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ASSESSMENT OF LASER SCANNING TECHNOLOGY FOR CHANGE DETECTION IN BUILDINGS

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ABSTRACT

There is an overall demand for real 3D data of urban environment, e.g. in the context of town planning, documentation of cultural heritage or local administration. A new, effective tool which may support the requirements is offered by Laserscan Technology. It may measure directly the height of objects from an airborne platform to the order of ± 10 cm.
The main purpose of this paper is to show the feasibility of Laser Scanning for detecting changes in urban environment. The method presented uses a 3D CAD model as a geometric basis. This model is compared to a digital height model (DHM) derived from Laser Scanning in order to evaluate geometric changes at the buildings. Results are given for the University Campus in Karlsruhe (Germany).

KURZFASSUNG

Die Nachfrage nach dreidimensionalen Daten städtischer Gebiete steigt stetig, z.B. im Zusammenhang mit moderner Städteplanung, der Dokumentation von Kulturerbe oder den Zwecken der kommunalen Verwaltung. Ein neues, sehr effektives Verfahren zur Gewinnung dieser Daten ist die sogenannte Laserscanner-Technologie. Hierbei werden die Höhen verschiedener Objekte mit Hilfe flugzeuggetragener Sensoren direkt gemessen, wobei die Genauigkeit in der Größenordnung von ± 10 cm liegt.
In diesem Artikel soll gezeigt werden, daß Laserscanning zur Änderungsdetektion bebauter Gebiete eingesetzt werden kann. Der vorgestellte Ansatz benutzt ein dreidimensionales CAD-Modell als geometrische Basis. Dieses Modell wird mit einem aus der Laserscanner-Befliegung gewonnenen digitalen Höhenmodell (DHM) verglichen, und es werden geometrische Änderungen an der Bausubstanz festgestellt. Als Untersuchungsgebiet wurde der Campus der Universität Karlsruhe gewählt.

1. INTRODUCTION

During this century the rate of changes in urban environment has increased for the whole world. These changes have been caused by different events; to give an example there were damages in Kosovo after war, or in Oklahoma after a hurricane last May. Despite these catastrophic effects there are changes caused by the latest building activities in the towns. In the past, the town development happened often without respect to the needs of the people. As a result, the housing in a city like São Paulo (Brazil), is very often of low quality, e.g there are a lot of high buildings facing each other and therefore preventing the appartments from having enough light or free views. The climate in such cities is often critical, because there are not enough possibilities for the necessary air circulation, leading in addition to negative effects e.g. a concentration of air polluting substances. Because of that, the responsible planners are presently testing new ways of city development, aiming to support a great increase of people in the cities, especially in megacities e.g. São Paulo, as well as to give the people in towns better conditions for living. But for that, the planners need to documentate the current state, analyze the situation and search for ways to improve critical structures. They also need to simulate the influences of new buildings to decide on positive or negative effects.
Especially in fast developing towns the officials often concentrate on these tasks and are not capable to care in addition to older structures which should be conserved as part of the cultural heritage like the colonial style houses in some brazilian towns.

Nowadays there are promising techniques that can support the responsible persons to administrate the existing parts of a town as well as to planning the town development. For the purpose of documentating existing situations the airborne digital photogrammetry is one of the fastest and most economic means. In this field a new technique arised in the last decade, the so called *laserscanning technology*. It is a method that can be used to acquire three dimensional data, even of big townswithin a short time.

The measurement done with laserscanning leads very fast to a digital elevation model (DEM) of the regarded areas. This is a good basis for many applications, e.g. for studies about flow of air or wave propagation in a town. Laserscanning can be used to detect and document changes, e.g. the propagation of slums can be documented or damages after catastrophic events like strong earthquakes. This is a big advantage, especially when considering that in these cases it is often dangerous and sometimes even unpossible, to make topographic measurements directly in the areas.

2. LASERSCANNER TECHNOLOGY

Nowadays, the main purpose of using Laserscanner systems is to acquire very fast the necessary height data for producing digital elevation models (DEM) of larger areas. The first attempts made with airborne laserscanner took place in the early nineties [Lindenberger, 1993]. At this time they were used to measure terrain profiles. During the last few years the systems have been improved and new technologies developed, so that these are now capable of measuring dense terrain models. There are several Laserscanner systems at operational status, e.g. the one used by TopoScan or TopoSys, which are both german companies that provide laserscanner flights. At the University of Karlsruhe the TopoSys system is used. This is described in the following sections.

2.1 Principle

Most systems are *pulsed* Laserscanner systems. These systems emit a laser pulse to the earth surface where it is reflected. The reflected signal is registered and the runtime is used to compute the distance between the airborne system and the measured point.

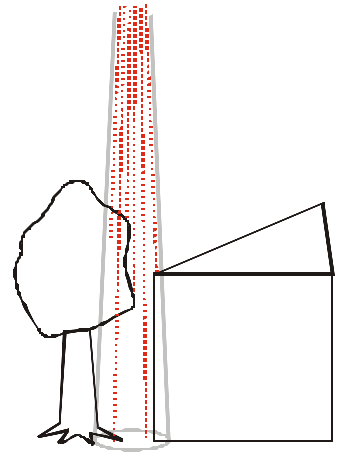

Figure 2: Reflection of one laser ray at different objects; outer borders indicated by light grey lines; points show where the signal is reflected

There are two different kinds of measurements: *first* and *last* pulse measurement. This means that either the first or last reflected part of the reflected signal is registered. This difference is made because the laser beam is widen by a certain amount until it reaches the ground. Therefore one pulse can be reflected at several points. Assuming a typical flight height of 1000 m, the signal covers on the ground an area of some square decimeters. Within this region, the laser beam can be reflected at different heights, e.g. different parts of a tree. In most cases the signal even passes through deciduous trees and therefore reaches the earth's surface or man-made objects covered by the vegetation (see figure 2). Because of this, the last pulse measurement is suitable for the determination of digital terrain models (see figure 3) whereas first pulse can be used to measure the surfaces of all included objects, e.g. tree canopies (see figure 1).

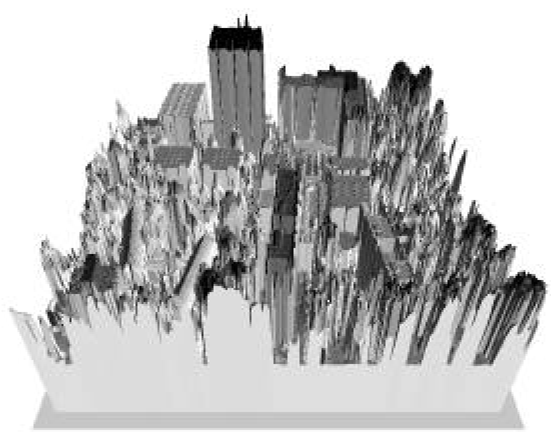

Figure 1: 3D visualization of laserscanner derived DEM; first pulse measurement was used

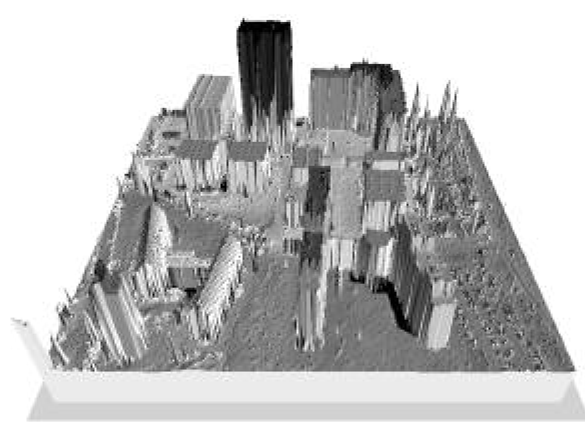

Figure 3: Same as figure 1, but last pulse measurement

To determine the three-dimensional coordinates of the measured points, the sensor position at the time of measuring a point distance must be known. This can be achieved e.g. by integrating dGPS (differential use of Global Positioning System) and INS (Inertial Navigation System) sensors in the airplane. dGPS can provide the position referred to a global cartesian system within good accuracies (± 10 cm) but with a low frequency (up to 10 Hz) compared to the possible laserscanning frequency (up to 300 Hz), whereas INS delivers the change of position with very high frequencies (up to 100 Hz) but the accuracy decreases very fast with time [Kilian et. al., 1996]. In combination these systems are suitable and deliver the position within good accuracy at high frequency. With this information the measured points can be coordinated following the well known polar measurement principle.

Very often the data has to be referred to a national or local coordinate system, different from the GPS systems used for georeferencing the measurements. Therefore a coordinate transformation has to follow. To compute in the end a DEM, the measurements are resampled to a regular grid. Therefore interpolation techniques are used. An overview of suitable attempts can be found in [Mélykúti, 1999].

2.2 The TopoSys Laserscanner system

In Table 1 the performance parameters of the TopoSys system are given. Generally the system can be divided into two *segments*: The *flight* and the *ground* segment. Here the flight segment comprises the airborne sensors, this means the equipment installed in an airplane. These are: Laserscanner, GPS antennas, INS tools and sensors for visual control purposes (e.g. videocamera).

Ground segment means the GPS reference stations, needed for differential GPS, and all the computing facilities for analyzing the measured data (see figure 4).

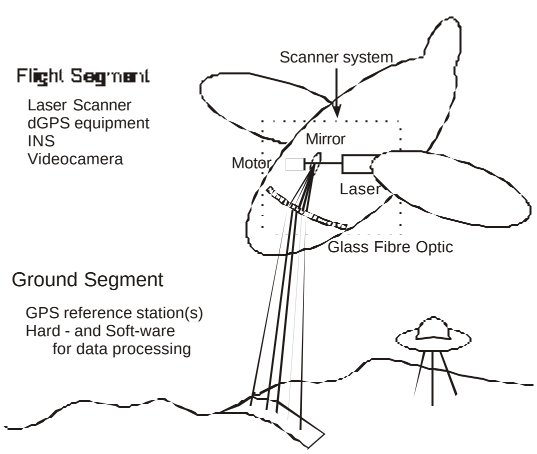

Figure 4: Laserscanner system used by TopoSys company

The scanning component of the system is based on a line scanner principle. It is realized by deflecting the laser ray with the help of a rotating mirror into several beams. They pass through a glass fibre optic which defines a line of 127 scanning points. With the system being installed normal to the flying direction, this results in a strip-wise data acquisition comparable to other photogrammetric measurements.

Sensor type	Pulse modulated Laser Radar
Range	< 1000 m
Scanning principle	Fibre optic line scanner
Transmitter	Solid state at 1.5 m
Measurement principle	Run-time measurement
Scan frequency	300 Hz (adjustable)
Field of view	+/- 7 °
Number of pixels per scan	127
Swath width (1000 m flight height)	250 m
Accuracy of a single distance measurement	< 0.3 m
Accuracies of point coordinates x, y, z	0.3, 0.3, 0.1 m
Resolution of a distance measurement	< 0.1 m
Laser classification	class 1 by EN 60825 (eye-safe)

Table 1: Performance parameters of the TopoSys system [Lohr & Eibert, 1995]

2.3 Advantages and Disadvantages

Laserscanning systems have some features that make them superior to other measurement techniques used to acquire DEMs.

Above all, they provide a fast measurement of dense grids of surface points with a good accuracy (see table 1). Because it is an active system, the measurement can take place independent of lighting conditions, e.g. even during night times. Some problems of optical airborne surveying, for example shadowed regions, do not influence the results here.

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The greatest problems of this technique are two physical effects: *absorption* and *total reflection* [Lindenberger 1993]. They occur as a kind of characteristic of some materials, e.g. water. Objects composed by these materials can not be measured, there are gaps in the dataset. This is because either the objects reflect only few parts of the signal, e.g. when they absorb it partially, in this case the reflected signal not can be separated from the appearing noise effects, or they are reflected away from the scanner system. Therefore some special weather conditions are also critical, e.g. when there is fog, great parts of the signal are absorbed.

The data is acquired directly in digital form. This makes it suitable for automation, and therefore fast, analyses. In addition, there are a comparably few number of pre-processing steps to get a DEM (see section 2.1).

Another great feature is that one can decide through the measurement method (first or last pulse) what objects should be surveyed. As mentioned before, either the terrain or the top points of all objects can be registered. This is why this technique can even be used for measuring terrain points in wooded areas. If the forest consists mostly of deciduous trees, there will be a great amount of points where the laser signal could reach the ground when using last pulse measurement.

But also the first pulse measurement technique provides solutions for special tasks which are difficult to solve with other techniques. For example it is possible to document high voltage transmission lines by this measurement method (see figure 5).

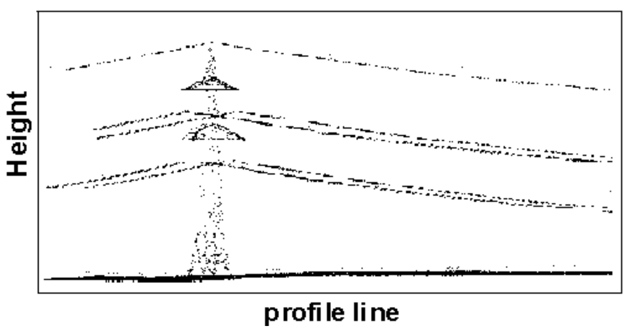

Figure 5: Profile of high voltage power transmission line acquired by laserscanning [Lohr & Schaller, 1999]

3. REFERENCE MODEL

There is need for a accurate description of a urban environment in order to be able to detect changes in buildings. A dataset should be established that contains at least a geometric description of the scene. One possibility is to represent the situation as a so called *CAD model*.

The Computer Aided Design (CAD) is a „technique“ in which man and computer are working together as one unit, aiming to harnessing the special advantages and skills of each other. Thus the result of this combination is amazing. This can be recognized often when using synergetic approaches.

In the following the special characteristic of both are compared:

Characteristics	Man	Computer
Reasoning Method and logic	Intuitive for experiences, imagination and judgement	Systematic
Inteligence Level	Learn easily, but it is sequential	Low capacity of learning
Method of input information	Great quality of entrance in one time, through listen and vision.	Sequential entrance.
Method of output information	Low sequential output through speak or manual actions.	Fast sequential output for equivalent manual actions.
Organization of the information	Informal and intuitive.	Formal and detail.
Endeavor involved in organization of the information	Not much	Too much
Hoard up of detailed information	Low capacity, dependent on the time.	Great capacity, independent of the time.
Tolerance for simple and repetitive works	Not much	Excellent
Capacity to get significatives informations	Good	Bad
Errors productions	Frequently	Rarely
Tolerance of wrong information	Good intuitive corrections for the errors	High intolerance
Method of errors detections	Intuitive	Systematic
Method for information edit	Easy and instantaneous	Difficult and complicated
Capacity for analysis	Good intuitive analysis, but low capacity for numeral analysis	None intuitive analyse, good capacity for numerical analysis.

Table 2: Characteristics of man and computer systems [Besant, 1985]

The CAD Systems were created to develop projects and technical drawing and to make this work easier and more effective with the help of computers instead of drawing-boards which were used before. Another advantage of these systems is that, for every application specific tools adopted to the projects can be used, i.e. civil eng., electrical eng., mechanical eng., architecture, cartography and others can have their own specific means. These systems are really useful in the field of mapping, because they simplify and speed up the work involved in generating a map.

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Today CAD systems have become popular such that these components can often be found as a tool in more complex programming systems, e.g. in software for digital photogrammetric workstations.

For the application of using CAD models as reference basis for change detection with the help of laserscanner systems some steps were necessary. The dataset used to establish the CAD models was a photogrammetric flight done in the summer of 1990. The used camera was a DSRGM and the flight was done in a height of approximately 120 m above ground. The scale of the photos was 1 : 5000.

At first the shape of the building roofs had to be measured. For this step the analytical stereo plotter DSR-11 (Leica company) was used. The measurements had an accuracy of about ± 0.12 m. As a result the building roofs as wireframe models were obtained. But for the further steps surfaces in the model had to be defined by manually creation. This means that for each surface the edge points were digitized.

In a second step the ground heights of the buildings were estimated from the laserscanner dataset. They are not necessary for the change detection process but they are used for a more realistic visualization.

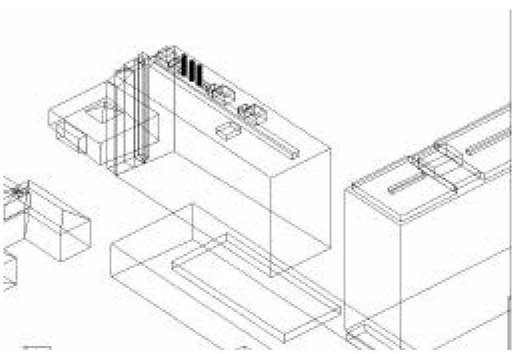

Figure 6: Example for a CAD model

4. CHANGE DETECTION IN URBAN ENVIRONMENTS

To be able to detect changes in a scene, one has to provide the scenery at two different epochs of time. At the IPF there is the project "Image Analyses in Geosciences and Civil Engineering", which is part of the collaborative research center 461: "Strong earthquakes: A Challenge for Geoscientists and Civil Engineers", located at the University of Karlsruhe (Germany) [SFB 461]. In this project the status before and after the occurence of a strong earthquake are compared. The aim of this is to provide basic information for management of hazards that has to decide about the priorities in the rescue measures and the appropriate tools to be used for this.

In the following the comparison of datasets of the Karlsruhe university campus is described, where they all show the same situation. This is to evaluate the feasibility of using the datasets in change detection.

4.1 Study area

The study area is the campus of Karlsruhe university. Karlsruhe is a town located in the south-west of Germany, close to the border with France. The campus is one of the oldest in Germany with some buildings from the end of the 18th century. On the other hand, most of the buildings were built in the 1970s. This means there is a great diversity in the buildings. Because of this the area is suitable for developing measures of change detection that should work with different kinds of buildings.

Another great advantage is, that for this area there is a lot of different kind of geospatial data. For example there was a topographic survey of the whole campus in the middle and a photogrammetric flight in the beginning of this decade. Further, there were two laserscanner flights (first and last pulse) in the last two years. Thus, an up-to-date database of this area can be developed. A three dimensional campus information system (CISKA) was developed at the IPF in the recent past ([Landes, 1998] and [Landes, 1999]). CISKA presents a more simplified version of the buildings at the campus. It is therefore possible to examine the advantage of using more detailed house models for visualization purposes.

4.2 Change detection

For this step, the previously described CAD-model is used as well as two laserscanner datasets (first and last pulse). The first pulse laserscanner flight was done in summer 1997, the last pulse flight in January 1998. As results, DEM of the campus were delivered in form of regular grids (1 m in both directions), wherein each point contains a height value that was created by interpolating the nearest laserscanner measurements.

In figure 7 and figure 8 examples for the overlay of the laserscanner and CAD data, visualized as VRML-models, can be seen.

It has to be kept in mind that the laserscanner measurement is an airborne technique and therefore one will only be able to detect changes at building roofs and other from aerial visible building parts. The statements which follow refer to such elements.

The datasets all show the same situation, this means no changes in the buildings occured between the data captures. As can be seen in the examples, even in this situation the datasets do not fit exactly. In figure 8 especially at the corners of the buildings differences can be found. In all cases the laserscanner data is deeper than the respective CAD point. The reason for this is the last pulse data capture (see also section 2.1.), this means in these regions the laser ray does not only hit the roofs but also points on the ground. In comparison to this, the first pulse measurement seems to fit better to the CAD model as can be seen in figure 7.

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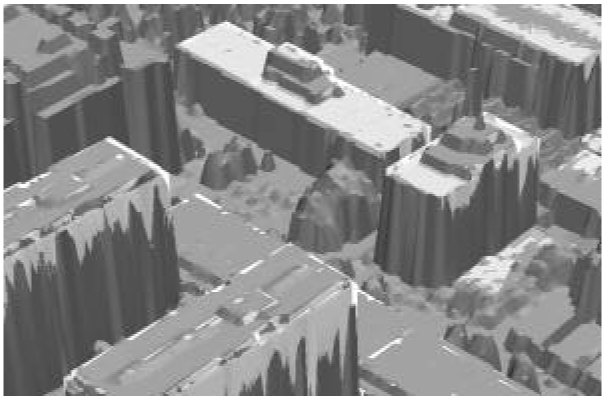

Figure 7: CAD- (bright) and first pulse laserscanner- (dark) data

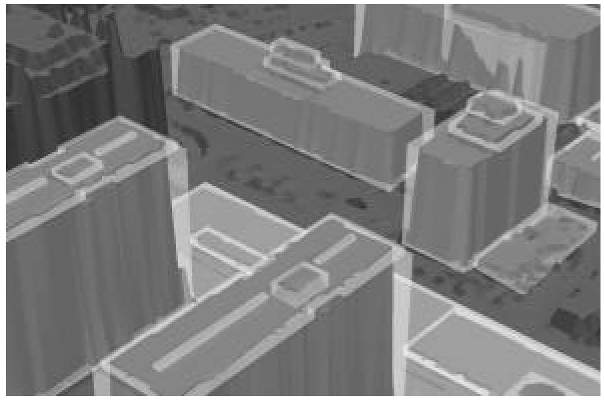

Figure 8: CAD- (bright) and last pulse laserscanner- (dark) data

Looking at this in more detail, one recognizes that there are other problems. In the center of the figures on the right hand side, there is a high building with a low building part in front of it. With the use of first pulse measurement this building part is covered partially by trees, appearing as little hill-shaped objects. In contrast to this, at the same place in the last pulse dataset the roof of the building part was determined. In this case the last pulse measurement method leads to more information about the building. Another obvious difference is the little peak on the top of the building in first pulse dataset. Here an antenna was hit by the laser signal. This shows that this measurement is more sensitive for small objects; but they are often not modeled in CAD files because of many reasons. For example they could be smaller than the resolution of the used surveying technique, they are not important for the purpose for that the CAD file was created or they are only temporary installations.

Both measurement techniques can be used for change detection, but in each case the special characteristic of the used dataset should be kept in mind. For most applications it seems to be more favourable to use the last pulse laserscanning, because it delievers more reliable building data and more generalized one.

To analyze the occuring changes, a pointwise direct comparison is used. For this, the CAD model is overlayed with the same grid as the laserscanner data. At each point the height is estimated as the height of the plane, the point is member of, at this position. The planes were previously manually determined as described in chapter 3.

When comparing CAD model and last pulse laserscanner data, the differences at each point are in the order of not more than some few decimeters, except of the border regions. But there are regions where these differences are larger.

This is due to problems caused by building parts which absorb or reflect the signal away from the sensor, as described in section 2.1. There are real gaps in the dataset (see figure 9). Large glass covered parts are problematic, too. In figure 10 a little glas pyramide is placed on the roof of a building. Here the laser passed the glass front and was reflected somewhere inside the building. These kind of problems are not only characteristic for last pulse, but for laserscanning in general.

Nevertheless these errors can be found and eliminated when using additional information, e.g. the knowledge about the used materials for a building part. But it also means that at such places a possibly existing change can not be detected.

Because of the differences in the range of decimeters between laserscanner and CAD data, this technique is not suitable for detecting very small differences in building structures, e.g. the lack of a small chimney or decorative elements at roofs. It is also not the appropriate mean for detecting critical cracks in buildings, which are often of great importance for the conservation of old houses.

The application of this technique is more likely in the detection of serious, and therefore often large, changes in the buildings. For example it is a fast means of detecting damages after catastrophic events like strong earthquakes or landslides.

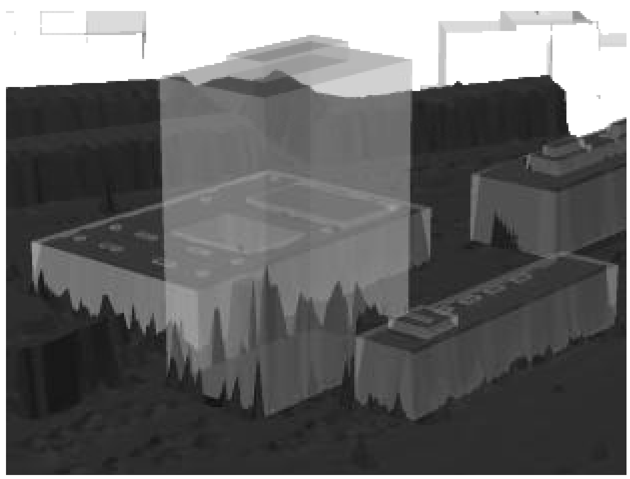

Figure 9: Lack in the laserscanner dataset, whole building is missing

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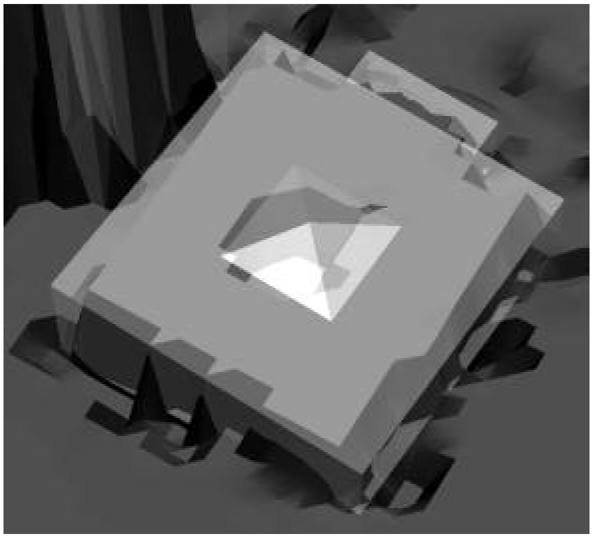

Figure 10: Glass pyramide on building, not measured by laserscanning

Another interesting application is to use laserscanning for the monitoring of the growth of slums. These areas can not easily be accessed for surveying missions because of safety risks. And it would be quite expensive to use topographic techniques in this case. On the first hand these areas are too big and on the other hand they are changing too fast. With the help of laserscanning the changes in size and even in volume can be determined by simply subtracting datasets acquired at different points of time very economically. When regarding a city like Rio de Janeiro where more than hundred slums around the city can be found, the importance of a tool to document their development becomes obvious.

5. CONCLUSION

Laserscanning measurements are suitable for the height data capture of large areas. This data can be used to establish DEMs very fast by reduced work. There are lots of applications where they can be used. Depending on the kind of measurement, first or last pulse, this can be the monitoring of power transmission lines, the acquisition of digital terrain models for planning purposes or the documentation of current states. Beyond that, laserscanning can be used for detecting changes in urban environment. It depends on the application in which resolution and therefore with how much efforts the change detection has to take place. In some cases, like monitoring the development of slums, a direct comparison of laserderived DEMs acquired at different points of time is sufficient. When the resolution should be higher, e.g. when detecting changes in houses after an earthquake, another kind of reference model should be established, for example a CAD model from analyzing image stereo pairs. This is because the laserscanner measurement is more inaccurate at certain points, e.g. the borders of buildings, and a detailed comparison could lead to a incorrect interpretation. It is also advantageous to use additional knowledge in these cases, for example knowledge about the building materials and their behaviour when measured with laserscanner (absorption, permeability) to avoid wrong conclusions.

Sometimes the usage of terrestrial surveying techniques for change detection is more adequate, e.g. when searching for cracks in walls or general changes at facades (see [Toz & Külür, 1999]), but when large areas and changes not smaller than the resolution of the DEM (1 m in each horizontal component) are regarded, laserscanning is one of the most superior means.

6. ACKNOWLEDGMENTS

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