



THE SCANNING OF THE PYRAMIDS PROJECT

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The Scanning of the Pyramids Project was invoked by the Austrian Archaeological Institute Cairo and VIAS-Vienna Institute for Archaeological Science in cooperation with the Egyptian Supreme Council of Antiquities, Dr. Zahi Hawass. The aim of the project is to apply and test latest state-of-the-art terrestrial laser scanners produced by the Austrian company RIEGL LMS for high accuracy, high resolution and long distance topographic scanning. The project was directed by Prof. Dr. Manfred Bietak, Director of the mission and Dr. Wolfgang Neubauer, Field Director and sponsored and equipped by RIEGL Laser Measurement Systems (www.riegl.com). Laser scanning has already shown its outstanding advantages in acquiring 3D information in many archaeological applications within the past few years (Doneus & Neubauer, 2004; Doneus & Neubauer, 2005).



Fig. 1: RIEGL LMS-Z420i Laser Scanner with a calibrated high resolution digital camera Nikon D100 connected to a WLAN-box in front and on top of the Cheops pyramid with the scanning team Dr. Manfred Bietak, DI Nikolaus Studnicka, Dr. Wolfgang Neubauer, Johannes Riegl jr., Karolin Kastowsky and Stefan Frenzel.



However, the archaeologist is not only interested in geometrical information, but also in additional information on the object's surface, i.e. the texture. Integrating a high-resolution calibrated camera into a laser scanning system provides a very efficient, convenient, and powerful system for an automatic generation of accurately textured high-resolution 3D models. The monuments selected for the first campaign are a monumental building, the Cheops Pyramid and a monumental statue, the Sphinx, two types of monuments typical for Egyptian heritage.

For the first campaign in 2004 (Neubauer et al. 2005) we used a terrestrial hybrid scanner system composed of a high-performance and long-range 3D Laser Scanner RIEGL LMS Z420i with a wide field-of-view combined with a calibrated high-resolution Nikon D100 digital camera (Fig. 1) firmly mounted onto the scanning head of the laser scanner. As for every image taken with the camera the position and orientation of the camera is measured with high accuracy within the scanner's own coordinate system, scan data and image data can be combined in a straightforward way without the need of user interaction.

The system is completed by a data acquisition system based on a standard laptop interacting with the scanner via a wire-less LAN connection. The whole system is battery powered and extremely mobile, but yet robust



The scanner in action in front of the north face of the Cheops pyramid

and operable in a wide range of environmental conditions and is perfectly designed for many archaeological applications.

The hybrid sensor provides geometry data from the laser scan and image data from the camera. These data can be automatically or semi-automatically processed to generate products such as textured triangulated surfaces or orthophotos with depth information.

Additionally, all the tools developed for image analysis, such as edge detection or signal detection, can be used for direct extraction of 3D content from the combined image data and scan data.

The collected data therefore provides a solid and large data base for any measurements related to scientific problems on the construction, the destruction and decay of the World Heritage Monuments as well as many of the structures in the surrounding

To carry out the project it was necessary to set up an array of retroreflectors to be used as control points for georeferencing the data collected by the 3D Laser Scanner. These control points have been surveyed using a Leica TCR703 total station in a local coordinate system set up during the survey. This local system will be transformed into the coordinate system set up by the Giza Plateau Mapping Project.

The control points are used to link the single scans from several scanner positions into one single project coordinate system to be transformed later in a world coordinate system. The scanner used has a field of view of 360 x 80 degrees and collects data in a range of up to 1 km with an angular resolution of down to 0.004 degrees. This produces a point cloud of recorded points with X, Y, Z coordinates and the intensity of each reflected laser pulse.

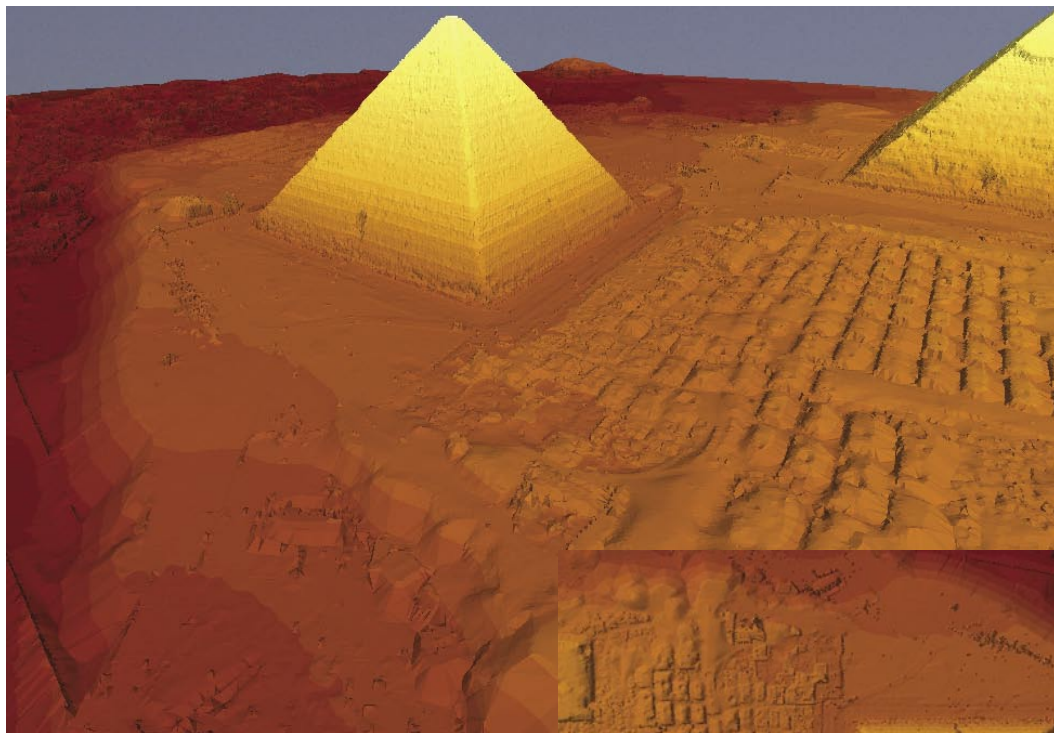


Fig. 2: Overview of the digital elevation model of the Giza Plateau visualized in ARC GIS 8.2.

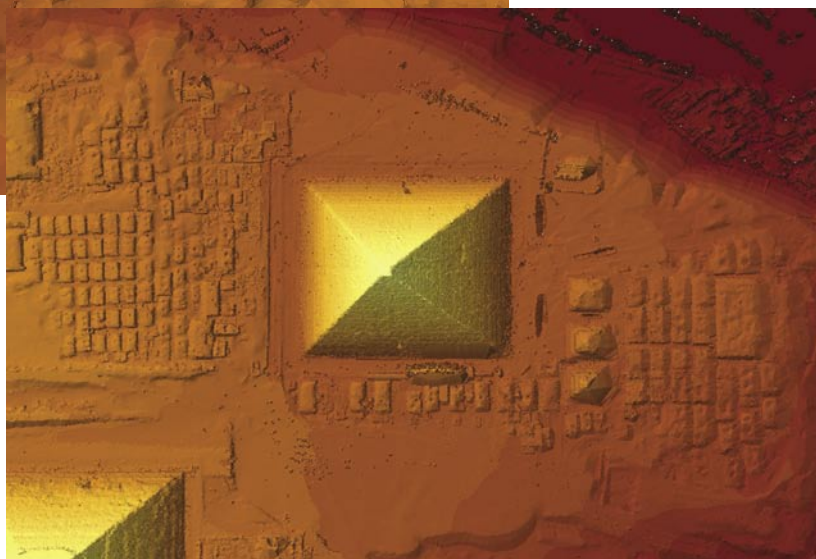


Fig. 3: 3D visualization of the triangulated point cloud measured from the top of the Cheops Pyramid using ARC GIS 8.2.

The internal radial registration accuracy of the scan data is about 1 cm standard deviation. Already during data acquisition the data is being registered, thus immediately after completion of fieldwork a registered point cloud is available. All point clouds acquired consist of about 100 million measurements.

Additionally without the need of further re-registration work about 1000 high-resolution digital images are available too, as the internal and external orientation of the camera is well-known because of a priori calibration and the fixed mounting of the camera on the scanner. During the five days of survey data was collected from 9 scanner positions to create a digital elevation model of the Giza plateau within a radius of 1.3 km around the Cheops pyramid. From the 4 positions at the top of the Cheops pyramid 14 millions of single readings with an accuracy of several millimeters were recorded. The resul-

ting point cloud from this scan positions was triangulated and visualised in a GIS system (Fig. 2) which will be used for subsequent combination of any other available data as satellite imagery, aerial photographs, excavation maps etc.

For the scanning of the four sides of the Cheops pyramid we set up 5 scanner positions around the pyramid (Fig. 5). This data will be used to produce orthophotographs and for the mapping of every single stone of the pyramid (Fig. 8). The north and east front of the Chepren pyramid could be recorded at the same time (Fig. 4). This data will need further processing as during field work more than 90 percent of the set up reflectors have been taken away overnight by the security forces. Therefore several working steps had to be repeated again and led to a reduced amount of scanner positions that could be recorded during the short campaign.

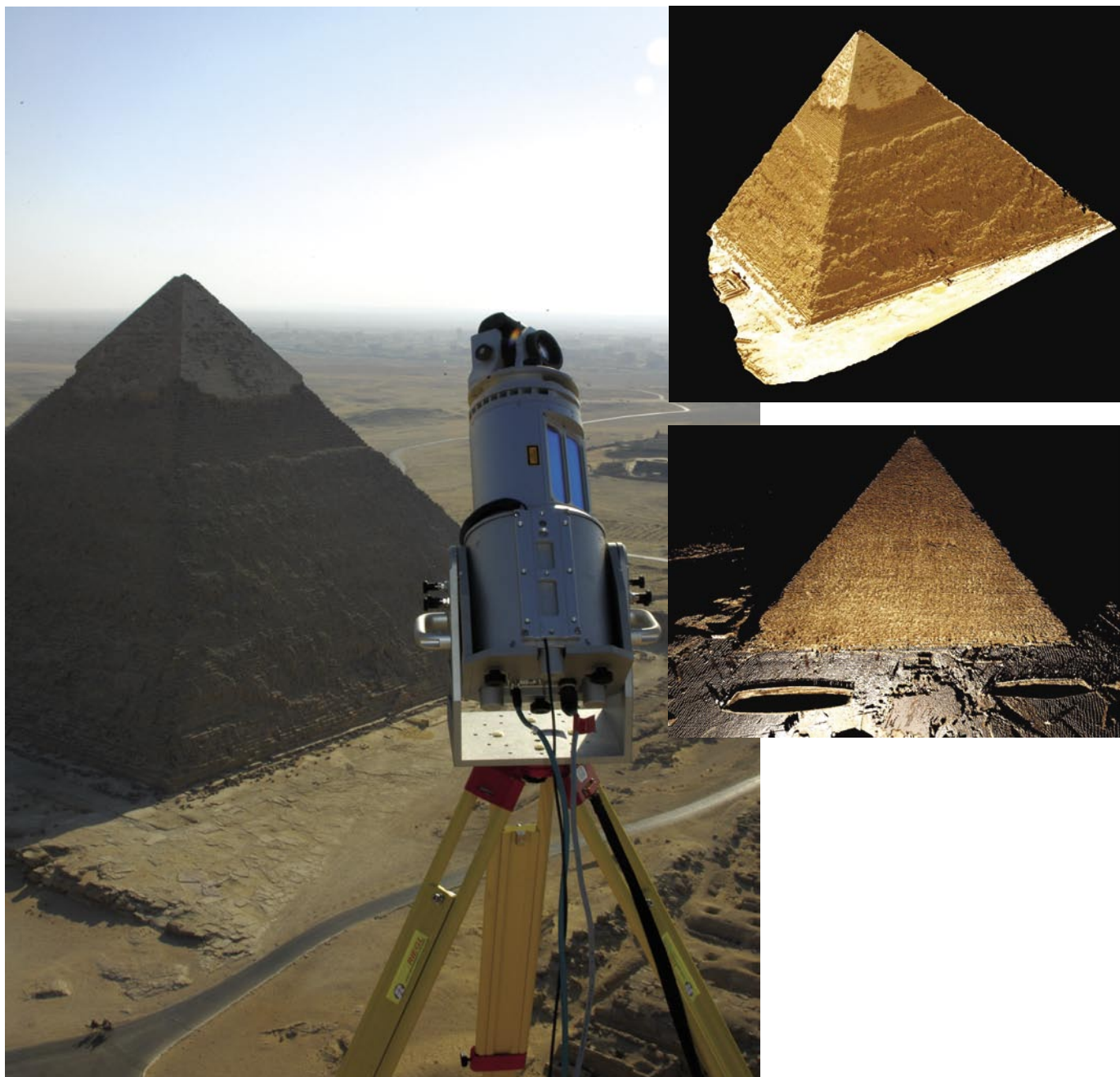


Fig. 4: Single scan from the north and east front of the Chepren Pyramid visualised in RiSCAN PRO 1.1.2 as coloured point cloud scanned from top of the Cheops pyramid.

Fig. 5: 3D view of one single scan from the east front of the Cheops Pyramid visualised in RiSCAN PRO 1.1.2 as coloured point cloud.



Fig. 6: Scanner mobile in front of the Sphinx.

The Sphinx was scanned first from the top of the Cheops Pyramid to get data from the otherwise invisible back of the monument. The working distance was approx. 570 m, scan resolution of 0.004 degrees resulting in a measurement spacing on the target of about 4 cm.

To complete the three-dimensional model of the Sphinx we recorded data from another 6 scanner positions set up around the Sphinx. Since the working time was limited by the local authorities to 5 hours we decided to use a scanner mobile (Fig. 1) for faster change of scanning position. Due to the limited time the model could not be closed completely. Therefore some areas hardly visible between the forelegs could not be scanned anymore. The data from the six ground positions were linked together and georeferenced using 20 reflectors set up in the pit where the monument is situated. This data

is completed with the scan from the top of the Cheops pyramid. In a first processing step the data was triangulated using RiScan Pro on site. The produced mesh was textured with the images from the calibrated digital camera. For a first presentation the textured 3D model was animated one day after collecting the data (Fig. 6).

The data collected can be post processed in numerous ways. According to the objectives of the project the first product to be derived from the collected point cloud is a detailed topographic model of the Cheops Pyramid and the surrounding Giza plateau. A first DTM was produced by reducing the amount of data points by resampling the point cloud into cells of a regular 0.5 x 0.5 m grid using RiSCAN PRO and exporting the data as formatted ASCII data for input to Arc GISTM. For the determination of the height value of each cell the lowest Z-values were selected. Using the functionality

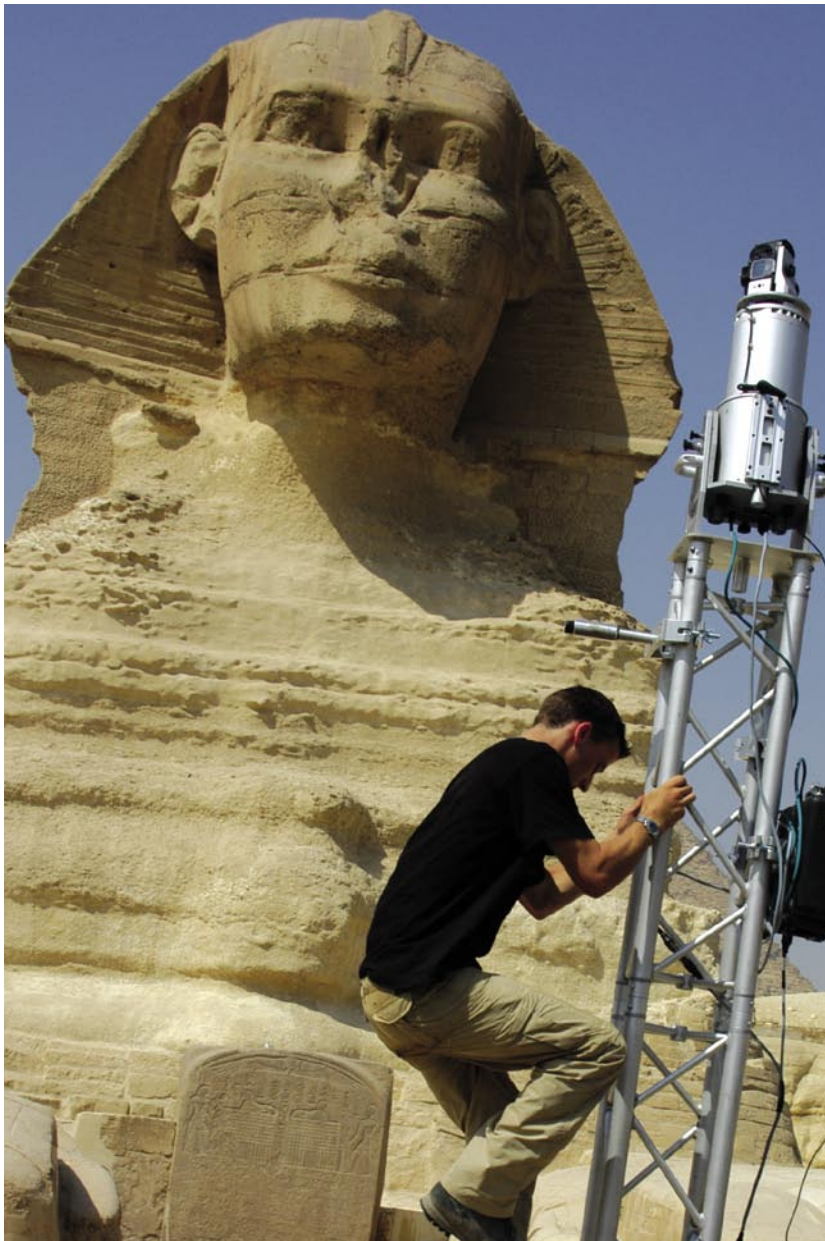


Fig. 6: Triangulated point cloud of a single scan textured with the acquired digital images.

of 3D-Analyst the point cloud was triangulated into the internal TIN-format of Arc GISTM. For future processing we plan to extract breaklines from the point cloud using the photographic record to be added in the triangulation process to enhance the DTM. From the triangulated model contour maps or cross sections can be derived. The detailed DTM of the Cheops Pyramid revealed four anomalous areas in the centre of each side. These anomalies are areas starting at the top and obviously proceed down to the bottom where a deficiency in stones became visible. By defining idealised planes for the four sides of the Great Pyramid using the point clouds made it easy to visualise this deficiency as to be seen in Figure 9. By animating the plane stepwise up

and down its normal vector showed that a channel-like structure must have been existing in the centre of the four sides, that later was enlarged from top to bottom by corrosion. The meaning of this anomaly is still under research but might be seen in relation to the construction technique of the pyramid itself or has derived from the interface of a substructure for control of the limestone casing which was stripped off long ago and once covered the inner masonry of the Great Pyramid. To triangulate a model it is necessary to reduce the number of measurements from the total number of points to a lower level by means of re-sampling the data with a defined resolution. For the first processing of the Cheops Pyramid the level of detail was set to 10 cm.

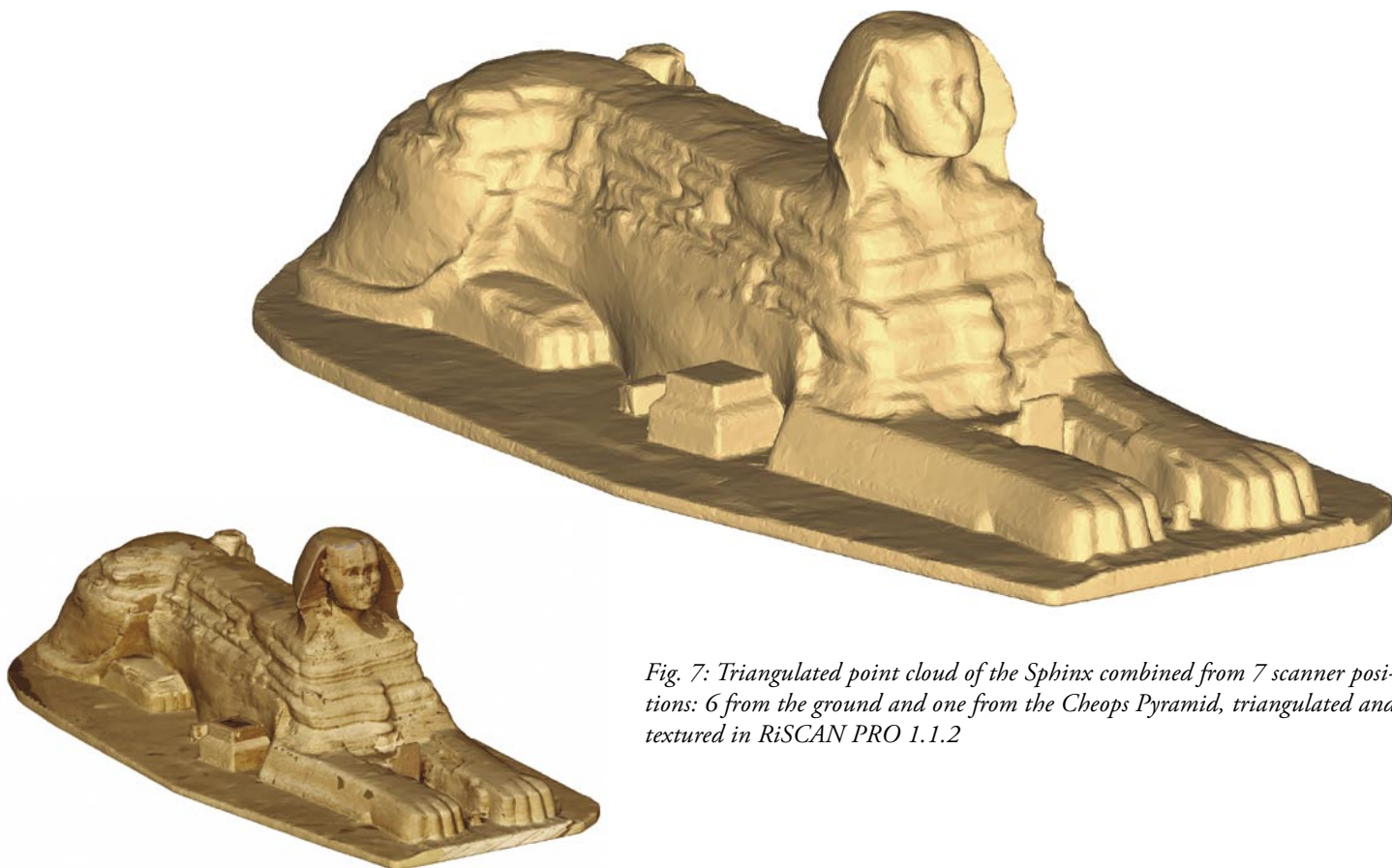


Fig. 7: Triangulated point cloud of the Sphinx combined from 7 scanner positions: 6 from the ground and one from the Cheops Pyramid, triangulated and textured in RiSCAN PRO 1.1.2

The model covers an area of nearly 100 m x 100 m, and consists of about 1.5 million points. The triangulation of this point-cloud generates coarsely 3 million triangles. The result is a “water-proof” 3D-Triangulation, which allows a straightforward calculation of volume and cross-sections. This procedure was as well applied for the production of a 3D model of the Sphinx (Fig. 7). The calibrated images taken during the scanning process have been used to texture this model.

An alternative approach to full exploitation of the 3D information of the data set is the monoplots procedure, as used by PHIDIAS (Effkemann 2003), a software plug-in designed for the CAD software MicroStation (Fig. 8). This evaluation system provides all the necessary photogrammetric tools for the combined evaluation of laser data and image data, while being able to display the image and the scan data as point clouds simultaneously, one on top of the other. The basis of a combined evaluation of both records is the perspective representation of the scan data. After

the definition of a drawing surface out of the scan data as plane or triangulated mesh, the object of interest can be digitized in the high resolution images (Fig. 8). The main geometrical information is extracted from the laser scan data, while for high-accuracy edge-detection and for digitizing high resolution details, which do not show up in the laser scandata, the image-information can be used. So far any single stone of the north face of the Cheops pyramid has been digitized (Fig. 8).

The data collected so far in this project form the basis for a detailed three-dimensional modelling of the monuments to show and to test the instrumentation as a major general-purpose tool for the documentation and monitoring of standing monuments. This has to be seen as a primary data base for the preservation of the monuments investigated by the method. The data collected is an important extension to the Giza Plateau Mapping Project, directed by Dr. Mark Lehner, and will be made available to the scientific community.

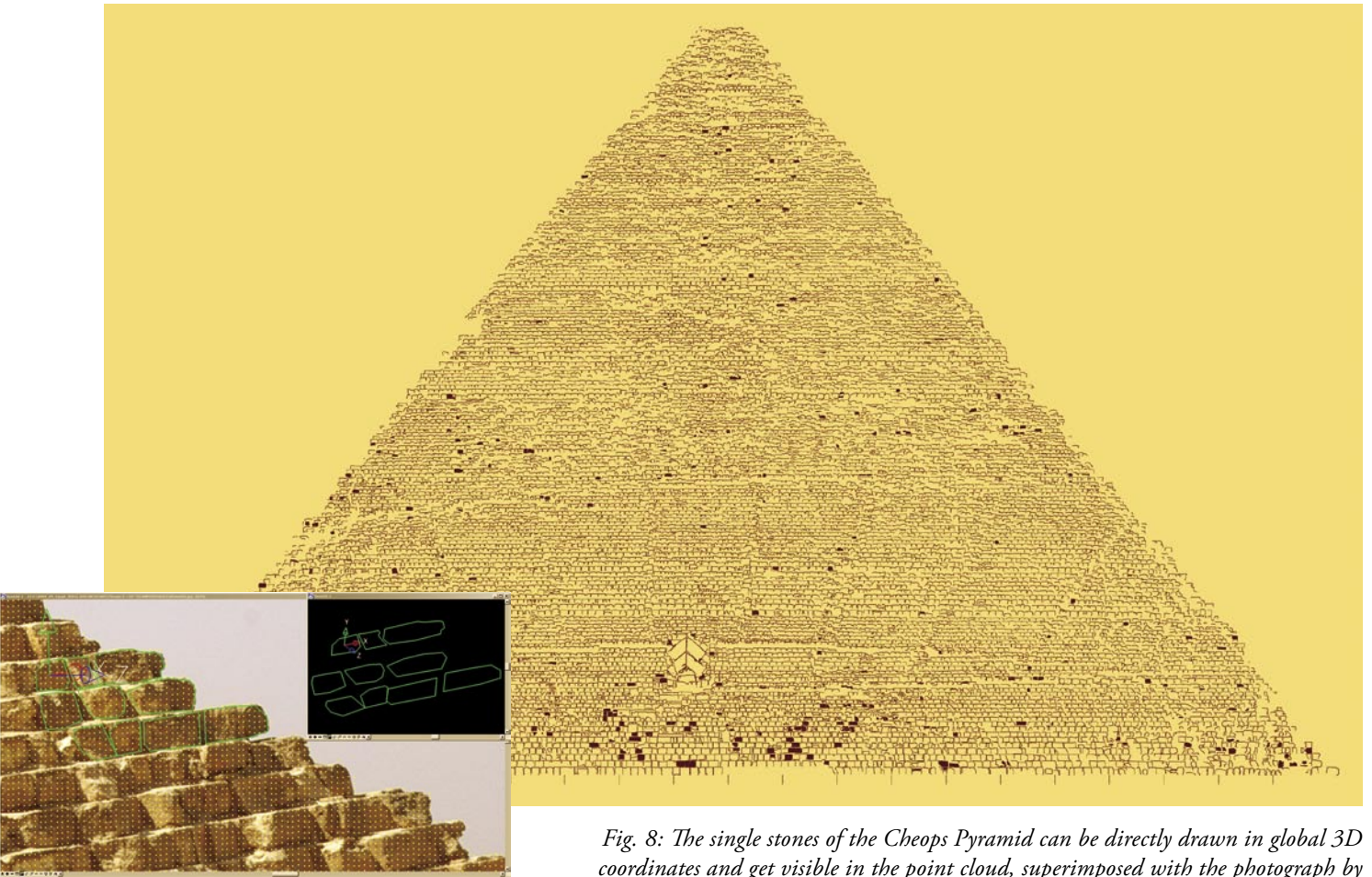


Fig. 8: The single stones of the Cheops Pyramid can be directly drawn in global 3D coordinates and get visible in the point cloud, superimposed with the photograph by the Microstation-application PHIDIAS. This procedure has been carried out so far for the north face of the Cheops pyramid.

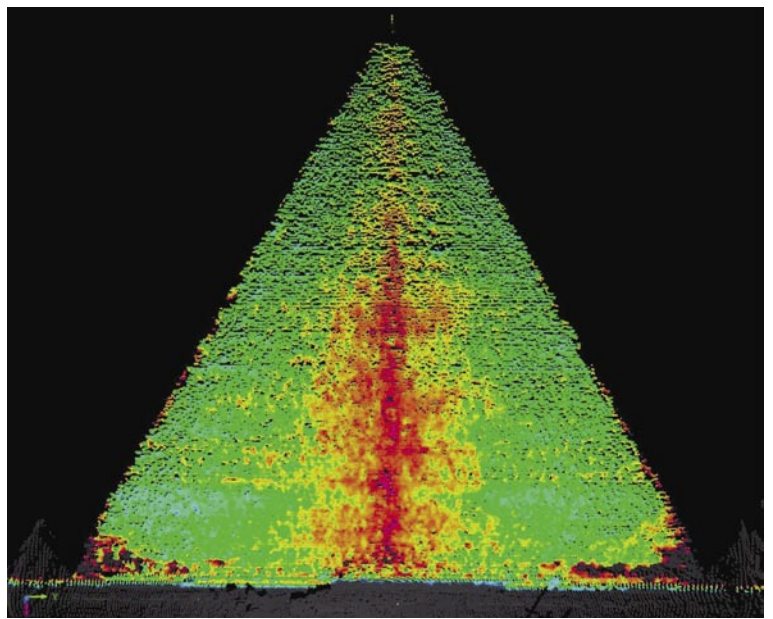


Fig. 9: Anomalous areas of the Cheops Pyramid visualized by color coded deviation from the ideal plane of the west face and as a horizontal projection showing anomalies within each side.

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