The benefit of Terrestrial Laser Scanner for archaeology

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Abstract: In 2010, the MA 41 - Urban Survey of the City of Vienna decided to purchase a terrestrial laser scanner (TLS) in order to be able to measure and document deformations, volumes and archaeological excavation sites comprehensively.
The data acquisition of irregular surfaces or complex structures can be carried out in relatively short time. The scanned objects can be analysed subsequently without direct access to the surfaces (i.e. also after protection of the excavation site through covering with soil) because the decision which points to extract is taken in the post processing of the scan data and not in the field as with conventional surveying. It is possible to analyse (reconstruct) details which are discovered even after the data acquisition based on the provided images of the TLS system.
The advantages are, on the one hand, the fast and complete data acquisition of the excavation site during the field work and, on the other hand, the ability for comprehensive documentation due to the acquired images and pointclouds. The benefit of TLS will be discussed based on realised projects.

Keywords: terrestrial laser scanner, benefit, data interpretation, field of application

Introduction

The tasks of the MA41, the Department for urban surveying can be divided into 3 main areas:

Engineering geodesy

This includes the following tasks: Production of any kind of project-orientated plans, deformation control, Tunnel surveys, Street projects surveys, Rendering of expert opinions

Land surveying for cadaster

These surveys always deal with measurements of boundaries in general.

Acquisition of basic data and mapping

This includes, for example, photogrammetric analysis

For more than 10 years, laser scanners are used for surveying tasks. In recent years, the use of the devices has become increasingly easier, so that the field of application have also become more and more. 3 years ago the Department for urban surveying decided on the purchase of such a device. The choice fell on the Faro Focus 3D, which provided the best price-performance ratio in comparison with similar products from other companies.

Measuring principle

The basic principle of laser scanning is the reflectorless detection of object surfaces with a laser beam. The laser scanner Focus 3D uses the comparative phase shift method, That means that the distance to the

measuring point is determined from the phase difference between the transmitted and the reflected signal. The maximum measurement range is up to 120 meter, dependent on the reflectivity of the surface. The automatic rotation of the instrument and the rotating mirror effect a continuous vertical and horizontal deflection of the laser beam and therefore a constant angular increment between the measuring points is fixed. The result of this polar point determination is a 3-dimensional point cloud, based on the positions of each scan. The point density and the measurement speed can be adjusted. The FARO Focus 3D can be operated simply via an integrated touchscreen display. In addition its minimal size and weight and the integrated colour camera makes the Focus 3D easy to use. The measurement speed reaches up to 1 million points per second but typical settings are 100 000 points per second and a point spacing of 5mm at 10m distance. With these settings a complete scan consists of more than 30 million points.
With the help of geometric shapes that are visible in two or more scans, the scans are brought in the correct position to each other, the so-called registration of the scans. By the use of control points the point cloud can be transformed into a superior coordinate system. Generally, we perform all measurements in the Austrian National coordinate system. We use the software Faro Scene mainly for the scan registration and Kubit point sense for further processing of the point cloud.

Applications

The surveys carried out so far can be divided into the following main applications:

As-built-documentation

Especially in the area of preservation and archeology a comprehensive three-dimensional representation of the object is desired. The point cloud represents the object´s exact size, shape, dimensions and position and in many cases there is no need for further processing.

Project-oriented plans

Besides the classic location plan Architects often need further illustrations as a basis for planning, such as sections, profiles and views. To fulfill these tasks, the laser scanner is ideal, because of the comprehensive data recording a significant improvement in quality can be achieved.

Deformation measurements

Depending on the accuracy requirements and local conditions, in some cases it may be an advantage to evaluate any deformations based on 3D point clouds.

Determination of extent

This means the determination of volume differences between measurements at different dates.

Examples for As-built-documentation

The Kilns Hernals

This is certainly an application where laser scanning has a very large benefit compared to other methods. A realistic three-dimensional object representation, to which you can refer at any time, is a huge value especially for archaeologists. But we already used the laser scanner in other projects as an additional measuring device to ensure that the current state is documented. With the Urban archeology of Vienna two projects had been carried out so far:

The first project was the scanning of two Roman kilns, that means ovens for hardening bricks. Last winter they were uncovered in the course of construction work. Meanwhile on this place a new house was built and therefore the documentation of this excavation site was even more important. From the perspective of surveying, no major difficulties occurred, it was only important to take care to avoid shadowing. In this case, this object was covered with 5 scan positions. Due to the small size of the object the point cloud is very dense and would probably easily allow to produce stone-by-stone drawings.
At the second Kiln, which was about 10m next to the first, in addition there were some stone vaults. As seen on the screenshot of the point cloud, the demand for a complete coverage of the surface cannot be complied. The distances between the pillars are so small that it is impossible in this case to detect the complete surface. [1]

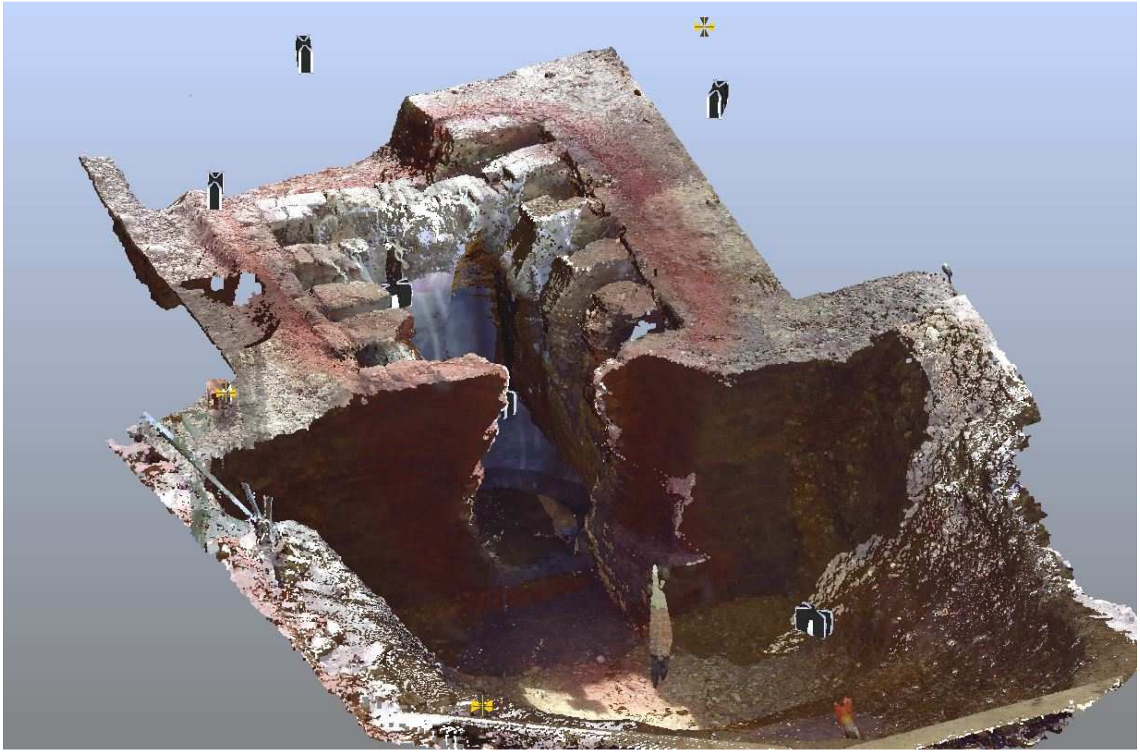

Fig.1 – Brick kiln in Wien-Hernals (Copyright: Stadt Wien)

Tunnel Kahlenberg

The other project was the recording of a short part of a tunnel in Wien Döbling. This survey was quite unusual because the scanned excavation had been carried out by unauthorized persons. These unknown people uncovered a 200-year old tunnel on a length of 15m, which had been buried at least for decades and was also partially filled with rubble. Again, we scanned the tunnel mainly for documentation purposes. Based

[1] M. Mosser (Fwien 16/2013): Zwei römische Ziegelöfen in Wien 17, Steinergasse 16/Geblergasse 47, 144-161

on this screenshot of the pointcloud you can see that scanning works in the dark. The result looks like a black and white picture, but in reality the reflectivity of the surface determines the gray value.

Fig.2 – Tunnel Kahlenberg (Copyright: Stadt Wien)

The deliverable output was – apart from the registered pointcloud – a location plan, a longitudinal section and a cross section. This type of analysis is frequently used by us, id est with the help of sections derived from the point cloud location plans are generated. [2]

Project-oriented plans

The next group are project-oriented plans. As an example of a typical object measurement the survey of a church in Wien-Inzersdorf was selected. Although it is a rather small church, 16 scans were needed for data acquisition inside and outside. The screenshot shows the point cloud of the outer region. Again, sections were generated from the point cloud in order to create various drawings. In this case it is the site plan, a longitudinal section and a cross section. By the way, the roofs are completed with airborne laser scan data, which are available for the whole area of Vienna.

In addition, we had to create views from this church. This can be easily accomplished using the program feature for the production of ortho-images. On the picture you can see some problems in the creation of orthophotos: At complex surface structures there are almost always areas not captured by the laser beam.

[2] H. Krause (Fwien 16/2013): Wien 19, Kahlenberg, Flur Wildgrube, Fundchronik, 208-213

At colored orthophotos different lighting conditions cause different colors. At last we decided to deliver line drawings, as it is seen on the right side.

Fig. 3 – Church in Wien-Inzersdorf (Copyright: Stadt Wien)

In this context I would like to point out that there is a possibility to edit photos with an external photo editing program or to match images taken by an external camera to the point cloud. First attempts to use this feature showed us that these methods are very time-consuming.

At the workshop of the CHNT2011 we scanned the Temple of Theseus, which is situated in the Viennese Volksgarten. To achieve a coverage as complete as possible the object was scanned from 10 scan-positions. The oblique view of the colored point cloud shows the problem of the data acquisition of facades and roofs from the ground: In the upper regions parts of the building are shadowed by overhanging parts of the façade. The flat roof is not visible from below, and therefore it is completely missing in the scan point cloud. To remedy this, airborne laser scan data can be used or the the scanner is brought in an elevated position by means of lifting platforms or even multicopter.

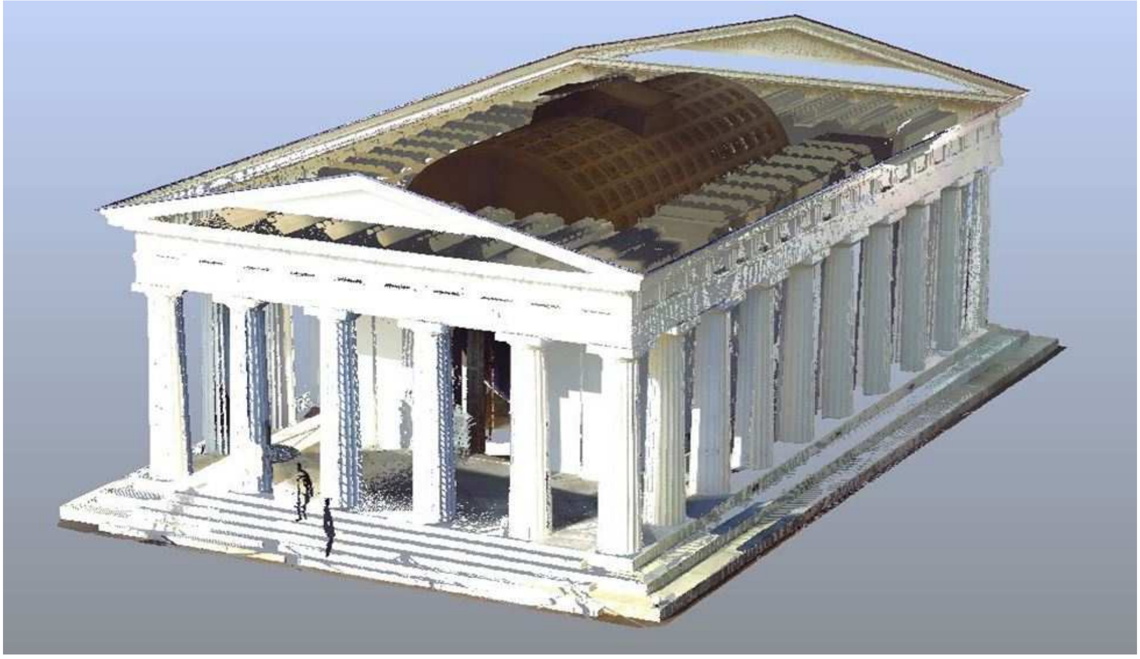

Fig.4 – Colorized pointcloud of Temple of Theseus (Copyright: Stadt Wien)

Our biggest project so far was the survey of the aqueduct in Baden near Vienna, which is 700m long and consists of 44 arches. We registered 1.5 billion scan points, of which at least 400 million points represent the building. There were also difficulties in the registration of the scans, because the calculation algorithm does not work very well when the object is elongated and the number of scans is large.

Deformation measurement

The next example shows a deformation measurement carried out with the laser scanner. Last year the Department of Waste Management stacked waste bales to 2 pyramids, each consisted of 385 one-ton bales of pressed household waste wrapped with plastic film. The aim is to determine changes of position and height of these pyramids over a period of 3 years. Due to the rounded edges of the plastic surface and because of safety reasons we had to keep off the stack and a measurement by laser scanner seemed the most appropriate solution. In fact, the vertical and horizontal movements of the stack or rather of the bales were fully documented. After 1 year, for example, the height of the Pyramids had been reduced by one meter.

Fig.5 – Pile of waste pales in construction (Copyright: Stadt Wien)

Determination of extent

The final type of application is the determination of the extent that is the determination of volume differences between measurements at different dates. Specifically, we got a request for measuring a tunnel of the Viennese water pipe. Drinking water is brought from the Alps to Vienna by two 150km long water transfer tunnels. In one of these tunnels, a layer of concrete was applied on the original rock surface. On these screenshots of the point clouds you can see the original situation and after work had been finished.

Fig.6 – Water transfer tunnel (Copyright: Stadt Wien)

Therefore, answers to the following questions had to be found: How much concrete was used and where the required concrete thickness fell below a limit. We scanned the 250m long tunnel section twice, each with 60 scan positions. Because a special and expensive software is required for this analysis, we awarded the contract to a company specialized in tunnel surveying. The result is colored plots of the flattened tunnel where the colors represent the concrete thickness. The red and yellow color represents those areas where the required concrete thickness has not been reached. Profiles were also supplied at a distance of 2 meters, which very well illustrate the concrete thickness.

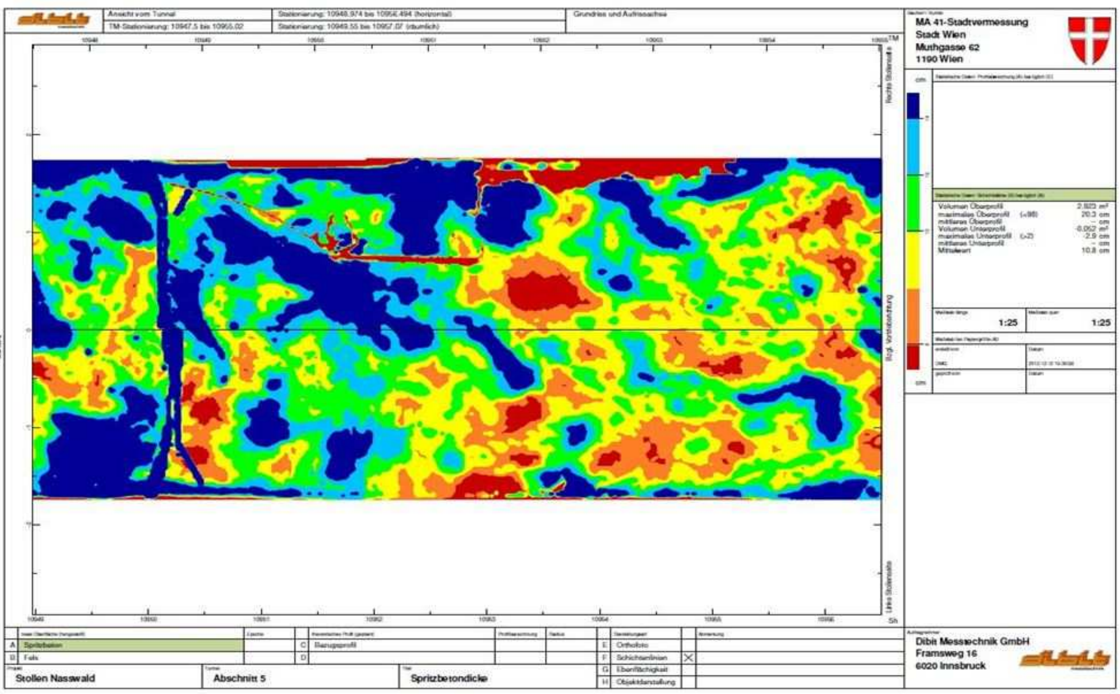

Fig.7 – Colored plot of flattened tunnel (Copyright: Stadt Wien)

Meanwhile measurements of water transfer tunnels have become a main application of our laser scanner. We got some orders for scanning tunnels, which sometimes turned out quite difficult. There is limited light and cramped working space underground, sometimes you stand in cold water or it is very dirty.

Final remark

As final remark it should be noted that due to the use of terrestrial laser scanner savings in time are observed in the field work. The calculations and analysis of the point cloud, however, take a lot of time, sometimes even more than with conventional methods. But there is no doubt that for many products an improvement of quality can be achieved.The terrestrial laser scanner does not replace the current measuring means, rather, it is a useful addition, which opens new perspectives for the survey in some areas.

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