

## 3D LASER SCANNERS ON ARCHAEOLOGICAL EXCAVATIONS

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### ABSTRACT

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”). During recent years we developed a GIS based procedure for the digital documentation of stratigraphic excavations.

The outstanding importance of 3D single-surface recording for the stratigraphic record demands the use of high resolution documentation techniques. During the last three years, we have been testing the use 3D laser scanners combined with digital imagery as a recording tool on archaeological excavations using various instruments (Riegl LMS Z210i, Riegl LMS Z360). They showed a high reliability and efficiency for topographic single surface recording in every day archaeological work.

### 1. INTRODUCTION\*

Every 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 archaeological finds. The archaeological excavation therefore aims at a complete description of the stratigraphy of the excavated area. Practically, this is done by dividing the stratification of the archaeological site into its components, the units of stratification by removing single deposits in the reverse order to which they were formed. This implicates, that any unit of stratification has to be destroyed as the excavation proceeds to the next one. It is therefore absolutely necessary to document each stratification unit by recording its physical and spatial properties and stratigraphic relations, while collecting finds and samples in relation to it as accurately as possible.

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. As Harris points out, every unit of 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.

Any deposit is enclosed, or defined, by its outer or top surface, at one time exposed to the air, and its bottom surface or contours, together forming the immaterial and complete surviving hull of any deposit. Single-surface recording provides the ability to virtually reconstruct the excavated volumes of deposits in three dimensions. Therefore, 3D recording of the top and the bottom surface of any single deposit as well as the 3D recording of interfaces is necessary to fully reconstruct the part of the site that was destroyed during the process of excavation.

### 2. THE DIGITAL RECORDING PROCESS

The most important concept to come out of the fore said is the need for an accurate and three dimensional single surface planning (Harris, 2001) and because it is of major interest, to check the recording during the excavation process. To be able to plan the next steps of excavating, it is important to have all the information from the already excavated deposits at hand. Using conventional means, this can be a very time consuming and often impossible task. During recent years, therefore, we have developed a GIS based procedure for the digital documentation of stratigraphic excavations (Doneus & Neubauer & Studnicka 2003; Doneus & Neubauer 2004). The main objective of our work is a standardized digital recording for all observations that are necessary for a good stratigraphic interpretation of the data. The resulting GIS-based system consisted of a total station, a digital camera and a PC/Laptop with Arc View GIS (Version 3.2) and Monobild (or similar software for rectification). For the creation of the stratigraphic sequence we use ArchEd.

The spatial dimensions of the single surfaces can be recorded in its entirety in 3D using a total station. We digitally document boundary polygons and topography of surfaces, finds and the photographic record of each unit of stratification. All data are stored using the internal data format of the total station, where code-blocks provide the number of the unit of stratification and the class of the recorded feature and can be immediately interfaced to the GIS.

The digital photographic record has to be rectified and georeferenced within an accuracy that would not exceed +/- 5 cm. This is done using the simple method of projective transformation, which can yield reasonably good results as long as the surface has minor differences in height or is evenly sloping up (Doneus & Neubauer & Studnicka 2003).

### 3. DIGITAL RECORDING PROCESS AND LASER SCANNER

Although much faster than conventional methods, measuring the topography using a total station is still time consuming, especially when the topography is rough. The quality largely depends on the skills and capability of the person handling the reflector. He should be capable to measure a number of points as small as possible while still getting a good

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\* This paper is a shortened version of Doneus, Neubauer 2005.

representation of the topography. If the network of measured points is too wide, interpolation of the documented surfaces will result in considerable height errors. Especially with thin deposits, this can consequently lead to topological errors, where for example the digital representation of the top and bottom surface of a deposit can intersect. On the other hand, measuring a high number of surface points can be very time consuming.

Upstanding features like walls or cross sections can make recording process time consuming and complicated. Local coordinate systems and vertical planes have to be defined to make a conventional 2 dimensional recording possible.

Additionally, quite often the archaeologist is confronted with situations, where the excavated surface is too vulnerable to be walked on (e.g. waterlogged environment, mosaics, organic material).

In all of these cases, application of terrestrial 3D laser scanning could be a solution. Terrestrial 3D laser scanning forms a method to automatically collect 3D coordinates of object surfaces in a given region without the need to touch the objects under investigation. Laser scanners acquire a large number of precise data points in 3D space representing the surface of objects and 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 archaeological deposit.

In the last few years laser scanners have been employed in various aspects of archaeology on numerous occasions. However, so far they were not used for "single context recording" of excavations.

### 3.1 Requirements

Therefore, in 2002 we started to test the usability of laser scanners throughout an archaeological excavation. The use of 3D laser scanners on archaeological excavations demands above all ruggedness. Even in countries like Austria, excavations often take place under high demanding environmental conditions (hot summer, cold winter, moisture, dust, caves, alpine region etc.). The scanner has to be portable, the acquisition time should be short. The accuracy should be high, but it is not necessary to go beyond the centimetre. The horizontal scanning range should be 360° with a distance range of at least 100 m, so that multiple surfaces can be recorded with a single scan. All these needs are fulfilled with the 3D laser imaging sensors of RIEGL.

Together with RIEGL LMS GmbH ([www.riegl.com](http://www.riegl.com)) the excavation campaign 2002 at the Iron-age hillfort in Schwarzenbach (Lower Austria) could be monitored for two weeks using a RIEGL LMS-Z210i device. During the tests we wanted to clarify, whether the scanners would be sufficiently robust for excavation conditions (dust, wind, both hot and low temperatures, moisture...) and whether the digital recording can be improved in terms of efficiency, accuracy and detail.

During the excavation campaigns 2002 and 2003 in Schwarzenbach, some 80 kilometres south of Vienna, the scanner was used to systematically document the surfaces of a 900 m<sup>2</sup> trench (Schnitt 5) on a plateau near the top of the hillfort. Here, altogether 350 units of stratification could be observed. Most of the deposits were quite thin having a depth of only a few centimetres. The sediment of most deposits included stones and therefore the topography of most surfaces was rough. Consequently, the recording process using a total station was very time consuming. Schnitt 6, the trench of the campaign 2004, was situated on a small terrace and had features like ovens with foundations of

stone, which again were difficult to document in detail in 3D. Additionally, the scanner was tested on the excavations of the middle Neolithic henge monuments in Steinabrunn and Immendorf. Both are located in the Weinviertel north of Vienna. It is an area characterized by Loess. Here, the surfaces of the stratification units were quite smooth with deposits of varying thickness.

### 3.2 First Experiences

We were using the LMS-Z210i and the LMS-Z360 (Figure 1). The Z210i was our preferred instrument. Its vertical scanning range is up to 80° while the horizontal scanning range is 360°. The distance measurement (having a range of up to 120 - 400 meter, depending on the reflection coefficient of the target) is computed from the travel time of the laser pulse between signal transmission and reception. The scanning accuracy is ±20 mm. The scanner is plugged to a PC laptop via TCP/IP Ethernet Interface. The reloadable batteries that came with the instrument were strong enough to keep the instrument working for at least one day.

The scanner has an integrated True Colour Channel, which provides the colour of the target's surface as additional information to each laser measurement. Colour data are included in the binary data stream of the LMS-Z210i.



Figure 1. Schwarzenbach: Riegl LMS-Z210i 3D laser scanner with a NIKON D100 digital SLR camera mounted on top (Photo: Martin Fera).

The primary data stream of the instrument carries the X,Y,Z coordinates, signal amplitude and colour value of each scanned point in a relative coordinate system (Scanner Own Coordinate System = SOCS). Usually, a 3 dimensional object or a topographically irregular surface cannot be fully documented from a single scan position. There are areas hidden from the current viewpoint, which would result in

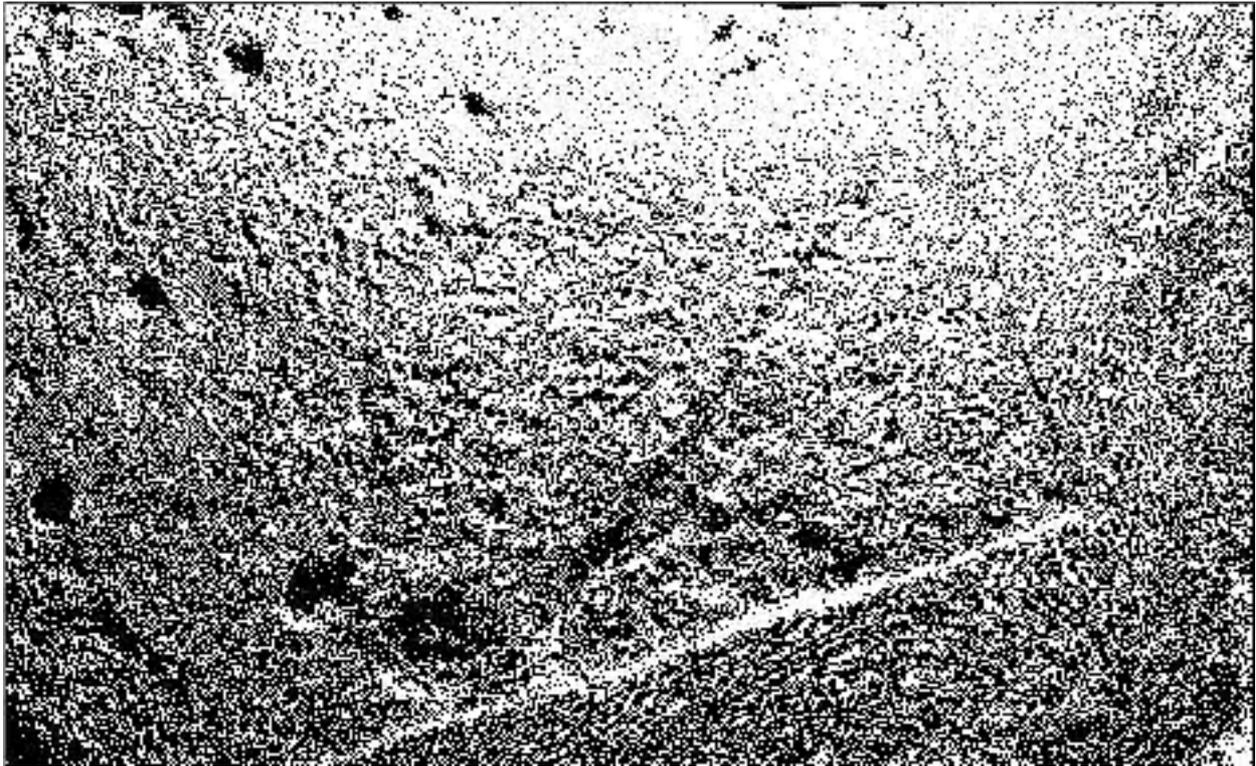


Figure 2. Detail of the point cloud of a single scan (LMS-Z 210i). Various excavated features (post holes, ditches) can be seen due to the shading effect. The shadows are blind spots in the 3D record, where the surface was not visible because of the oblique scanning angle. Therefore, most of the surfaces are recorded from two opposite scanning positions.

holes in the 3D record. Therefore, in most cases more than one scan position is necessary. The scans from the different positions are registered into a common coordinate system (Project Coordinate System = PRCS). This is done by a minimum of 4 retro-reflective targets per scan. The targets can be detected automatically using the signal amplitude of the data stream. If these targets are measured using a total station, they can function as ground control points and the scans can be registered into the global coordinate system (GLCS). To make registration even more accurate, the detected targets additionally can be automatically fine-scanned with high resolution, resulting in a more precise definition of the centre of each target.

We usually placed more than 10 targets in an asymmetrical layout around the excavation area, so that we would have a minimum of 4 targets visible per scan. The targets were on fixed positions and would stay there throughout the entire excavation campaign. To avoid holes in the 3D record (Figure 2), most of the surfaces had to be documented from at least two scan positions. Once the instrument is set up, the laptop ready and the RISCAN project defined (these steps take up to 15 minutes), a single scan takes only about 4 minutes acquisition time. Therefore, even when scanning from two or more scan positions, the documentation is still a fast procedure. Usually only two scan positions per stratification unit are sufficient. Especially with large excavation areas and some organizing, we often managed to record several surfaces together and in that way saved even more time. Using more than one scan position helps solving also a second problem (AVERN 2005), where because of the oblique sampling angle of the scanner, resolution of the data changes with the proximity of the surface to the scanner (see Figure 2, where the density of data points gets lower from top to bottom). To reduce the problem of obliquity even

more, the Z210i can be tilted so that it can be placed in an almost vertical position above the surface to be recorded. Here, the mobile scanning platform MSP 250 will also come in handy (Figure 6). It can lift the scanner to several meters height, where it can be tilted and consequently measures a large surface from an almost vertical viewpoint.

Experience showed that although acquisition time is quite fast, it is not worth documenting every surface using the laser scanner. Especially small features like postholes can be recorded faster using the total station. Since the data of both sources are compatible, it makes no difference for the post processing of the record in GIS (see below) if the surfaces were scanned or measured using the total station.

### 3.3 Postprocessing of scanner data

A single scan results in 2 million data points with X,Y,Z coordinates, signal amplitude and colour value (Figure 3). The point cloud can be viewed in the scanners software (RISCAN PRO) in 2D and 3D with options for colour-encoding each point by the laser sensor's intensity, by range or height, or by colour of the true-colour channel. This makes visualization and interpretation of the data much easier.

Point clouds of multiple scan positions can be visualized together in RISCAN PRO. The software comes with tools to smooth and filter the data to reduce noise. Parts of the point cloud can be clipped and consequently processed separately. Therefore, the post processing of the data is a straightforward process. Once the point cloud is registered to the global coordinate system (which is usually done directly after the data acquisition), the data are smoothed, decimated, and resampled on a 5 cm regular grid. After processing, the data are exported as ASCII text files, which later on can be

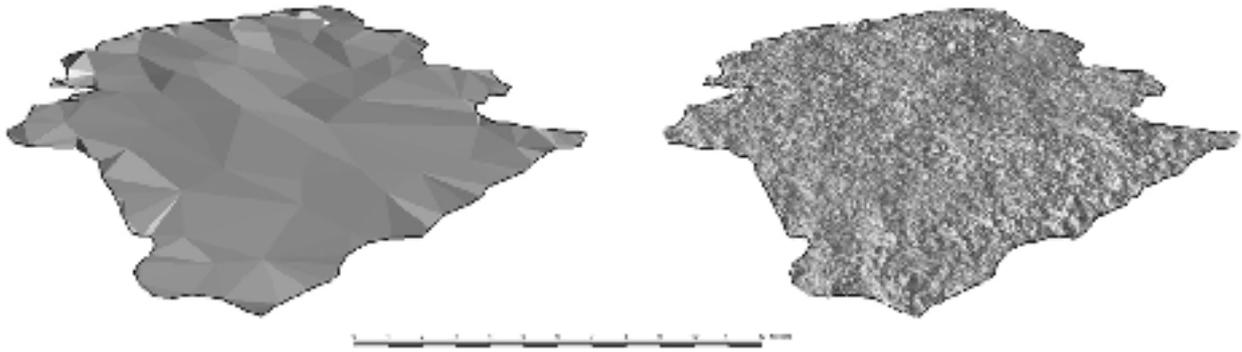


Figure 3. Schwarzenbach, SE005: comparison of interpolated surfaces of the interface using a total station (left) and a laser scanner (right). The roughness of the surface can be clearly seen in the visualization of the scanner data.

imported into a GIS system. Once we were familiar with the software, the post processing usually did not take longer than a few minutes.

### 3.4 Combining laser scanner and photogrammetry

Rectification of digital photographs recorded so far, was done applying a projective transformation. This in many cases provides sufficient accuracy. However, it gets more problematic, when the topography of the unit of stratification is rough, having large height differences on several locations. In this case 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. Another possibility would be to use software capable of differential rectification using a DTM. Here, RIEGL laser scanners again offer a solution: during the excavation campaigns 2004 in Schwarzenbach and Immendorf, the LMS-Z210i was combined with a NIKON D100 digital SLR camera (see Figure 1). The calibrated camera is firmly mounted on top of the laser sensor but can be removed quickly. Both mounting position and orientation of the camera with respect to the scanner's coordinate system are well defined.

After acquisition of the scan data, a series of photos covering the field of view of the scan data are taken. The camera is plugged to the laptop via USB from where it can be controlled. This ensures, that the aperture setting and shutter speed are set correctly.

The image data can be used to assign a colour value to every vertex of the scan data or to apply the images as a high-resolution texture to the meshed surface generated from scan data. Generation of meshed surfaces allows moving from the point cloud data to triangulated surfaces. This is done using a Delaunay triangulation in the scanner's internal coordinate system.

True orthophotos with additional depth information can be generated using the triangulated mesh, a defined plane of projection, defined depth values in front and behind the plane, and the desired resolution. The parameters for defining a plane of projection can be interactively chosen in the visualized point cloud, or in the case of surfaces of stratification units, the x-y axis of the global coordinate system can be used (Figure 4). In that way, orthophotos can be created as well from surfaces of stratification units as from walls or cross-sections.

If the scan position and therefore also the photographing angle of the camera are highly oblique, and the topography of the surface is rough, the true orthophoto will have many blind spots, which are filled by interpolation of the neighbouring pixels. The results are still accurate but unsatisfying and not very useful for interpretation (Figure 5). That is why we still use additional digital photographs which are rectified using the projective transformation as described above (see chapter "digital recording process"). They still are a better source for interpretation. Maybe the problem can be solved combining the tilting facility of the scanner and the newly developed scanning platform mentioned above. In that

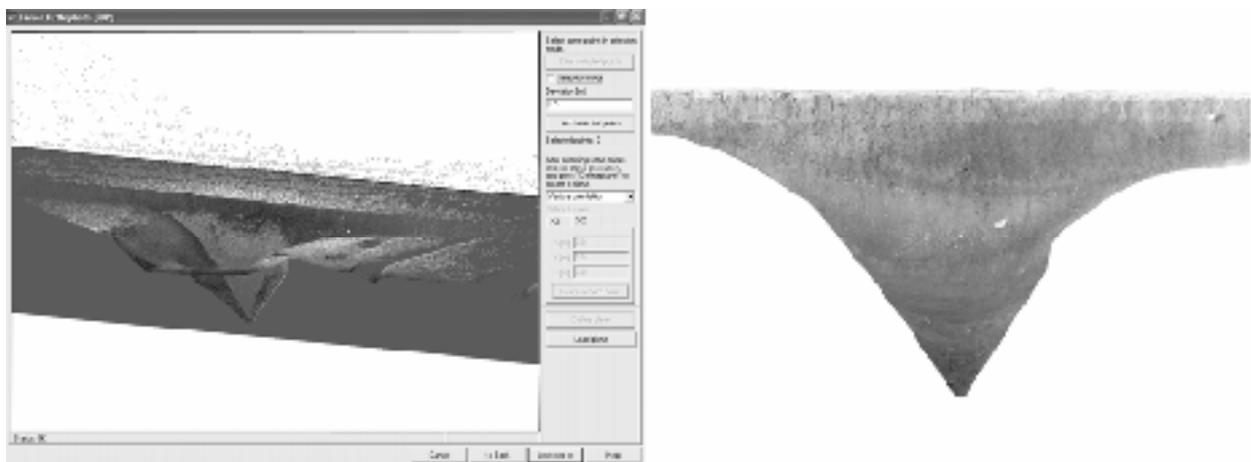


Figure 4. Left: screenshot during a session of RISCAN Pro. A true orthophoto is created from a scan and a sequence of photographs. The plane of projection (gray area) is defined by interactively selecting data points located on the required surface. Right: resulting orthophotograph from the middle Neolithic ditch of Steinabrunn.

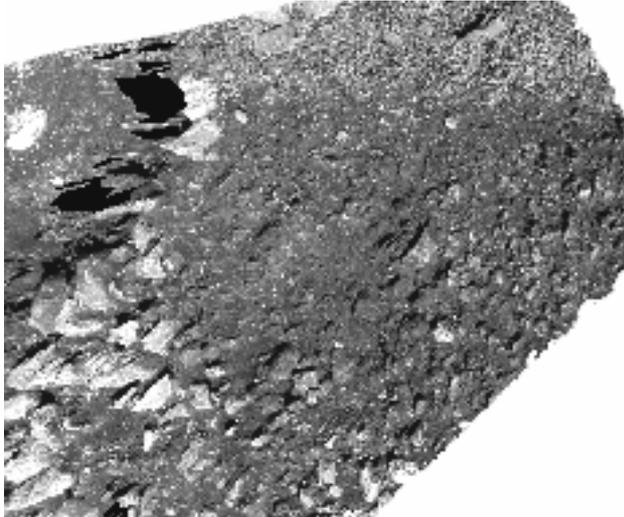


Figure 5. Schwarzenbach, I068. True orthophoto created from a scan and a sequence of photographs. Due to the oblique scanning angle and the rough surface, there are blind spots on the left side.

way, we could make almost vertical photographs which would result in accurate orthophotographs without blind spots.

The results we obtained using the laser scanner were very encouraging. In 2004, we got funds to purchase the LMS-Z210i laser scanner which consequently will be used at future excavation campaigns as a standard tool for the documentation process.

#### 4. INTERFACING TO GIS

The results gathered so far - point clouds, triangulated meshes, and orthophotos - are part of the high quality documentation of the excavated surfaces, which need to be archaeologically interpreted. During the process of interpretation, the documents have to be combined with all the other excavation data, especially with finds and samples. This is best done using GIS.

As GIS provides the ability to store, visualize and analyze graphical information in combination with descriptive information, 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). The outstanding value 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 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 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 various aspects (location, material, date etc.) of the finds

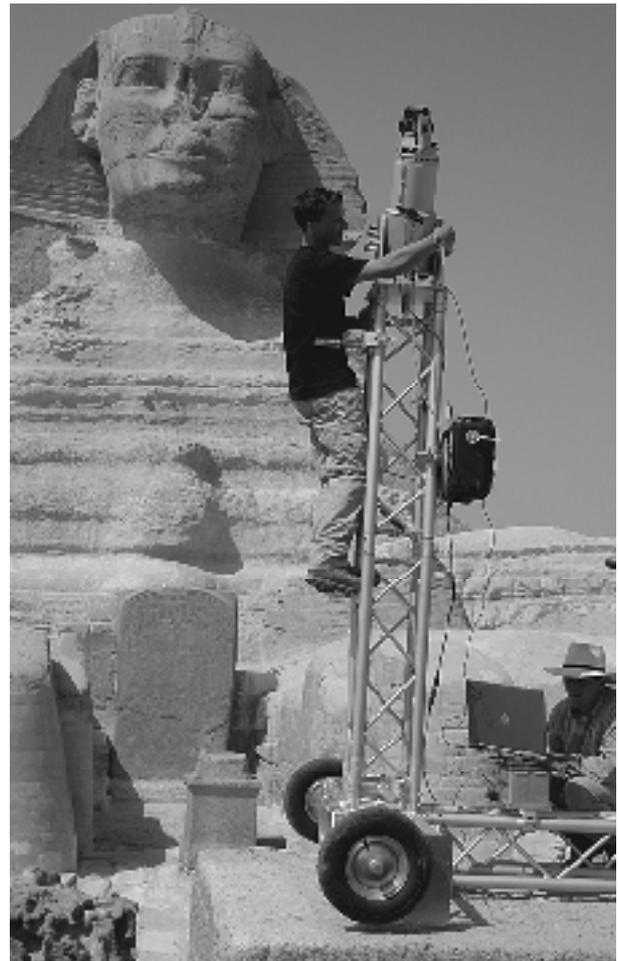


Figure 6. Mobile Scanning Platform MSP250 as used during a project in Egypt. (Photo: Wolfgang Neubauer)

uncovered is stored in the spatial database of the GIS. There, it can be combined with the graphical visualizations, analyzed and counterchecked.

To be able to automatically import and analyze the spatial data in Arc View GIS, the extension module ArcDig was programmed using Avenue, the object oriented programming language of Arc View 3.3. The import routine reads the native ASCII data file format of the geodetic instruments (total station) and the exported laser scanner data and converts them into the native shape file format of Arc View. 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 surfaces and optional breaklines are imported as 3D points respectively 3D lines. Finds and samples are imported as 3D 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.

Both rectified images (projective transformation using "Monobild") and true orthophotos (from the laser scanner) can be directly displayed in the GIS.

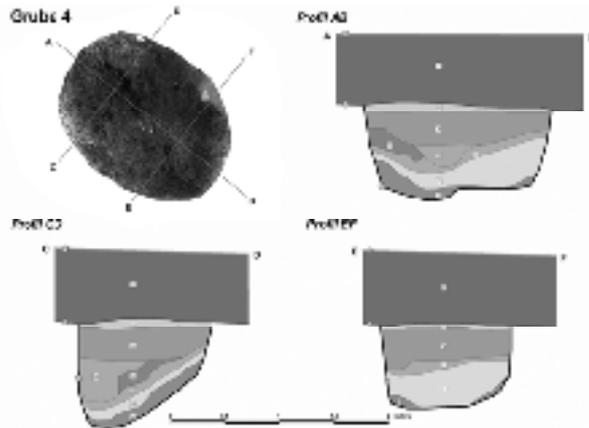


Figure 7. Calculated cross-sections of a working pit of the middle Neolithic Lengyel culture in Platt.

## 5. POSTPROCESSING

After import the entire graphic record is available in the GIS and can be checked for errors. 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. To prevent unintentional drawing in the outside areas, the images can be clipped to the boundary polygon of the corresponding stratification unit. Points, breaklines and 3D boundary of each surface are then automatically used to create a digital elevation model of each single surface. 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.

The descriptive information stored in databases can now be linked to the graphic record.

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 each underlying surface. The resulting intersection lines are then compiled into a new drawing representing the section (Figure 7). The advantage is clearly to be seen: sections can be reconstructed automatically at any line of interest. Since the accuracy of the calculated intersection lines depends on the quality of the documented surfaces, the results are much better where laser scanners were used for documentation.

## 6. CONCLUSION

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.

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