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New Data about the structure of the Pyramid of Cheops

Measuring a height of 139 meters (455 ft.), the largest of the three pyramids of Giza is one of the oldest edifices in the world. Yet, even after 4,500 years, this architectural masterpiece still leaves some questions unanswered. Christian Grosse, Professor for Non-destructive Testing at Technical University of Munich (TUM) has performed fascinating measurements at the Pyramid of Cheops in coordination with Cairo University. In this interview, he presents his experiences.

As part of your research, you were allowed to enter parts of the structure that are generally not accessible to the public. How did this fascinating project come into fruition?

Our measurements were part of the ScanPyramid Project (http://www.scanpyramids.org/index-en.html), in the course of which muon anomalies were detected, in other words, density deviations in the construction. These anomalies were made visible using detection devices. Changes in density within a structure can be an indicator for hidden structures. Regardless of that, our measurements are also meant to provide a better understanding of the construction history of the Great Pyramid of Giza as well as its internal composition. When we did our research trip, our goal was to use modern devices to find out how ancient Egyptians built pyramids. Which volumes do the building blocks have? What are the dimensions between the single block joints?

How did you prepare for this research project?

First, we performed numerical simulations based on all the data we had about the pyramid, so geometric and material data. Based on the results, we chose the best possible non-destructive testing procedures to be used in this instance. We figured out where to place sensors and how to set up suitable parameters for the measurements – such as frequencies and wavelengths – in order to be able to analyze the most interesting sections in an optimal yet non-destructive way.

After these preliminary considerations, we chose our measurement methods. In addition to three different radar methods, we also chose a special array-based ultrasound technology as well as electrical resistivity tomography. All these methods generate complementary datasets that can be compared to one another in the context of data fusion. This approach of using various measurement techniques in parallel based on simulations had never been tested before in the pyramid.

How can data obtained by various measurement methods be compared eventually?

In order to make the measurement profiles comparable, we had to calibrate our measurement points using geodetic datums. In order to do this, you need reliable models; after all, most of our measurement points were inside the pyramid, not outside. We received some highly valuable support from our Egyptian colleagues lead by Prof. Hany Helal from Cairo University. They had geodesic measurement teams who calibrated all these measurements points.

Furthermore, we had extensive literature including images from the inside of the pyramid at our disposal. We entered our measurement profiles in those existing schematics.

The one thing that turned out to be a bit difficult, however, was that we were not allowed to leave any markings on the structure, meaning the walls; usually that is something we do in construction. But we had tested techniques here in Germany for performing calibration without markings or direct contact on comparable objects using cross-line lasers. This approach worked quite well for us. This cross-line laser technology is used to project laser lines onto an object. This works notably well in dark environments and that is what we have inside a pyramid.

What were you examining in particular?

We performed measurements in the three main chambers of the pyramid: the Lower Chamber located in the bedrock underneath the pyramid, the Queen's Chamber built into the core masonry a bit higher up, and in the King's Chamber that is open to the public and contains King Cheops' sarcophagus in which the king is said to have been entombed. We also did measurements in the very long and only one-meter (3 ft.) high shaft system as well as in the entrance area of the pyramid.

Naturally, we focused our measurements on hidden sections in the pyramid, but also measured well-known parts in order to validate our measurements. It is essential to create confidence in the measurement technique you are using. The methods are complementary regarding the parameters of penetration depth and resolution. Every device offers a certain penetration depth and therefore the various devices allow us to "look into" the structure of existing rooms and shafts at varying depths. Our techniques "scan" the structure. As part of this scan, the devices are moved along a straight line while performing continuous measurements – this is comparable to seismic measurements.

How did you cope with the conditions inside the pyramid?
My Ph.D. students actually built the trolley we used for moving the radar equipment through the narrow shafts. In many cases, a project like this requires unconventional approaches. One measuring device broke down in Egypt, but luckily, my colleagues are able to repair these things on location. The research environment truly is not ideal for the kind of measuring devices we use. Everything is narrow and covered in desert dust. You need to use highly robust technology and still things break down from time to time – so you need a lot of talent for improvisation. My colleagues really invested a lot of effort into this project but we also received plenty of support from our Egyptian partners.

Are there first results from your research expedition that you could share?
We have recorded data in outstanding quality and I am positive that we can provide a range of new information. But first, the data needs to be evaluated in cooperation with out Egyptian colleagues.

In particular, our department cannot perform the interpretation of the data alone. For this, we need interdisciplinary expertise from the areas Archeology and Egyptology, as well as sensor technology and data analysis. Furthermore, we plan to make use of new evaluation technologies from the fields of data fusion and machine learning, in order to improve our ability to identify structural components. Therefore, it will take some time until we are ready to publish results – and perhaps we get another opportunity to perform further measurements.

More information:

This project was supported within the scope of an IGSSE project by TUM (https://www.igsse.gs.tum.de/research/project-teams/14th-cohort/1402-ndtofch/) as well as by DAAD in the scope of the "German-Egyptian Progress Partnership, Programme Line 2" under the title "Non-Destructive Techniques for the Preservation of Egyptian Cultural Heritage".

The Egyptian Ministry of Antiquities has approved and supported this research. As part of the research and training project, Egyptian students were instructed how to use new measuring methods and devices for the structural clarification of buildings and other constructions.

Prof. Grosse is holding the Chair of Non-destructive Testing at TUM. His professional focus is the further development and combination of various testing processes with the main purpose of making the inner structure of objects visible by applying non-destructive and in some cases contact-free methods. His main area of work is quality assurance in the fields of machine engineering (automotive and aeronautics) and construction (bridges, structural engineering, tunnels). Together with his team, he also cooperates closely with other scientific fields such as medicine, criminalistics, forensics and the preservation of historical buildings and monuments.

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Anhang Prof. Große before his lecture on non-destructive testing techniques at Cairo University.
http://idw-online.de/de/attachment85588

Pyramids of Giza
Prof. Christian Große / TUM

The Egyptian-German measuring team in the King's Chamber of the Pyramid of Khufu with the sarcophagus of Khufu.
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