy this is a relatively straightforward task, complicated stratigraphic structures, which are characterised by high changeability, do present a serious challenge (Urbańczyk 1987, 254). In view of the potential offered by hardware and software these days, a large number of solutions have been proposed (mainly based on 3D scanning and close-range photogrammetry), but none of them are optimal and each has its stronger and weaker points (Cattani *et al.* 2004; Doneus and Neubauer 2005a).

In this paper, we would like to focus on the problem of postprocessing data obtained during archaeological field investigations, illustrated by the work conducted in Paphos on Cyprus. One of the main objectives of the field work conducted during the Paphos Agora Project is to build a 3D database which will simplify the future processing of the material collected on site. This will be possible as a result of gathering all information in one place, in a form accessible to all potential users. With this objective in mind, we have faced the challenge of developing the proper course of action when recreating the stratigraphy of a site in a 3D space (Ćwiąkała *et al.* 2015; Miszk *et al.* 2018). One of the problems related to creating visual databases for archaeological sites is the 3D visualisation of the stages of site exploration in a way which would enable us to reconstruct its progress and visualise archaeological layers. The layers, despite formally using 3D recording (whether by means of scanning or close-range photogrammetry), are visualised in the form of two separate models, by recording their top and bottom area. Our main objective in presenting the results of our experiments is to propose a solution in order to create a 3D visualisation of the explored layers (contexts) in their original position, which will enable us to better understand their character, as well as relations which occurred between successive stages of the exploration. Such a solution meets the requirement of maximising the record of the destructive process of exploring archaeological layers so that the decision-making processes and progress of the excavation work can be reconstructed.

## Methods and recent work

The problems of using 3D documentation in archaeological work (whether in the form of laser scanning or close-range photogrammetry) already have a rich literature and history in the scientific discourse on the methodology of collecting field documentation. The possibility of using techniques such as Structure from Motion (SfM) or laser scanning has already been discussed and critically evaluated many times (Pollefeys *et al.* 2003; Doneus and Neubauer 2005a; 2005b; Forte *et al.* 2012; Dell'Unto 2014; Berggren *et al.* 2015; Opitz 2015). The research project implemented in Çatalhöyük (one of whose objectives was to develop optimal procedures with this regard) is an excellent example illustrating the development of documentation techniques (Forte *et al.* 2012; Berggren *et al.* 2015). However, in the majority of projects which use close range photogrammetry on a large scale in order to document the progress of excavation work, archaeologists do not address the problem of visualising layers, believing that the recording of their surface is a sufficient procedure of creating archaeological documentation. The issue of being able to reconstruct archaeological sites in a 3D environment, which (thanks to the proper quality of data and the possibility of correlating them with other archaeological sources) enables us to better understand the processes which take place on site, is a different matter (Tspidis *et al.* 2011). The effects of works such as the ones conducted in Greek Koroneia enable us to give a positive answer to questions about the actual use of 3D techniques not only to visualise but also to interpret data (Piccoli 2014). The problem of presenting the reconstructed archaeological layers has not been thoroughly explored so far, which is probably due both to the technical challenge and to the still discussed doubtful use of such techniques in the course of excavations from the point of view of archaeology (Barcelo *et al.* 2003; Berggren *et al.* 2015).

Digital visualisation of the process of excavation is mainly based on the proper representation of archaeological stratigraphy, preferably in a 3D space. The most characteristic features which distinguish methods used to this end include: the software and hardware used, the initial data which is the core of the final result, the format of the final file, and the possibility of later visualisation, processing and analysis. These methods can be divided into two main groups:

1. Raster 3D modelling – graphical representations in the form of a pixel grid.
2. Vector 3D modelling – graphical representations in the form of solids or geometric figures.

*Raster 3D modelling*

One of the proposed solutions for the digital documentation of the process of archaeological exploration is the use of volumetric picture elements, or voxels. In computer graphics, voxels are the 3D equivalent to pixels (Orengo 2013, 4) and are mainly used to represent volumetric data e.g. in geology or medicine (Zachow *et al.* 2007; Bartakovics *et al.* 2014). It was geologists' software and experience that archaeologists used when they introduced this solution into their arsenal (Cattani *et al.* 2004). Over time, the GRASS GIS software became the most popular tool for creating 3D stratigraphy with the use of voxels. A simplified model of creating 3D layers is based on three stages here. The first consists in preparing a digital form of drawn documentation using any software, followed by generating DEM models for each stratigraphic unit. Then, the data are imported into the GRASS GIS software where, following calculations on the basis of the *r.vol.dem* algorithm, the space between rasters is filled with voxels (Liebewirth 2008, Orengo 2013) (Pl. 1: 2). Information prepared in this way can then be used to make quick calculations of mass, volume and area of the explored layers of soil. However, we should note that raster graphical representations (including 3D ones), depending on resolution, require a lot of disc space to store data as well as high performance computers to display them, which may make the processing and editing of data more difficult (Tsipidis *et al.* 2005). Moreover, as Losier *et al.* (2007, 278, 282) emphasise, using voxels in modelling is not an easy task. Especially choosing the correct voxel size for each visualisation may be problematic, as holes and the so-called staircase effect tend to appear.

*Vector 3D modelling*

So far, the most developed group of methods used in attempts to reconstruct archaeological stratigraphy have been various types of vector modelling. The data which are necessary to prepare such models are usually obtained by means of various surveying techniques, which include Total Station and GNSS RTK, Terrestrial Laser Scanning (TLS), and close-range photogrammetry. Depending on the material at the archaeologists' disposal, the site's characteristics, the software and hardware available, as well as their knowledge and experience, they are able to reconstruct the successive stages of excavation work in digital form. An example to illustrate this is a system developed on two sites, Thessaloniki Toumba and Ayia Triada Karystos in Greece (Katsianis *et al.* 2015). The system involves inputting all data into one 3D GIS database. As for the stratigraphy, it is reconstructed in several ways, largely based on field surveys of individual characteristic points of each layer. They were used to georeference drawings of stratigraphic units and to generate TINs, which are a digital representation of the plane of their top or bottom. Then, the elements were combined in such a way as to make closed solids. This is not a faithful representation, but it gives the approximate idea about the stratigraphic sequence of a place.

*Terrestrial laser scanning*

Terrestrial laser scanning is a non-invasive and quick way that enables archaeologists to collect an enormous amount of data (point cloud), which is a digital representation of the surroundings of a surveying instrument. Scanners have been applied in many areas of industry as well as science. In archaeology, they are usually used to record the condition of sites before and after excavations, as well as for inventory and reconstruction purposes (Balletti *et al.* 2015). Some archaeologists have also been testing scanners for documenting stratigraphic units (Doneus and Neubauer 2005a, 2005b; Alby 2015; Ćwiąkała *et al.* 2015). Doneus and Neubauer (2005a, 226-227) point out that laser scanning can make the process considerably faster, but this is completely dependent on the site's characteristics. What is more, the results of this form of documentation (xyz points) are similar to the results obtained using total station surveys. The basic difference between the two methods consists in the fact that in the case of total station surveys what is surveyed is a group of points specified by an archaeologist, which in their opinion best represents the geometry of the surveyed layer, while in the case of laser scanning the entire area is surveyed in high density (usually the spaces between points are smaller than a few millimetres) and the result is call a point cloud.

*Photogrammetry*

In recent years, photogrammetric methods have started to be used alongside laser scanners to obtain point clouds (Forte *et al.* 2012; Dell'Unto 2014; Berggren *et al.* 2015; Opitz 2015). The process of photogrammetric modelling which is standard today enables archaeologists to create both a point cloud which is comparable to data obtained through laser scanning in terms of accuracy and precision, as well as ready models in the form of 3D mesh and raster DEM models (Barsanti Gonizzi *et al.* 2012).

*Postprocessing*

Focusing on the final result of vector 3D documentation, whether in the form of a point cloud or 3D mesh models representing the bottom/top of a given layer, we should pay attention to their postprocessing, the possibility of archiving data, and using them in GISs. While at present software for processing point clouds and 3D meshes, which enables us to combine, edit and generalise them, is widely available and commonly used e.g. in computer graphics, such tools are not widespread in GISs. The simplest explanation for this situation is their origin in geography, which means that so-called 2.5D models are commonly used, in the form of TIN or GRID, in whose case 2.5D means that each point in a 2D space can be assigned to only one height. This leads to a number of problems with storing and integrating 3D data with descriptive attributes in GIS databases. Similarly, due to the fact that there is practically no possibility to ascribe descriptive attributes in GIS in archaeology, it is not common to use just point clouds as sufficient vector documentation, which is done e.g. in museology (Bunsch and Sitnik 2017).

## Case study

*The archaeological site*

The experiment was conducted on a site located in the remains of ancient Nea Paphos. It was an urban centre located on the south-east coast of Cyprus. The city was established at the turn of the 4th and 3rd c. BCE (Młynarczyk 1990, Bekker-Niesen 2000). The layout of the new city was based on the Hippodamian Plan, whose elements are fragmentarily preserved in the landscape. The individual quarters (residential, housing, workshop, trade/port, and administrative) were planned and marked out in such a way as to make the most use of the existing natural conditions. The city was crossed by an orthogonal grid of streets which were at the same time the borders of plots, so-called *insulae* (106 x 34m). Nea Paphos grew quickly throughout the Hellenistic and Roman periods, it occupied the area of *c.* 95 hectares and was surrounded by a city wall. Within the city wall, the oldest permanent theatre on Cyprus was built *c.* 300 BCE, along with a *gymnasion*, an Odeon, numerous temples, and the island's westernmost port. The city also housed an acropolis, probably located on the hill of Fanari, and an agora, or city square, at its foot (Młynarczyk 1990). It is here that excavations have been conducted since 2011, under the Paphos Agora Project (PAP) (Papuci-Władyka *et al.*, forthcoming).[1]

*The database*

The proposed solutions will be illustrated by the example of using close range photogrammetry during the excavations of the Nea Paphos site. The ongoing excavations carried out under the PAP focus on selected remains of the economic infrastructure located in Nea Paphos. The documentation recorded during the excavations is based on photogrammetric recording of all the trenches after completing the exploration of each successive layer (context), using the methods developed for archaeology with the use of close-range photogrammetry. In this way, an entire set of documents is created for each context, i.e. a 3D model, an orthophoto map, and a DTM. Such a data set may be used to attempt to create a 3D visualisation of contexts. The project includes a wide range of tasks which are aimed at organising and implementing advanced methods of documenting archaeological work, as well as organising data in a GIS environment (Miszk *et al.* 2018). From the very beginning, specialists from various disciplines have participated

[1] Maestro grant no. 2014/14/A/HS 3/00283 in 2015–2019 with contributions by the Department of History of the Jagiellonian University in Krakow and private sponsors.

in the PAP, delivering their findings in various digital forms. This information has been gradually collected since 2015 in the database called the AAIS (Archaeological and Archeometrical Information System) for PAP, which is being built in the ArcGIS (ESRI) environment. Several main groups of the collected data can be distinguished, i.e. vector, raster, photogrammetric, and text data. Ultimately, the database is meant to be a digital repository of documents collected during the PAP and a virtual representation of the completed explorations (Ćwiąkała *et al.* 2015, 214-218). The solutions proposed so far have been helpful in organising all the information in selected categories, which has considerably improved the quality of database management and searching. This form of organising information also offers better abilities to perform various analyses, such as a visibility analysis, attribute selection, map overlaying, spatial analysis, statistical analysis etc. (Żyszkowska 2003; Statuto *et al.* 2017, Nsanziyera *et al.* 2018).

*The object of the experiment*

For the purposes of the experiment, one trial trench was selected, located in the northern part of the Nea Paphos Archaeological Site. The trial trench was made in order to verify the geomagnetic surveys which indicated that the remains of a kiln might be located there (Papuci-Władyka 2018, 64 – 65; Seifert and Babucic 2018) (Pl. 1: 1). Indeed, excavations confirmed this hypothesis, uncovering a limekiln dated to the Late Roman period. As we have mentioned above, all the explored contexts within the trial trench (no. TTIV) were recorded using close range photogrammetry, according to the procedure of collecting, processing and storing data on site developed in the previous years (Ćwiąkała *et al*. 2015, Miszk *et al.* 2018). The selected example is a case of a relatively simple stratigraphy, but its composition is sufficiently complex to use the potential solutions for the parts of the site where the sequence of layers is more complicated. The developed solutions of representing layers in 3D are meant to be adoptable for the AAIS for PAP database mentioned above.

## The experiment

The object of the experiment was to create 3D models of successive archaeological layers (contexts) recorded during the exploration of the limekiln and its immediate surroundings. 73 contexts were identified and explored during the excavation. 3D models were created for 49 of them (they were contexts for which creating a visual documentation was justified); in turn they allowed us to visually reconstruct 35 solids of archaeological contexts (the difference resulted from the method of recording layers – creating a context model means to record its bottom, which is simultaneously the top of the layers below it). The input data for this process was the 3D documentation created using photogrammetric methods during the archaeological exploration. Previous studies (Ćwiąkała *et al.* 2015) considered two alternative methods of creating 3D GIS. The first one focused on rendering 3D models in ArcGIS, while the second was based on importing vector 3D models created outside GIS software into ArcGIS and storing them as a multipatch geometry (Pl. 2: 1). A multipatch object is a method of representing 3D geometry in a GIS database offered by ESRI. A single 3D object (record in a spatial database) can be composed of multiple patches. A single patch can store information which will enable us to render the geometry of triangles, triangle fans, triangle strips, or rings. The object recorded in this way may also include texture, along with geometry and descriptive attributes[2].

In the experiment in question, it was decided to continue using the second of the presented solutions, i.e. importing ready 3D models created in other software, such as Agisoft Photoscan or MeshMixer, into ArcGIS. This solution is not simple, not least due to the restrictions on the supported 3D file formats; out of the popular formats used for the storage of 3D models, ArcGIS only supports OBJ. However, in comparison to the other possible solutions (such as rendering 3D models in ArcGIS or using voxel models), this method should make it possible to obtain visually satisfactory results in a relatively short period of time.

*The first solution*

The first of the conducted experiments focused directly on editing data – 3D models (in the form of meshes) created in photogrammetric software (Agisoft). This editing was carried out using tools for creating and editing 3D graphics. The main advantage of this method was the easy control over the precision of mesh models at the stage of creating them and the possibility of overlaying texture from photographs on them. During these experiments, two software tools were used: the commercial ZBrush, used in computer graphics, and the free MeshMixer.

The described method was based on an assumption analogous to the theoretical concept proposed by G.J. Avern (2010), which consisted

[2] Retreived from: http://desktop.arcgis.com/en/arcmap/latest/extensions/3d-analyst/multipatches.htm

in attempting to combine geometries from two successive models, so that one of them formed the top layer of a context, and the other its walls and bottom. This solution, although very simple in theory, turned out to be difficult to implement. During the first step, redundant parts of both models had to be manually selected and deleted, and then the models had to be combined. The key problem was the fact that it turned out that after deleting the redundant parts (Pl. 2: 2), the model of the top layer usually had a smaller extent than the walls[3]. This made additional manual editing of the model necessary, in particular filling the gaps.

*The second solution*

The second of the tested solutions was based on using Boolean algebra, which in the case of 3D models identifies overlapping parts of 3D geometries and then makes algebraic operations (addition, subtraction) possible to perform on these models. In order to apply this solution successfully to 3D mesh models of the trench, it was necessary to render them as closed solid, since the model created in photogrammetric software is the surface. Therefore, in the first place, redundant parts were removed from both models (i.e. the terrain and possibly the top part of the trench) and the remaining part was filled (a solid was created). The next step was to subtract the models, i.e. find their overlapping part and remove it (Pl. 3: 1).

Like in the previous case, the main problem which had an impact on the amount of manual work were the small differences between the geometries of the two models in their overlapping part; this led to the creation of incorrect fragments of the model, which then needed to be removed manually. However, a much more important problem during the implementation of this method was the calculation time both during the operation of closing individual models and subtracting them. Another problem was the software's instability during the latter process; if it failed, the entire operation had to be repeated.

*The third solution*

The third and last of the tested solutions abandoned the original concept of using 3D mesh models. It was predicated on using intermediate results, on the basis of which 3D models, i.e. point clouds, were created. A point cloud is the result of dense image matching in photogrammetric software. The input data are therefore two successive point clouds, where for each

[3] This followed from the characteristics of the site – the main material which fills the layers is rubble, which makes keeping the profiles of the trenches ideally level much more difficult.

point, along with the 3D coordinates, a normal vector is recorded (which contains information about the direction perpendicular to the plane of the model at a given point). Due to using intermediate data, this method is more complex than the previous two, but it has a distinct advantage: it is possible to perform it entirely using the open-source CloudCompare software. In the first step, the density of both point clouds needs to be homogenised so that the average distances in both clouds are similar. For the purpose of our experiments it was decided that the distance of *c*. 1cm between adjacent points will be sufficient (Pl. 3: 2) (which in the case of the test data reduced the number of points to 1.2-6.4 per cent of the original data, see Table 1). This value followed from the guidelines set out earlier in the project about the precision of creating 3D models for visualisations in the GIS database[4].

The next step was to remove the points from those parts of the trench which were represented in both point clouds. To automate this process as much as possible, it was decided to calculate the distance between neighbouring points from both point clouds and then to remove all those for which the neighbour from the other cloud was closer than the specified threshold value. The choice of the threshold value is problematic since if the value is too low, the number of the remaining points is considerably higher, and if the value is too high, points are deleted in the area where the bottom from the first model is close to the profiles from the second one. In the end, having analysed the results, it was decided to set the threshold value of double the average distance between points, which was believed to be an acceptable compromise.

The method does have its drawbacks, however, since as we can see in Pl. 4: 1, after deleting closely spaced points, individual points still remained. These points required manual editing of the point cloud – they needed to be selected and deleted before the next stage. The last stage of the tested method was creating a 3D mesh model using the remaining points (Pl. 4: 2), when normal vectors played the key role.

## Conclusions

The methods presented above were aimed at creating 3D models in the form of solid geometries for successive layers explored during archaeological excavations (Pl. 4: 3). Although previous studies (Ćwiąkała *et al.* 2015) and theoretical concepts (Avern 2010) assumed using 3D models

[4] These guidelines were presented during the conference Computer Application and Quantitative Methods in Oslo in 2016.

as input data, as a result of our experiments it turned out that at the current technological level of tools for editing 3D mesh models, it is more efficient to use intermediate results (point clouds) and to create the final 3D model on this basis. Conducting the experiments on 49 contexts enabled us to propose this method for creating graphical representations of archaeological layers. Considering the specific character of the documentation created by archaeologists, which from the scientific point of view is a model of reality, i.e. its simplified representation, we should aim to achieve as high a level of complexity as possible (Nakointz and Kitter 2016, 36). The main advantage of the proposed method of postprocessing 3D data is its relative speed[5], the reproducibility of the process and the possibility of using it in conjunction with GIS software (which is the most common environment for creating archaeological databases at present). For potential users, this means the possibility of creating a virtual representation of a layer/context to which information of a different nature can be assigned, thus creating a convenient tool for analysing the explored site. From the point of view of creating databases for conducting field excavations, at present this solution seems to be the most efficient method of graphical representation of the explored layers/contexts.

[5] The authors deliberately did not present an analysis of how time-consuming it is, realising that the specificity of archaeological sites is so high that simply transposing experiences gained while working on data from one to another can only lead to misunderstandings.

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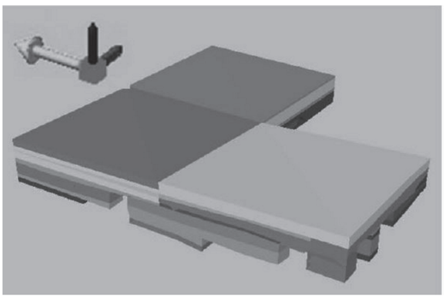

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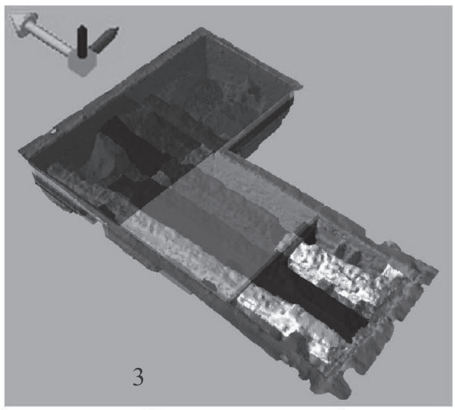

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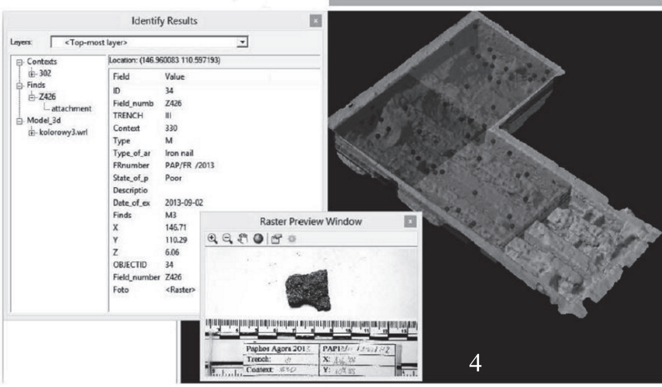
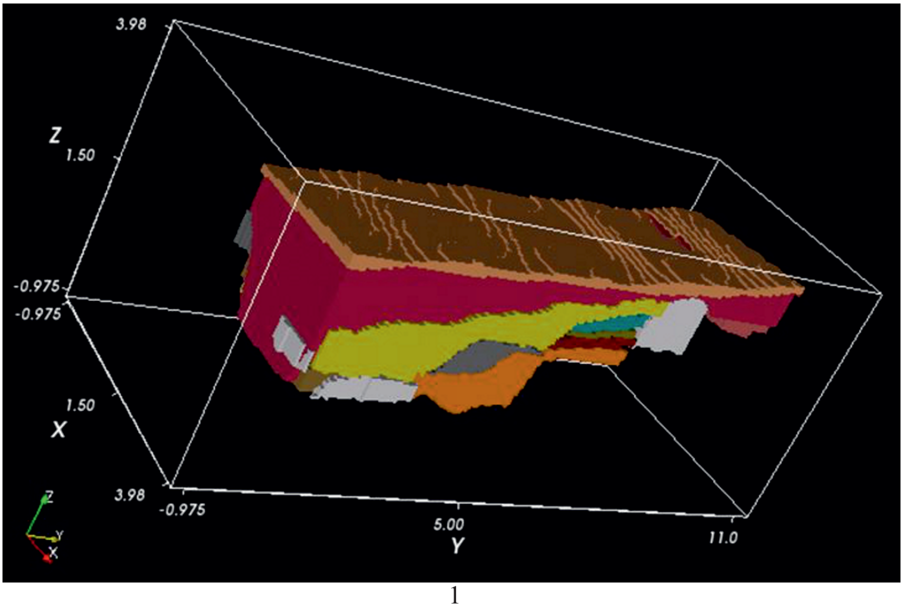



4

Pl. 1: 1. A limekiln excavated in TT.IV – the object of the experiment
Pl. 1: 2. An example of a reconstruction of archaeological layers using voxels. Reproduced from U. Lieberwirth 3D GIS Voxel-Based Model Building in Archaeology, in Posluschny, Lambers and Herzog 2008, Fig. 7, 6

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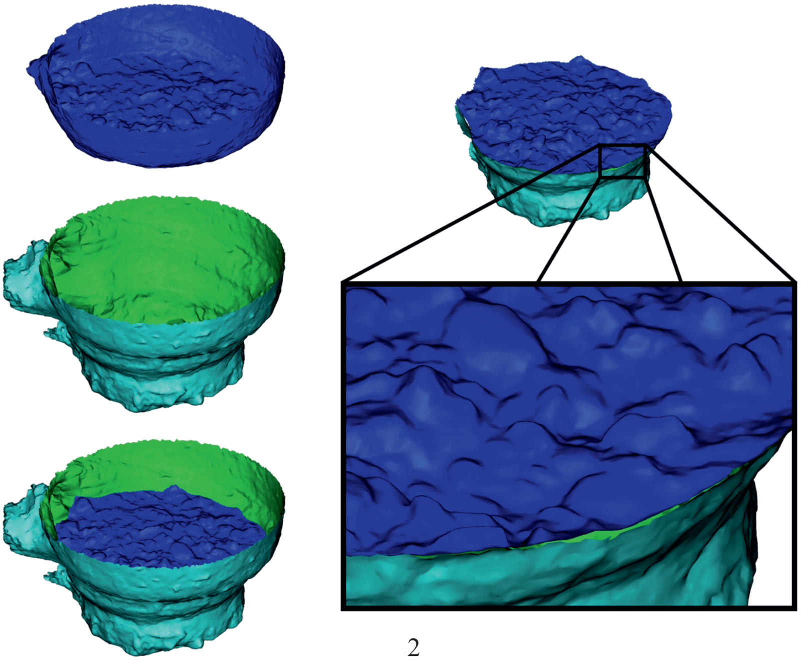

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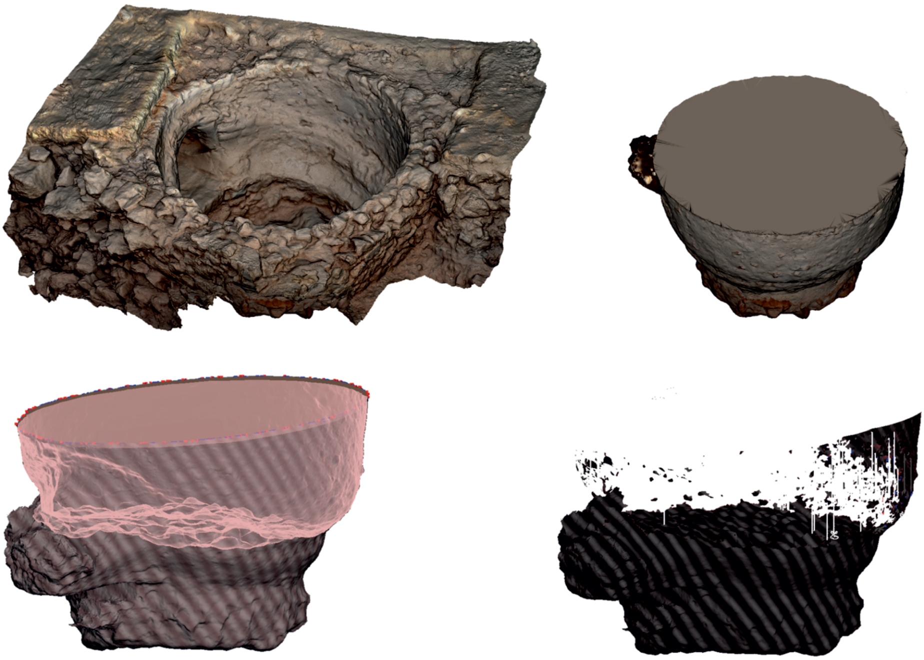
Pl. 2: 1. A reconstruction of the sequence of layers in T.III by means of importing ready 3D models into ArcGIS. (Ćwiąkała *et al.* 2012, Pl. 8 drawn by Weronika Winiarska)

Pl. 2: 2. A context reconstruction based on combining the geometries of two models. The effect of combining the geometries of two models. On the top left (a) the model after exporting context no. 323 (b) the model after exporting contexts nos. 324 and 325; the two models together. On the right, the models after removing redundant (overlapping vertical) parts; a gap is visible between the two models (in the enlargement)



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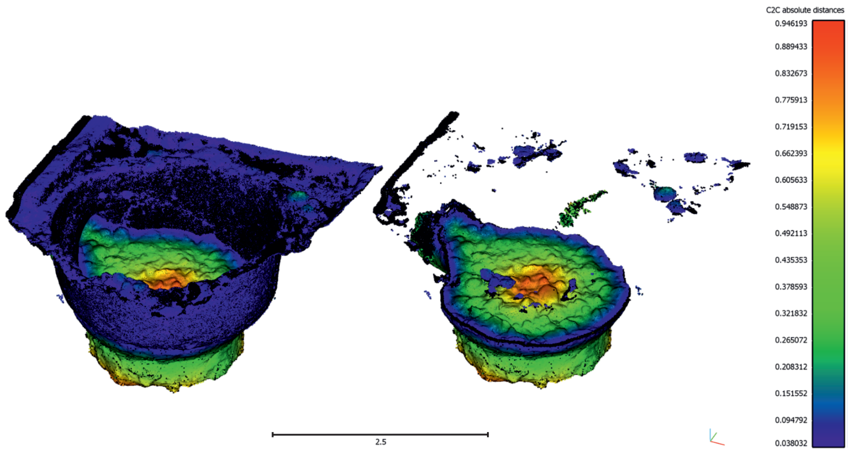
Pl. 3: 1. A context reconstruction using Boolean algebra.
Top: Creating the solid figure of the trench model (filling), illustrated by the model after exploring contexts no. 324 and 325. On the left, the model prior to removing the terrain and filling it; on the right the model in the form of a solid figure
Bottom: On the left, a superposition of solid figures for the next two models. On the right the resultant model created using Boolean algebra, on which some noise is visible (small elements of geometry located in the overlapping area of the two solids, which result from the precision of the modelling)
Pl. 3: 2. Homogenisation of the density of point clouds. On the left, the original point cloud for the trench after the exploration of context no. 323 was completed (*c*. 2.5 million points). On the right, a cloud with the homogeneous density of 1cm (*c*. 110,000 points)

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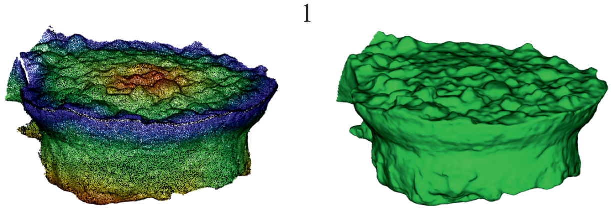

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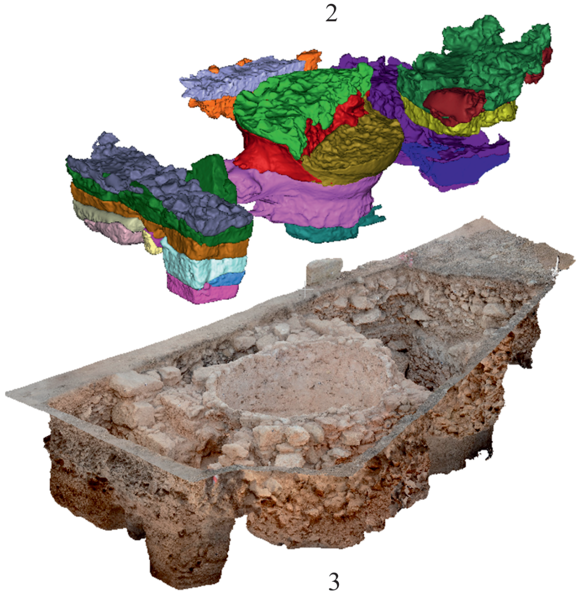

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Pl. 4: 1. Point clouds after removing overlapping parts. Removing the overlapping parts of point clouds documenting two successive stages of exploration (i.e. points spaced less than 2cm from the nearest neighbour in the other cloud). On the left whole point clouds, on the right point clouds after the overlapping parts were removed. Illustrated by point clouds after the exploration of contexts no. 324 and 325. The colours mark distances between points

Pl. 4: 2. A 3D context reconstruction

Pl. 4: 3. Final 3D visualization of the stratigraphy on the TT. IV

Table 1. The parameters of the point clouds used in the experiment. The context no. refers to the context whose bottom was documented in a given cloud. The original number of points refers to the cloud used for the documentation; the subsampled number of points is the number of points in the diffused cloud (the average distance between points being 1cm).

| Context no. | Number of points | | Dimensions [m] | | |
|---|---|---|---|---|---|
| | original | subsampled | x | y | z |
| 302, 303 | 4,174,360 | 131,496 | 4.17 | 3.00 | 1.81 |
| 304 | 5,173,485 | 222,945 | 5.81 | 4.37 | 1.74 |
| 306 | 3,601,666 | 106,118 | 3.78 | 2.49 | 1.53 |
| 307, 308 | 4,392,114 | 127,860 | 4.76 | 3.38 | 2.12 |
| 309 | 4,082,321 | 131,658 | 3.73 | 2.34 | 1.73 |
| 310 | 4,569,113 | 149,934 | 4.95 | 3.18 | 1.92 |
| 311 | 6,138,169 | 148,149 | 4.33 | 4.35 | 1.59 |
| 312, 315, 316 | 4,859,249 | 124,027 | 3.52 | 2.30 | 1.98 |
| 313 | 5,081,795 | 128,642 | 3.69 | 3.34 | 1.72 |
| 321, 322 | 4,734,194 | 118,206 | 3.54 | 2.54 | 1.92 |
| 323 | 3,119,786 | 162,410 | 3.75 | 4.39 | 1.93 |
| 324, 325 | 19,245,432 | 362,055 | 5.92 | 5.71 | 2.47 |
| 327 | 4,614,685 | 229,498 | 6.67 | 6.38 | 1.66 |
| 328 | 2,505,663 | 76,260 | 3.62 | 3.14 | 1.60 |
| 329 | 2,596,763 | 37,994 | 2.17 | 1.87 | 0.70 |
| 330, 331 | 2,724,398 | 134,110 | 4.65 | 4.44 | 2.39 |
| 332 | 3,946,828 | 122,055 | 3.38 | 2.45 | 2.12 |
| 334 | 3,573,030 | 119,534 | 4.06 | 4.98 | 1.20 |
| 335 | 3,810,870 | 86,399 | 4.07 | 4.76 | 0.97 |
| 337 | 2,466,419 | 32,652 | 3.06 | 2.14 | 0.77 |
| 338 | 3,239,360 | 138,893 | 3.85 | 4.36 | 2.18 |
| 341 | 3,434,163 | 49,943 | 3.31 | 2.19 | 1.15 |
| 343 | 5,120,874 | 179,858 | 5.04 | 4.44 | 2.55 |
| 344, 347, 353 | 4,356,668 | 140,927 | 3.79 | 4.67 | 1.41 |
| 349 | 9,863,602 | 249,257 | 6.46 | 5.79 | 2.40 |
| 350 | 1,742,753 | 112,156 | 3.41 | 3.81 | 1.60 |
| 354, 355 | 5,083,119 | 127,646 | 3.80 | 4.60 | 1.51 |
| 356 | 5,120,596 | 126,718 | 3.28 | 3.64 | 2.32 |
| 357, 358 | 7,623,759 | 194,428 | 5.39 | 6.02 | 1.49 |
| 359 | 4,798,574 | 178,416 | 3.51 | 4.13 | 2.62 |
| 360, 361, 362 | 2,293,694 | 54,513 | 2.64 | 3.36 | 0.58 |
| 367 | 12,636,771 | 206,311 | 3.79 | 4.34 | 3.22 |
| 370, 371, 372 | 7,307,387 | 104,692 | 2.65 | 3.68 | 2.01 |
| 373 | 3,053,254 | 35,826 | 1.65 | 1.58 | 1.32 |
| final | 56,724,891 | 982,563 | 11.11 | 8.76 | 4.45 |