DIGITAL RECORDING OF STRATIGRAPHIC ARCHAEOLOGICAL EXCAVATIONS USING TERRESTRIAL 3D LASER SCANNERS

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3D Laser Scanner Riegl LMS Z210 as first in use in Schwarzenbach in 2002.

Any archaeological site shows a stratification formed by single 3D volumes, the deposits and specific 3D surfaces of human origin as pits, ditches or wall-surfaces known as the units of stratification. Excavation forms the main data retrieval process in field archaeology - a destructive process to be documented in three dimensions. To fully reconstruct the part of the site destroyed by excavation these units have to be documented in 3D. The outstanding importance of a 3D documentation of the stratification by the means of the single surfaces indicates the use of terrestrial 3D laser scanners combined with digital imagery as a standard documentation tool. They provide high topographic detail and texture for the efficient digital documentation and monitoring of the excavation process. This monitoring demand opens a wide field of future development – hardware and software - to integrate laser scanners in the daily archaeological work flow.

3D Laser Scanner Riegl LMS Z420i overlooking a valley on Crimea, Ukraine.

Terrestrial laser scanning has been successfully applied to document historic buildings or archaeological features like walls, columns, monumental statues all over the world. Our own projects scanning the pyramids of Giza and the Sphinx (ViaVIAS 01/2007), the Celsus Library at Ephesos or the monumental graves of the Tang emperors, just to mention a few, proofed this technique to be able to collect reliable, high resolution data of such monuments in a short time. More specific applications include the documentation of caves or mines as the oldest prehistoric salt mine at Hallstatt, megaliths, incised rock formations, Early Christian chapels and tombs cut into the bedrock or any buried features still visible in the topography as ramparts, burial mounds or former field systems. The acquired data can be used for archaeological documentation purposes only. However, further processing provides the possibility for virtual reality modeling, restoration planning or virtual reconstructions and provides fascinating products to a wide public.

Pointcloud of the castle and the church at Leopoldsberg, Vienna.

3D Laser Scanner Riegl LMS Z420i combined with an Nikon D100 scanning Early Medieval tombs and chapels carved into the bedrock at Eski Kermen, Ukraine.

In archaeology not only the monument itself is of interest but the surrounding topography should be captured as well. Therefore such specific archaeological applications require wide range and long distance scanners which are compact and robust. We found the RIEGL LMS Z420i and Z390 perfect multi-purpose scanner for the most archaeological projects (www.riegl.com), reliable even in harsh archaeological field situations, including high temperature changes, dust, mud, rain or storm. Carrying the Z420i up the great pyramid of Khufu we would have liked to have a more light-weighted scanner instead. During the 10 hours of data collection on the top we immediately changed our mind and got convinced of our heavy machine which worked perfectly even in a sand storm. Nevertheless the monitoring of an archaeological excavation process by the means of a 3D laser scanner is still underestimated by professional archaeologists and providers of scanners or scanning services.

Every archaeological site is stratified and any archaeological stratification – a three-dimensional buried volume - is unique. The stratigraphic excavation method is based upon the distinct excavation of its single units in the reverse order of their deposition or creation. Therefore the archaeologist has to observe and document their stratigraphic relations. These relations are based upon topological observations of the distinct units during the excavation process. They can be deduced as well from a topological analysis of a complete 3D topographical record of these units. If documented, such a complete topographical record provides the possibility for a verification of the stratigraphic sequence or Harris Matrix.

3D pointcloud of apses cut into the bedrock at Ephesos, Turkey.

3D scanning of historical buildings at St. Anna in der Wüste, Austria.

Scanning of an urban excavation site at Leipzig, Germany.

During the last years VIAS developed a digital 3D documentation process for stratigraphic excavations in theory and practice which forms the base for future developments, necessary to introduce terrestrial laser scanners into the archaeological toolbox. The standardized process developed for the stratigraphic recording of surfaces is divided into subsequent steps to be repeated for each excavated unit of stratification forming a documentation algorithm. Every single unit - surface or deposit - is given a unique number and documented by its boundary polygon as well as its topography. The collected point-clouds from specific surfaces, the surfaces of deposits and the according texture derived from digital photographs are the primary raw data for further mapping and analysis in a GIS. The material aspects of deposits can only be captured by sampling. For the stratigraphic record, each deposit, represented by its top and bottom surface 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. 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. All further data derived from the finds can be stored in a database, photographs and find drawings.

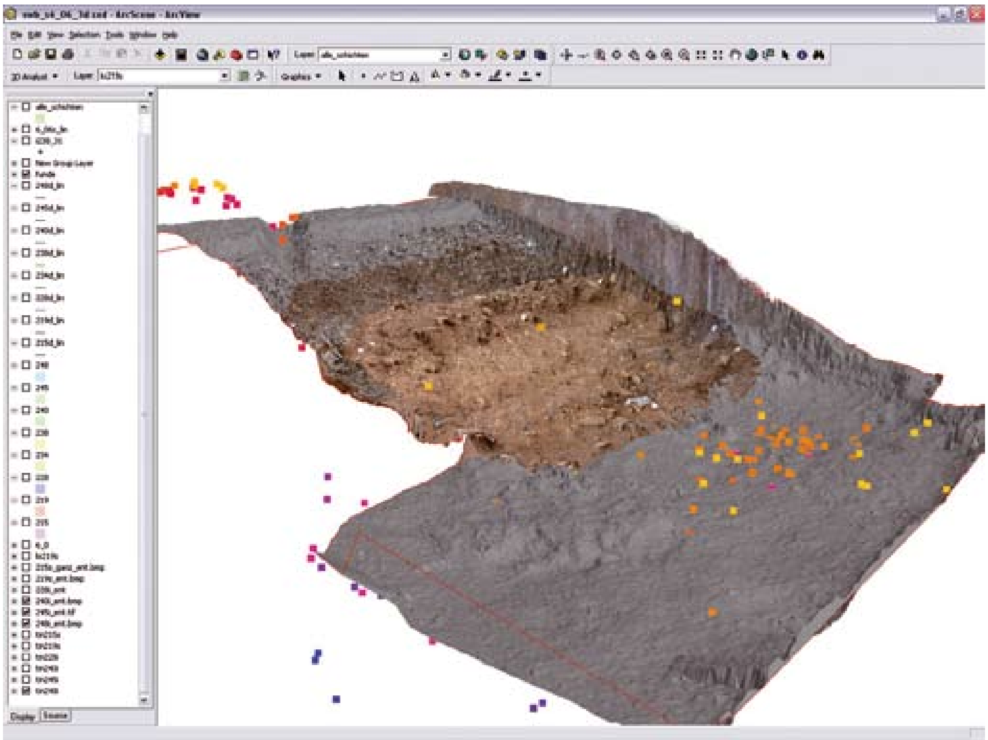
Triangulated and textured cellar with chimneys at Leipzig, Germany.

It is of major interest, to control 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.

Arranging the 3D Laser Scanner for the record of complex surfaces uncovered during the excavation of the Iron Age workshops at Schwarzenbach-Burg.

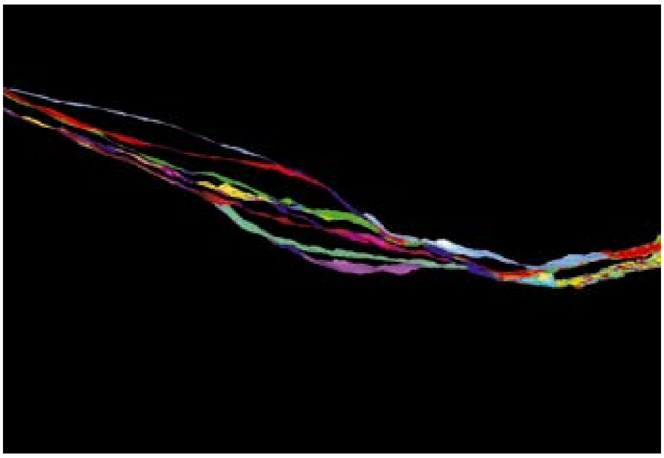
The main objective of our work is a standardised digital recording by collecting the fundamental data for a 3D virtual reconstruction of the mass of the unique stratification destroyed by the excavation process. The stratigraphic relations of any top surface, bottom surface, or feature interface (see page 31 -37), have to be observed and recorded. From these relations, the stratigraphic sequence is formed. 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.

Using our standardized technique of recording we digitally document boundary polygons and the topography of surfaces, find points and a photographic record of each unit of stratification. All data is immediately interfaced to the GIS. The spatial dimensions of the single surfaces can be recorded in their entirety in 3D using a total-station. To allow a continuous recording of the excavation, the total station is set up during the entire duration of the excavation.The digital photographic record has to be rectified and georeferenced. After extensive testing, we decided to use 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. Although much faster than conventional recording 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, who should be capable to measure a number of points as small as possible while still getting a good representation of the topography. If the network of measured points is too wide, interpolation of the documented surfaces will result in considerable height errors. Having thin deposits in mind, this can consequently lead to topological errors, where for example the digital representation of the top and bottom surface of a deposit might 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 two-dimensional recording possible. Quite often the achaeologist is also confronted with situations where the excavated surface is too vulnerable to be walked on (e.g. waterlogged environment, mosaics, organic material).

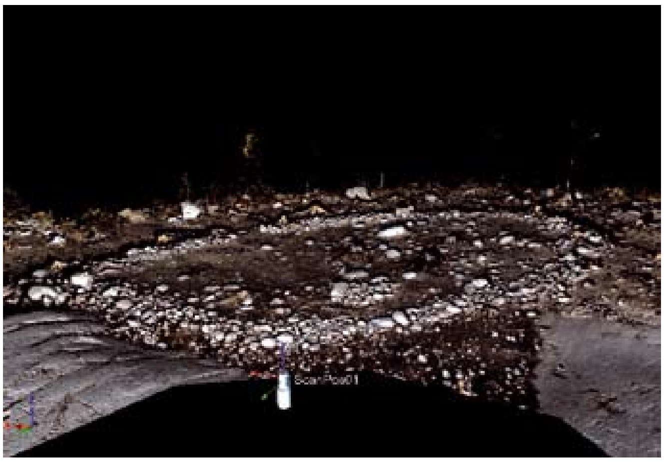


The scanning is repeated for every top and bottom surface of the excavated deposit. The collected data allows to reconstruct the e xcavation process virtual. The colored dots mark the location of the three-dimensionally recorded finds.

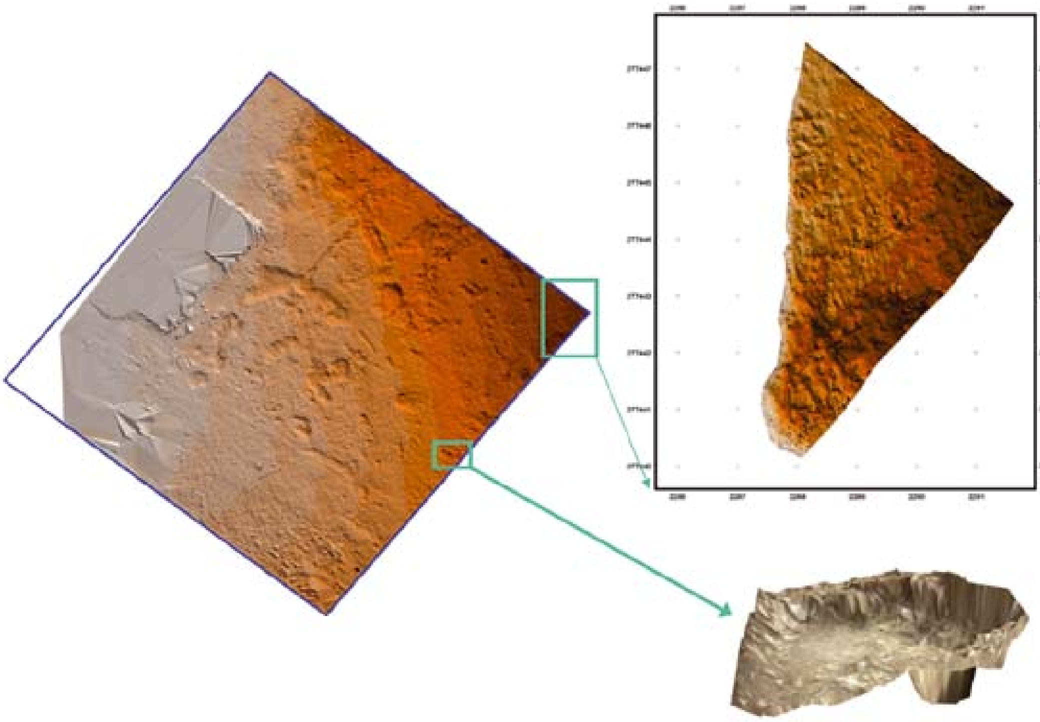
In all of these cases, the application of terrestrial 3D laser scanning is the up-to-date solution to automatically collect 3D coordinates of object surfaces without the need to touch the objects under investigation. These scanners acquire a large number of precise data points in 3D space representing the surface of objects in short time 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 single surfaces. 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. Therefore, we started to test the usability of laser scanners throughout the archaeological excavation in 2002 at Schwarzenbach-Burg. During the tests, we wanted to clarify, whether the various scanners would be sufficiently robust for excavation conditions (dust, wind, high and low temperatures, moisture…) and if the digital recording can be improved in terms of efficiency, accuracy and detail. During the excavation campaigns 2002 and 2003 the scanner was used to systematically document the excavated surfaces of a 900 m^2 trench on a plateau near the top of the hillfort. Altogether 350 units of stratification could be observed. Most of the deposits were quite thin having a depth of only a few centimeters.



Sectional view of a series of scan surfaces representing the stratification.



3D Laserscan of a prehistoric enclosure excavated at Bengstorp, Sweden.



Triangulated Scan of the surface of trench 5 at Schwarzenbach-Burg with single surface map of a single unit of stratification and a 3D visualisation of a feature interface.

The sediment of most deposits included stones and therefore the topography of most surfaces was rough. Consequently, the recording process using a total-station would have been very time consuming. Additionally, the scanner was tested on the excavations of the Middle Neolithic Kreisgrabenanlagen in Steinabrunn und Immendorf, both located in the Weinviertel on loess soil. In these cases the surfaces of the units of stratification were quite smooth with varying thickness proving the scanner to be a perfect tool.

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 within a single scan. All these needs are fulfilled with the 3D laser imaging sensors of RIEGL (www.riegl.com), especially the Riegl LMS Z420i proved to be a perfect instrumentation for the digital recording of single surfaces during the stratigraphic excavation process. Even when scanning from more than one scan-position, the documentation is still a fast procedure. Normally 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. The mobile scanning platform MSP 250 will also come in handy. It can lift the scanner to several meters height, where it can be tilted and records from an almost vertical viewpoint. Point clouds of multiple scan positions can be visualized together and 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 is smoothed, decimated, and resampled on a 2 cm regular grid and transferred to a GIS system. The Riegl LMS Z420i is combined with a NIKON D100 digital SLR camera. This calibrated camera is firmly mounted on top of the laser sensor. 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 hybrid sensor is interfaced to a laptop via a wireless LAN and thus can be controlled remotely. 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. The generation of meshed surfaces allows the conversion of the point cloud data into triangulated surfaces. 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 laser scanner can be seen as a future standard tool for the high resolution 3D recording on

3D Laser Scanner Riegl LMS Z 420i in use to record a narrow excavation trench esposing the V-shaped section of a Neolithic circular ditch at Steinabrunn, Austria.

a stratigraphic excavation. The scanners tested so far showed a high reliability and efficiency for topographic single surface recording in every day archaeological work. The scanner did 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 up to 100 man hours at a typical 1 month excavation. Problems to be solved are the automated extraction of the boundary polygon marked by a chain of reflecting targets to be used for the clipping of the data of the top and bottom surfaces in the subsequent scans directly in the scanner software. This polygon can be additionally used for the clipping of the orthophotos and the immediate export of the triangulated mesh into the native GIS format.

For analysis the primary data from the excavation process have to be combined with all the other excavation data, especially with finds and samples. As GIS provides the ability to store, visualise and analyse 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 reconstruction of the site through time is achieved through the analysis of all artefactual data in relation to the stratigraphic sequence and the display of the topographical data in stratigraphic order. The GIS 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 single-surface 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. Therefore we are working at a new Harris Matrix program incorporating a direct interface to the GIS-software. The matrix then will be used as a GUI for the creation of composite maps and 3D reconstructions of phases and periods. Such reconstruction has often been impossible to achieve on most archaeological sites until the introduction of the Harris Matrix methods and the advent of GIS technology, and, we would add, the proposal made here for the complete identification of all surface units and their efficient and detailed recording as proposed above (see page 31-36).

Reference

Harris, E.C. (2001): *The only way to see.* In: Workshop Computer and Archaeology, Vienna.

Zusammenfassung

Terrestrische 3D Laser Scanner werden von VIAS seit Jahren für die Dokumentation archäologischer Monumente und historischer Gebäude eingesetzt (ViaVIAS 01/2007). Von besonderer Bedeutung sind diese Geräte jedoch für die Dokumentation stratigraphischer Ausgrabungen. Jede archäologische Fundstelle weist eine Stratifikation gebildet aus einzelnen Voluminas, den sogenannten archäologischen Ablagerungen und speziellen, vom Menschen geformten dreidimensionalen Oberflächen wie Gruben, Gräben oder die Oberflächen von Mauern auf, die als Stratifikationseinheiten bezeichnet werden.
Die Ausgrabung ist der grundlegende Prozess zur Datengewinnung in der Archäologie - ein zerstörender Prozess der dreidimensional dokumentiert werden muss. Die besondere Bedeutung der dreidimensionalen Dokumentation in Form einzelner dreidimensionaler Oberflächen von Ablagerungen und den besonderen Oberflächen von Gruben, Gräben etc. indiziert die Verwendung von 3D Laser Scannern kombiniert mit digitaler Fotografie als standardisiertes Werkzeug zur Dokumentation des archäologischen Grabungsprozesses. Diese Technik liefert Aufnahmen mit hohen topographischen Details und entsprechender Textur für die effiziente digitale Dokumentation und Nachverfolgung des Ausgrabungsprozesses. Die bisherigen Entwicklungsarbeiten haben ein breites Feld für weitere Entwicklungen sowohl von Hardware und als auch von Software geöffnet, um 3D Laser Scanner in den täglichen archäologischen Arbeitsablauf zu integrieren.

Wolfgang Neubauer using a 3D Laser Scanner Riegl LMS Z420i on a tripod scanning a cave system below the Royal Naval Dockyard at Bermuda.
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