

DIGITAL RECORDING OF STRATIGRAPHIC EXCAVATIONS

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ABSTRACT

The single deposits with their related surfaces are 3D volumes that are destroyed and recorded in the reverse order of their formation during the stratigraphic excavation process. To be able to fully reconstruct the part of the site destroyed by excavating, the surfaces of the excavated deposits have to be fully documented in 3D ("single surface planning"). Every single surface is photographed using a digital camera and rectified on site. The boundary polygon, the topography and the location of finds are recorded using total stations. First tests were carried out applying terrestrial 3D laser scanners. All data is imported into a ArcView GIS, where the georeferenced data is immediately available for further on-site analysis. The importation of data concerning terrain modelling and contouring of the surfaces is automated by the developed extension ArcDig 1.1. Further modules of the extension allow to calculate cross sections along arbitrary defined lines and to calculate the volume of any deposit. All additional attributable data like descriptions of surfaces and deposits, the find database etc. are integrated in the GIS for further analysis of the data. The creation of the stratigraphic matrix is done using ArchEd so far without interfacing to the GIS.

1. INTRODUCTION

Much has been written during the years on the documentation of archaeological excavations, but only a small amount of publications can be found dedicated to the methodological background of excavating. For a long time in its history, archaeology was considered a science dominated by pragmatism and adapted its methods or techniques from other disciplines, mainly natural sciences. Methodological criticism was and still is mainly based on the methods of interpretation but not on the processes to gain the primary facts or the archaeological record.

One of the most important realizations of the last centuries, that changed archaeological research, was the fact that any archaeological site is stratified and any archaeological stratification is unique (Harris, 1989). Stratigraphy, the description and interpretation of stratification is the main key for any further analysis of any archaeological finds. It defines the relative sequence of events marking any sites unique history. This most important attribute of stratigraphy made it necessary to base the recording of archaeological excavations on the principles and needs of stratigraphy. The recording process which takes place during excavation aims at splitting the site into its component parts, the units of stratification. This is done by removing them in the reverse order to which they were formed. During this process, their physical, spatial, and stratigraphic properties are recorded, and finds and samples are collected.

As GIS provides the ability to store, visualise and analyse graphical information in combination with descriptive in-

formation, it is a perfect general tool for the visualization and analysis of excavation results. With GIS, archaeologists are able to reproduce the topographical development of sites in an efficient manner that was almost impossible to carry out before the invention of GIS and computers (Harris, 2001).

During the last years we tried to develop a GIS based procedure for the digital documentation of stratigraphic excavations. This paper will outline the recording of stratigraphic excavations of the type that directly relates to stratigraphy and GIS, namely plans or maps and related databases. We will present a state of the art recording technique developed during the last 12 years under real fieldwork conditions on excavations in Austria. The main objective of our work is a standardised digital recording of all aspects that are necessary for a good stratigraphic interpretation of the data by collecting the fundamental data for a virtual reconstruction of the mass of unique stratification units destroyed by excavation.

2. THE STRATIGRAPHIC RECORD

The stratigraphic excavation method, as defined by E.C. Harris (Harris, 1989) makes it possible to record the single *units of stratification* (i.e. deposits and surfaces) along with all its attributes and relations, and to create, a *stratigraphic sequence* or a Harris matrix from this data, named after its inventor. As Harris points out, every stratification is formed by material (*deposits*) and immaterial aspects (*surfaces or interfaces*) that have to be found and recorded by the excavating archaeologist. In the first instance these two aspects are the main objects to be recorded on a stratigraphic excavation. Any *finds, samples,*

or *other information and observations* have to be related to the deposits and surfaces, i.e. the units of stratification.

Single deposits are 3D volumes of material that are destroyed by excavating them in the reverse order of their deposition. Deposits can only be recorded partially as most of their mass is simply excavated. The material aspects of stratification, the deposit's data, can only be captured by sampling. For the stratigraphic record the deposit is reduced to a unique number in the stratigraphic sequence. It imparts this number to all of the portable finds and samples found within its volume during the process of destruction. The finds or samples are isolated from the stratigraphic unit while excavating it. Their 3D position can be easily defined upon discovery or extraction. The finds and samples are recorded in 3D space as three dimensional points or small volumes, thus reduced to a set of coordinates. All further data derived from the finds can be stored in a database, photographs and find drawings.

In contradiction to deposits, surfaces, the immaterial aspects of stratification, can be recorded entirely. Single-surface recording provides the ability to virtually reconstruct the excavated volumes in three dimensions. Therefore, 3D recording of the top and the bottom surface of any single deposit is necessary to fully reconstruct the part of the site that was destroyed during the process of excavation. The recording of a single surface can be done by giving it a unique number and documenting its boundary polygon as well as its topography. Therefore it is reduced to a set of coordinates, too. The collected sets of coordinates from surfaces and deposits are the primary raw data for the GIS.

Contrary to the deposit, a surface can be recorded in its entirety and that is the reason for its outstanding importance to stratigraphic analysis. Any deposit is enclosed by its top surface, once exposed to air, and its bottom surface which is in superposition to the top surfaces of older deposits or interfaces. Interfaces are surfaces in their own right as the surface of a pit, ditch, wall etc. Thus it becomes clear that surfaces always comprise more than 50 % of any stratigraphic record! Surfaces represent the use periods of a site and thus account for far more time in the site's history than deposits do. It's the single surfaces that can be recorded and have to be recorded entirely. They are the primary element for the reconstruction of the topography of the site through time.

Stratigraphic recording ends in the creation of a stratigraphic sequence based on the spatial relationship of the units of stratification. The stratigraphic sequence provides the ability to visualise time. It is the important diagrammatic representation of time and provides a relative calendar, the testing pattern for any further analysis.

3. THE STRATIGRAPHIC RECORD AND GIS

The most important concept to come out of the fore said is the need for single surface planning (Harris, 2001). Conventionally analogue single surface planning is done by measuring relative or absolute coordinates (orthogonal or polar) of the boundary polygon using tapes. The poly-

gon is then drawn by hand on paper ruled in millimetre squares or a pre-printed recording sheet. This procedure usually takes up a great deal of time. The accuracy depends largely on the used method of measurement and the skills of the archaeologist. The result is a two dimensional plan of the single surface. The third dimension is added by spot heights. To be able to use hand drawn plans in a GIS, they have to be digitised. Again, this procedure takes up time and budget. Therefore, in many places, archaeologists went over to using total stations for the mapping of single surfaces, quickly measuring absolute coordinates with high accuracy. The use of totalstations also provides the possibility for easy 3D mapping of find and sample spots.

The photographic documentation is usually done analog, where pictures of the exposed surfaces are captured on film from a more or less oblique perspective. One of the major problems of films is the processing time. Thus the photographic record cannot be checked immediately. As the excavation advances, the photographic record will be missing if processing fails. Digital cameras are therefore used more often in combination with B&W or colour prints.

The outstandingvalue of a GIS is its ability to reproduce the complete record of a stratigraphic surface as well as any related descriptive information. The GIS functionality provides the ability to visualize surfaces as contour plots or triangulated irregular networks. It makes it easy to combine the boundary polygon of surfaces or deposits as once exposed to air with rectified digital images. The finds can be mapped as registered within the volumes defined by top and bottom surfaces of the corresponding single deposits, classified by stratigraphic position or material aspects.

The way GIS functions, it permits the dynamical mapping of single surfaces or the creation of composite maps (phase or period maps, sections at any position, etc.), based on the recorded data. The decisions on how to compose the necessary maps is derived from the analysis of the stratigraphic sequence. The secondary data dealing with the various aspects (location, material, date etc.) of the finds uncovered is stored in the spatial database of the GIS. There, it can be combined with the graphical visualisations, analysed and counterchecked.

4. THE RECORDING PROCESS

At stratigraphic excavations it is of major interest, to check the recording during the process of excavating. Therefore, we developed techniques of recording, where boundary polygons and topography of surfaces, finds and the photographic record of each unit of stratification are recorded digitally and immediately interfaced to the GIS. The resulting GIS-based system consists of a total station, a digital camera and a PC/Laptop with ArcView GIS (Version 3.2) and Monobild (or a similar software for rectification). For the creation of the stratigraphic sequence we use ArchEd (<http://www.ads.tuwien.ac.at/arched/>).

The standardised process of recording is divided in several subsequent steps, that are repeated for any excavated deposit:

- Defining the limits of the top surface of the upper most deposit
- Unique numbering of the top surface and the deposit (s004, d004)
- Photographic record
- Measuring ground control points
- Measuring boundary polygon and topography of the top surface
- Excavating the deposit, taking samples, measuring find and sample coordinates, describing deposit, describing finds
- Unique numbering of the bottom surface (b004)
- Photographic record of the bottom surface
- Measuring ground control points
- Measuring the topography of the bottom surface

The process of recording of interfaces is as follows:

- Unique numbering of the interface (i004)
- Photographic record of the bottom surface
- Measuring ground control points
- Measuring the topography of the bottom surface
- Describing the interface

The stratigraphic relations of the top surface the deposit and its bottom surface are trivial. The stratigraphic relations of any top surface, bottom surface or interface have to be observed and recorded. Find and sample records, descriptions and stratigraphic relations are recorded on pre-printed sheets or directly in a database on site referenced by the unique number of the unit of stratification.

5. INTERFACING TO THE GIS

To be able to use the digital photographic record in the GIS, it has to be rectified and georeferenced. We had been running extensive tests to find a fast and easy way to rectify the digital image within an accuracy that would not exceed +/- 5 cm. During these tests, we realized, that to stay within this range of accuracy, a combination of vertical photographs and a projective transformation of the image would be sufficient in most cases. The use of a projective transformation assumes, that the topography of the surface is relatively flat. The plane of the surface is defined by at least 4 ground control points, which must be well distributed around the surface to be recorded. They are measured in 2D space and define the parameters of the transformation.

This simple method of rectification could yield reasonably good results as long as the surface has minor differences in height or is evenly sloping up (Figure 1). The issue gets more problematic, when the topography of the unit of stratification is rough, having large height differences on several locations. In this case an accuracy within +/- 5 cm cannot be guaranteed. To solve this problem, more control points have to be added defining smaller plane units within the surface, which then are rectified individually. The transformed parts are mosaicked together again in GIS. Another possibility would be to use software capable of differential rectification using a DTM, as we did in our tests. So far, the procedure of rectification is done using the soft-



Figure 1: Comparison using a stratification unit with a height difference of 25 cm within an area of 1 m. White lines: visible artefacts drawn from photogrammetrically produced orthophoto (maximum error +/- 1.5 cm).

ware "Monobild" (<http://www.geosi.at/produkte/monobild/monobild.htm>). It is an easy to use software designed for our needs.

To be able to automatically import and analyse the spatial data in ArcView GIS, the extension module ArcDig was programmed using Avenue, the object oriented programming language of ArcView 3.2. The import routine reads the native ASCII data file format of the geodetic instrument and converts the data into the native shape file format of ArcView. The measurements of the boundary polygon are stored as a 2D polygon shape and as a 3D polyline shape. The 3D mass points of the surface and optional breaklines are imported as points respectively lines. Finds and samples are imported as points, where the numbers of the finds are automatically added to the database connected with the shapefiles. Ground control points are written to ASCII text files – one file per unit of stratification. The format is fitted to the needs of the import function of the rectification software.

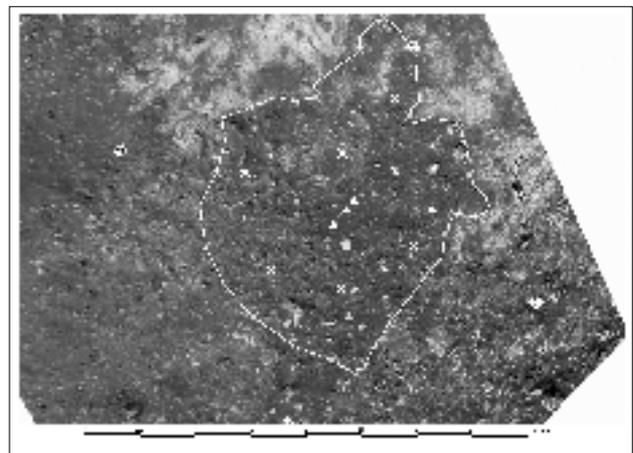


Figure 2: Graphic raw data of stratification unit s059 in Schwarzenbach after import.

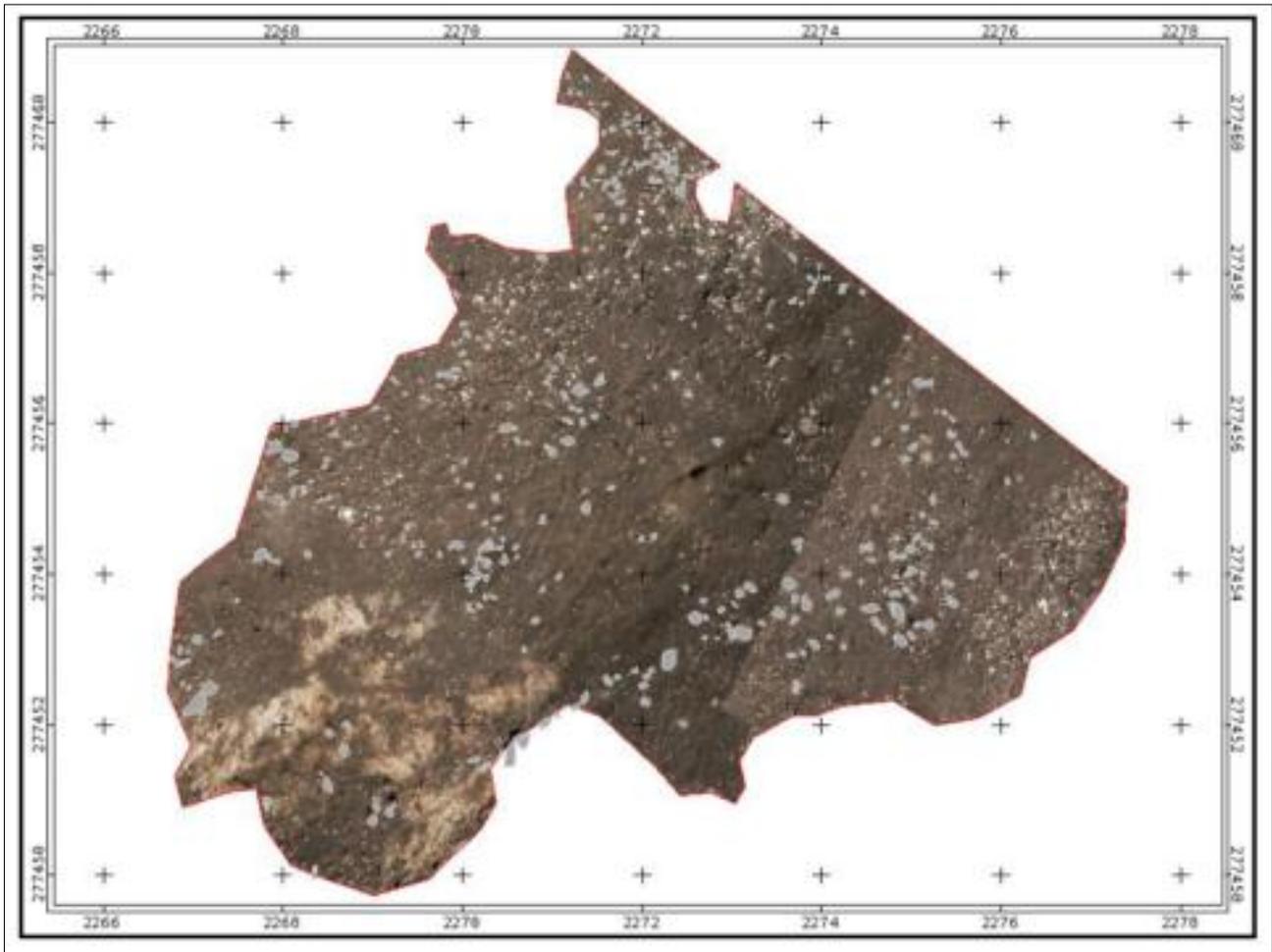


Figure 3: Stratification Unit 003 of Schwarzenbach. On top of the clipped, rectified image, details were drawn using ArcView GIS.

Points, breaklines and 3D boundary are then automatically used to create a digital elevation model of the surfaces (Figure 2). During this process of surface creation, contour lines are automatically interpolated from the triangulated elevation models of each unit. The interval can be chosen interactively.

6. POSTPROCESSING AND FIRST ANALYSIS

After the importation of the entire graphic record, it is available in the GIS and can be checked for errors. The descriptive information stored in databases can now be linked to the graphic record.

The rectified images are added. Experience showed, that in many cases, the outline of a deposit can be better recognized in the digitally enhanced image than on site. Therefore, each boundary polygon is displayed on the rectified image, checked and – if necessary – corrected. Details like skeletons, layers of stones, ceramics, pavements etc. can be drawn directly on screen using the rectified images, while the next deposit can already be excavated. During this process, only those parts of the image, which lie within the control points can be drawn with the desired accuracy.

The accuracy decreases largely outside of the area enclosed by the control points. To prevent unintentional drawing in the outside areas, the images can be clipped to the boundary polygon of the corresponding stratification unit (Figure 3).

For the production of arbitrary sections out of the three dimensional spatial record we programmed another script, which enables the user to interactively calculate sections at any part of the excavated area. To do so, a line has to be drawn, which is then intersected with the triangulated irregular network of each underlying surface. The resulting intersection lines are then compiled into a new drawing representing the section. The advantage is clearly to be seen: sections can be reconstructed automatically at any line of interest (Figures 4 and 5).

7. FUTURE ASPECTS OF DIGITAL RECORDING

Terrestrial 3D imaging laser scanning forms a method to acquire a large number of precise data points in 3D space representing the surface of objects under investigation. These scanners are an effective tool for the collection of data to create a digital elevation model of the topography of a site as well as of the surface of a single archaeologi-

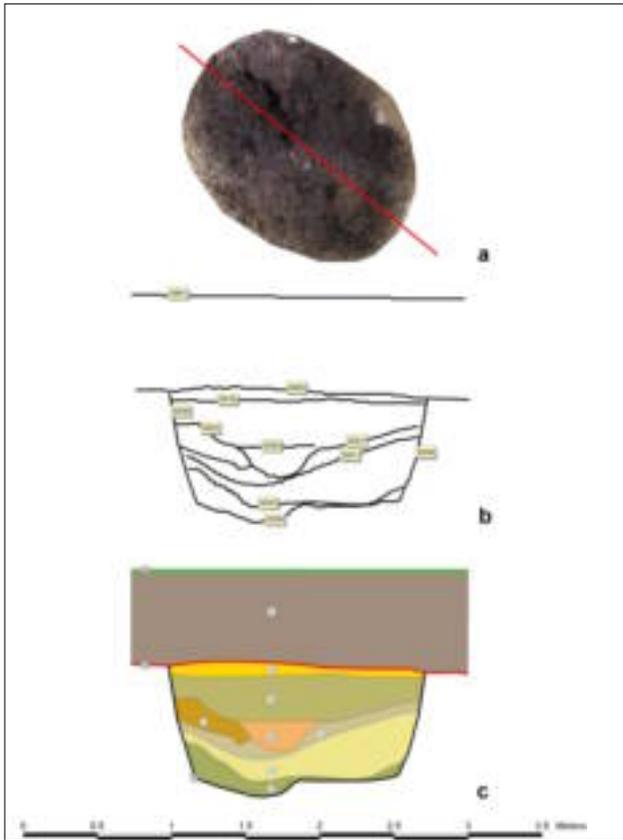


Figure 4: Procedure of creating a cross-section. (a) Defining the line of the cross-section. (b) Calculation of intersection lines with each underlying surface. (c) Cross-section after editing.

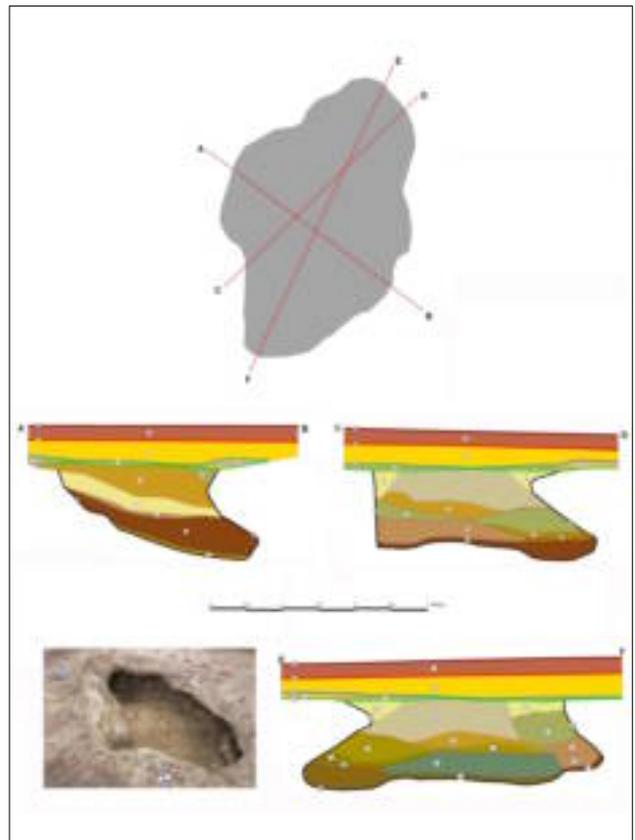


Figure 5: Calculated cross-sections of a large working pit of the Neolithic funnelbeaker culture in Platt.

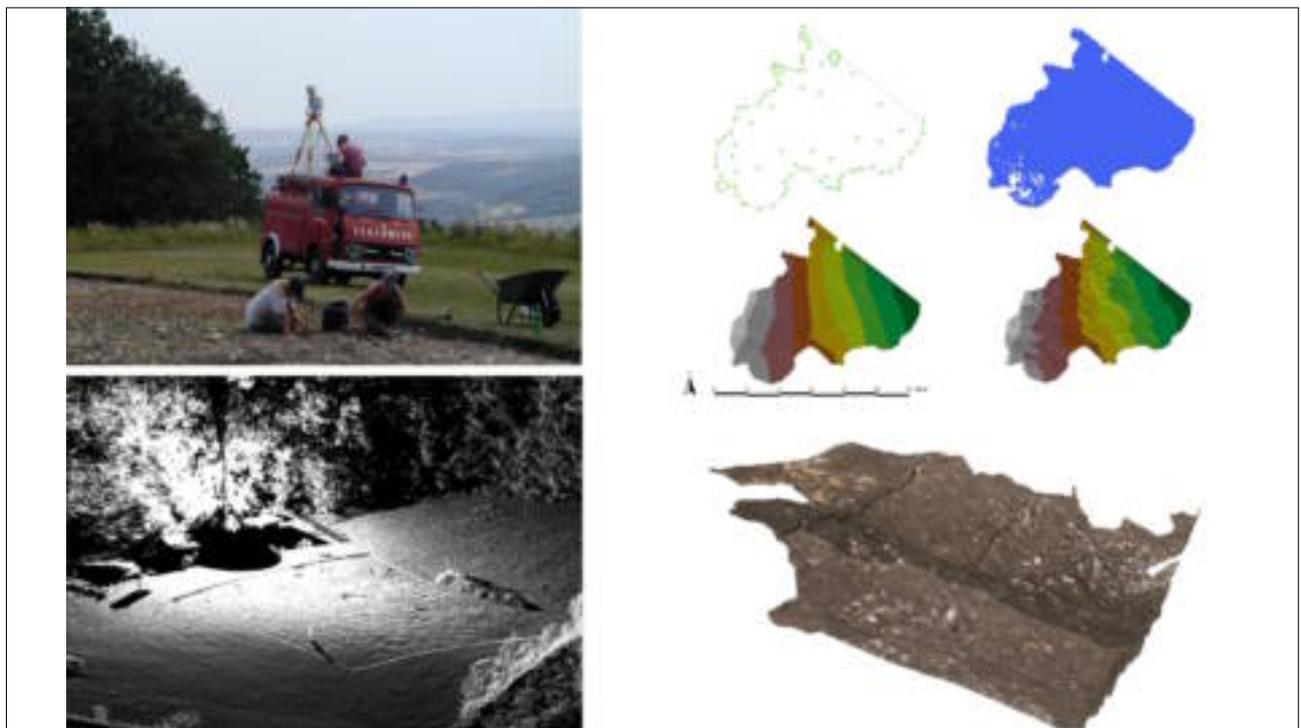


Figure 6: 3D laser scanning for the documentation of single surfaces at the excavation Schwarzenbach. Upper left: Laser scanner in action. Lower left: Intensity image of a *RIEGL LMS-Z210* laser scanner showing the excavation. Upper right: comparison between data and TIN using a total station (left) and a laser scanner (right). Lower right: Visualization of the surface.

cal deposit. Together with *RIEGL LMS GmbH* (www.riegl.com) the excavation campaign 2002 at Schwarzenbach could be monitored for two weeks using the *RIEGL LMS-Z360* and *LMS-Z210* devices. The scanners were used for a high resolution 3D recording of the surface of the open 900 m² trench, so far done using a total station.

The primary data of a 'scan' is mainly a so-called 'point-cloud' in the sensor's local coordinate system. In general it will be necessary to obtain multiple 'scans' from different positions to overcome the problem of occlusions that will be present in any scan from a single point of view. In order to obtain a quite complete representation of the surface by a point cloud, in general numerous scans have to be merged into a common coordinate system ("registration").

For the registration of the scans 11 reflectors were mounted on fixed positions. Right after the digging out of a single deposit, the surface of the trench or parts of it were scanned, using the highest resolution of the specific instrument. The collected and registred point clouds were resampled on a 5 or 10 cm regular grid and converted into a native *ArcView* shape-format.

For further data processing we used the function of the GIS *ArcView*. The single surface of a deposit was clipped from the triangulated topographic scan data using the out-bound polygon of the stratification unit, measured with the

total station. Rectified digital photographs were mapped on top of the triangulated surface (Figure 6). The 3D laser scan devices showed a high reliability and efficiency for topographic single surface recording in every day archaeological work. The scanner, as used here, could do the same recording job, done so far by two people, in only 20% of time collecting up to 50 times more data. This would save at a typical 1 month excavation up to 100 man hours. The 3D laser scanner can be seen as a future standard tool for the high resolution 3D recording of single surfaces on a stratigraphic excavation.

8. REFERENCES

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