

3D-Monoplotting

Combined evaluation of laser scanner data and photogrammetric images

Ralf Becker, Wilhelm Benning und Christoph Effkemann

Zusammenfassung

Die Nachfrage nach digital erfassten und gespeicherten Objekten aller Art in digitalen Modellen nimmt zu. Hierzu zählt im Nahbereich z.B. die Bestandserfassung von Gebäuden und industriellen Anlagen für Planungs- oder Denkmalschutzzwecke. Für eine derartige Massendatenerfassung bietet sich inzwischen die gleichzeitige photogrammetrische Aufnahme und terrestrische Laserscannervermessung in einem kombinierten Aufnahmesystem an. Aus den Rohdaten werden geometrische Primitive wie Punkte, Linien und Flächen extrahiert und zu einem Modell des Objekts zusammengefügt. Vorge stellt wird die kombinierte Auswertung von Laserscanner- und photogrammetrischen Daten im Auswertesystem PHIDIAS.

Summary

The demand for digitally registered objects of any type in digital models is increasing. Buildings and plants are recorded for as-built-documentation, planning or protection of historical monuments. Photogrammetry and laser scanning simultaneously used in a combined system offers high speed data capture of the geometry and details of the scene. The captured data are used for the extraction of geometric primitives namely points, lines and surfaces, which are combined, forming a model of the object. Presented is the combined modeling of laser scanning and photogrammetric data in PHIDIAS modeling system.

1 Introduction

For planning structural changes at and/or in existing buildings or industrial plants, for the documentation of structural facilities or the restoration of protected historical monuments the knowledge of existing geometry is of great importance. The structural facility, the material world object, must be transferred in a planning and/or a documentation system. These are today the usual geo information systems. The representation in geo information systems is based on a limited number of modeled basic forms of lines, surfaces and volume elements such as straight lines, planes and right parallelepipeds, in order to call only the

simplest types. Edges, surfaces and/or volume elements of the material world object are represented by it. The developing model of the material world object must agree in an accuracy sufficient for the purpose with the material world.

For the measurement of the objects in the location different methods such as manual measurement from a total station of attributed single points to the mass point measurement with the help of photogrammetry and the laser scanner. With the traditional measuring techniques much time is needed. Photogrammetry combined with laser scanning quickly measures the geometry - from the point of view visible points of object and extensive information from the image. This data does not contain the attributes of traditional methods but the data capture process is reduced to a minimum. .

2 Combining laser-scanning and photogrammetric measurement techniques

Laser-scanners capture three-dimensional points measuring horizontal and vertical angles as well as the range distance. The distance measurement takes place by electro-optical ranging using - depending upon the type of device - the pulse or the phase-difference method. Using simple trigonometric operations one receives the measured points of object in a scanner-referred Cartesian coordinate system. Horizontal and vertical angles are incremented automatically. Thus the resolution of points at the object depends on the distance of the object to the device position and the tilting of the object surface to the measuring axis.

Photogrammetric measurement techniques require objects in - today regularly digital - black/white or color images. The resolution depends on the camera optics and - in the case today with digital cameras - on size and number of photo-sensitive sensors as well as the focal length of the camera. It can be, that the measurement (exposure) takes place parallel for all captured points, substantially higher than by the serially measuring laser-scanners. Two-dimensional image-plane coordinates are measured. The third dimension results from the intersected light rays of two photographs of the same

object point. With increasing distance to the two photographs points of view the quality of this distance calculation sinks. The ranging of the laser scanner is however as far as possible distance independent.

For the evaluation of the photographs, visualization in a geo-information system is necessary. Captured data, whether from the point cloud of the laser-scanner measurement or the pixels of the digital images, becomes descriptive and interpretable. The black/white and/or color values of the images are substantial attributive components. Additionally, laser-scanners supply intensities of the returning pulse signals.

The specific advantages of photogrammetry and laser-scanning technique are optimal when used by combining both results during object evaluation. The manufacturer RIEGL equipped its laser-scanner with a high-resolution photogrammetric camera (Fig. 1).



Fig. 1: Riegl scanner LMS-Z420i with mounted camera Nikon D100

In the digital evaluation system PHIDIAS (Benning and Schwermann 1997) scanner and photogrammetric data are visualized in superimposition (Fig. 2). The mutual orientation of the scanner and the camera position is carried out by the scanner software. Additional photographs can be oriented by PHIDIAS. Data of both measurement methods can be used simultaneously for object modeling. The digital photogrammetric evaluation system PHIDIAS combined with the CAD system MicroStation has been extended by functions for evaluation from laser scanner data.



Fig. 2: Visualization of laser-scanner and photogrammetric data in superimposition

3 Extraction methods

3.1 Measuring single points

The laser scanner measures object points in angle steps given by the scanner. The photogrammetric resolution is usually higher than those the point cloud. Supported by the black/white or color information, photogrammetric image point identification is simpler than on basis of scanners point cloud. The position of a photogrammetrically identified point in relation to the scanner points can be determined by intersection of the photogrammetric light ray and the plane computed from the neighboring points of scanner. For increasing redundancy further, surrounding points of scanner data can be used for plane calculation (fig. 3). The distance of the points to the intersection can be used for weighting methods. This procedure was presented of Schwermann und Effkemann (2002) as monoploting method.

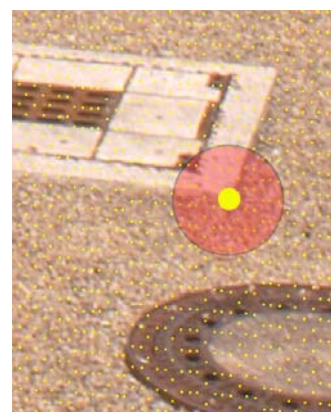


Fig. 3: Single points measuring method with surrounding points of scanner

It is suitable for points of a model, which lie within

a plane. For selection of points of scanner data, it must be guaranteed by selection functions that these points lie in the dimension of a given accuracy in the same plane.

3.2 Automatic extraction of geometrical primitives

The object of the real world (fig. 4a) is to be transferred into a model (fig. 4b), consisting of corners, edges and surfaces. One connects corners to edges. Edges border surfaces. Surfaces border volume elements.

Surfaces of structural facilities contain often plane surfaces, which intersect in the objects corners and edges. Plants often contain cylindrical objects such as tubes, or pillars at buildings.



Fig. 4a: Image

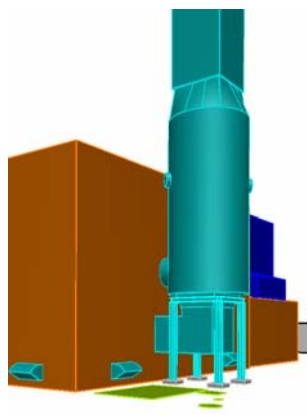


Fig. 4b: Model

Modeling e.g. corners from scanner data is not optimal as the scanner places points on the surface in a systematic manner which does not guarantee a specific location. (fig. 5, point 1). Only by intersection of the adjacent edges one receives the looked for constructional corners (fig. 5, point 2), and/or the edges from the intersection of surfaces.

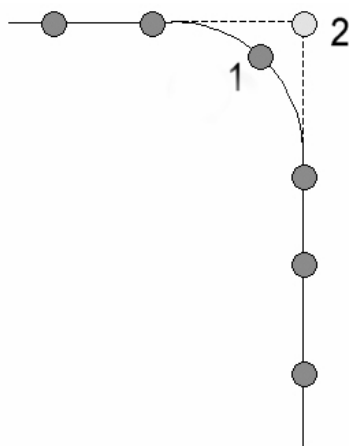


Fig. 5: Roundness of an edge

3.2.1 Extraction of regular surfaces

For the elimination of equipment-conditioned random

error portions of the points of scanner and of random distributed object structures, which are not aim of modeling, (fig. 6) surface modeling takes place by the least-square estimation method.

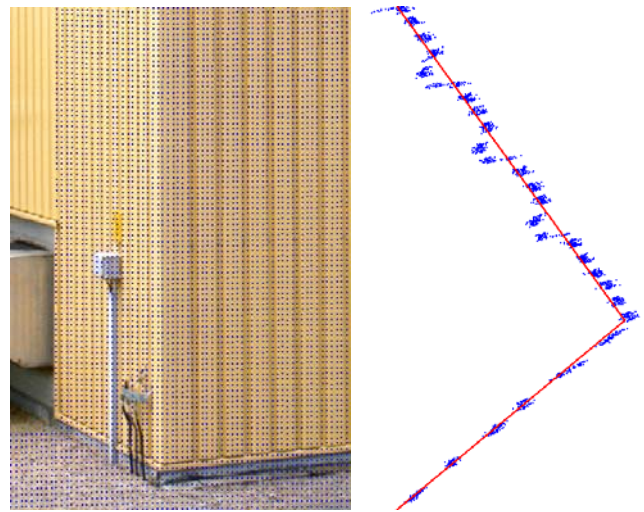


Fig. 6: Object structure by the example of a trapezoidal sheet metal
a) view from the front b) view from above

By the crosshair in the photogrammetric image the CAD operator selects a set of points of scanner, in which one alternatively searches for even surfaces and/or cylinders.

The point set, which will be introduced to the least-square method, is aggregated by an automatic search method recursively on the basis of spatial point-neighborhoods from the total point set or a part of it (fig. 7). The neighborhood relations are inferred from a three-dimensional Delaunay-triangulation. For the evaluation of the surface affiliation local curvature values in the points of scanner in two to each other perpendicular directions are computed. The curvature parameters of the modeled regular surface are improved thus gradually.



Fig. 7: Automatically aggregated points of cylinder surface

The least-square estimation supplies the parameters of the regular surface and for accuracy evaluation the

Forming profiles is an important component of the modeling. In the simplest case the point cloud of scanner may be reduced by selection functions and rotated in such a manner that the operator can model individual pieces of a profile. The point's representative for a piece of profile is averaged by visual inspection.

After interactive presetting of the profile orientation by a straight line already modeled and the profile extension by two pre-selected points in the view the point selection takes place automatically. These interactions are supported visually by the photograph.

A profile as a whole consists of individual profile pieces (space lines). They result as the intersections of extracted regular surfaces with the profile plane. The object surfaces are formalized, extracted in the given search area and, in consideration of holes, intersected with the profile plane to pieces of straight lines and/or elliptic arcs. The found neighboring pieces of profile are concatenated by intersection (fig. 12).

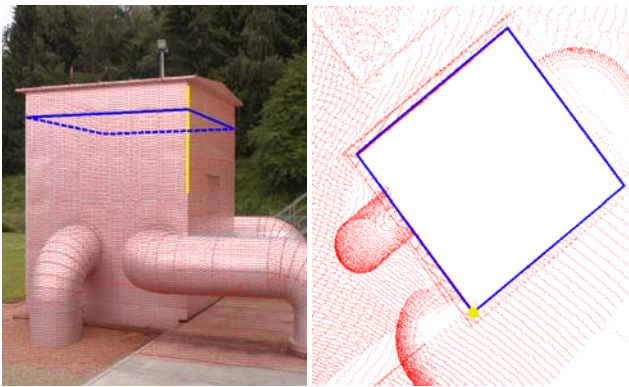


Fig. 12: Extracted profile:
a) View from the side b) View from above

The extracted profile can be supplemented on basis of the more highly dissolved photograph of missing details. By extruding along the profile-normal e.g. building fronts can be modeled on the basis the photograph.

4 An example of use from the industrial facilities construction

The described modeling methods were used intensively for the as-built-documentation of a gas compressor plant and compared with total station and purely photogrammetric methods.

The as-built-plans of the plant existed up to now in form of two-dimensional digital plans. With the new version the transition to a three-dimensional documentation in a geo-information system is to be carried out. The data capture concentrated on the aboveground part of the plant. Only a small part of the underground running pipelines, due to a structural

alteration, was included.

4.1 Object recording

A substantial characteristic of laser scanner data capture is, that the plant can be almost completely recorded locally within a short time. The amount of time in highly combustible areas, by which additional safeguards and personnel are necessary, is reduced to a minimum. The selection and modeling of the representative components are accomplished away from the combustible areas..

The comprehensive collection of approx. 18000 m² area took place from 40 evenly distributed scanner points of view. For the selection of the points of view: the resolution and range of the scanner are taken into account. The density of the structural elements of the buildings is crucial. The more closely a plant is cultivated, the more points of view are needed, in order to minimize scan-shadows.

Here the laser scanner RIEGL LMS Z420i with an attached calibrated digital camera Nikon D100 (fig. 1, tab. 1 u. 2) was used. The coupling of the camera with the scanner has the advantage linking the coordinate system of the scanner with the coordinate system of the camera which results in the correct orientation of the photographs and of the point clouds. The pixel measurements and orientation computations necessary with free-handled photographs can be omitted. With a total number of more than 400 pictures that corresponds to saving of time of approx. 40 hours.

Tab. 1: Performance of the 3D laser scanner

Model	RIEGL LMS-Z420i
Scanning range horizontal	360°
Angle stepwidth horizontal	min. 0.008°
Scanning range vertical	80°
Angle stepwidth vertical	min. 0.010°
Range resolution	+/- 10 mm (Einzelmessung)
Measurement rate	8000 Punkte / Sekunde

Tab. 2: Performance of the digital camera

Model	Nikon D100
Number of pixel	3008 x 2000
Sensor size	23,46 mm x 15,6 mm
Pixel size of image	7,8 µm
Objective	20 mm Festbrennweite

The maximum resolution of the scanner was not exhausted, in order to reduce the time for scanning and to keep the data sets manageable. An extremely high resolution of the point cloud is not necessary as the detail provided by the high resolution digital image are better recognizable (fig. 13).



Fig. 13: Comparison of the resolution of detail of photograph and pointcloud in 10 m distance

From table 3 it becomes evident that the image resolution of 3.9 mm is for the factor 5.4 better than the resolution of 21 mm of the point cloud. The detail recognized in the digital image can be further increased by use of objectives with longer focal lengths. The number of photographs rises thereby however likewise and the vertical opening angle becomes smaller accordingly. The opening angle of the 20mm-objective is 60° for upright photographs and covers ¾ of the vertical scan range. With a 14mm-objective one could cover the entire scan range, in this concrete case was however a larger image scale more important. Meanwhile miniature cameras with image sensors are available. For example the Canon 1Ds covers with approximately the same pixel size nearly the double surface.

Tab. 3: Resolutions of the single scans and the photographs

Angle resolution horizontal and vertical	0,12°
Number of points horizontal	3000
Number of points vertical	666
Number of points per scan position	max. ca. 2 mio.
Time for scanning	4 min.
Mean distance to object	ca. 10 – 20 m
Resolution of the scan points in 10 m distance	21 mm
Number of photographs perscan position	10
Resolution of the photographs in 10 m distance	3,9 mm

The scanner is installed on a mobile rack (fig. 14). It facilitates and accelerates the shifting of the scanner, provides for safe conditions and increases the photograph position, so that flat objects near the ground e.g. manhole covers even in larger distance are still well visible. The rack can be divided into 8 parts, so that the entire equipment finds space in a station wagon. At the

mobile rack beside the scanner with put on camera a small notebook computer for wireless communication by WLAN with the main computer and a 12V-battery for the electric power supply are fastened.



Fig. 14: Shifting the scanner by a mobile rack

The costs for the local work amounted to 2 full days of 2 persons. The pass points were determined by the reflectorless Total Station Zeiss RL during scanning.

The so-called registration of the scan positions, i.e. the computation of the transformation parameters between scanner coordinate system and project coordinate system was accomplished immediately after each scan process, in order to have immediate control of the registration accuracy. The transformation of the point clouds into the common project coordinate system besides was used for the recognition of shaded ranges. The period needed for one point of view amounted to approx. 20 minutes.

Target marks or reflex marks, were placed on well visible positions on buildings or components, or cylindrical reflex marks, which have the advantage to be recognizable from all directions, are used. The scanner recognizes these marks automatically on basis of the stronger reflection. The matching of the recognized marks to the total station determined coordinates from the list of control points takes place automatically, if sufficient points are found and, due to the different distances between the points, a clear matching is possible. The distribution of the reflex marks must be therefore irregular. In addition, attention must be paid to the fact that the marks are distributed over the entire horizon, in order to ensure a stable transformation of the different point clouds into the project coordinate system.

If the vertical measuring range of the scanner is not sufficient, in order to measure very high buildings or towers completely, the equipment can be tilted. The tilted positions, so-called "tilt mount positions" can be calibrated first. It is sufficient, if in the regular vertical orientation sufficient reflex marks are measured.

In order to be able to identify the reflex marks in the image more simply the camera flash is switched on. The light from the flash lightens the marks very clearly, without affecting the exposure of the remaining objects (fig. 15).



Fig. 15: By reflex mark signaled pass point

To the calibration of the camera belongs the determination of the inner orientation inclusively distortion parameters as well as the relative orientation, thus the camera position and orientation related to the coordinate system of the scanner. The camera calibration runs automatically and during the 2 days only one calibration was needed. In addition on two lantern masts of vertical rows distributed marks with high resolution were scanned and taken with the camera several times in small angle steps. A large connected field of tie points is simulated by the high number of deviated photographs and high calibration accuracy is achieved.

4.2 Object modeling

Modeling of the plant took place to a large extent by the methods described in chapter 3. Even surfaces, cylindrical pieces of pipelines and edges of buildings were extracted automatically from the point cloud. The objects were completed afterwards by single photograph photogrammetry.

Very thin pipelines and other details, which could not be extracted due to the noise of laser scanner data automatically, were measured either in frames or modeled with the help of the classical multi photograph photogrammetry. Single photograph measurements were possible whenever the level and/or the axis of an element were well known. For the adjustment and construction of the design elements all functions of the CAD-system MicroStation can be used directly in the photograph. The photographs, the point cloud and the constructed elements are visualized in superimposition (fig. 16).

Curved pipe axes were indirectly modeled, as only a narrow range of the point cloud was visualized (fig. 17). Afterwards the pipe's surface could be extruded along the mean axis with constant radius.



Fig. 16: Super-imposition of photograph and constructed elements

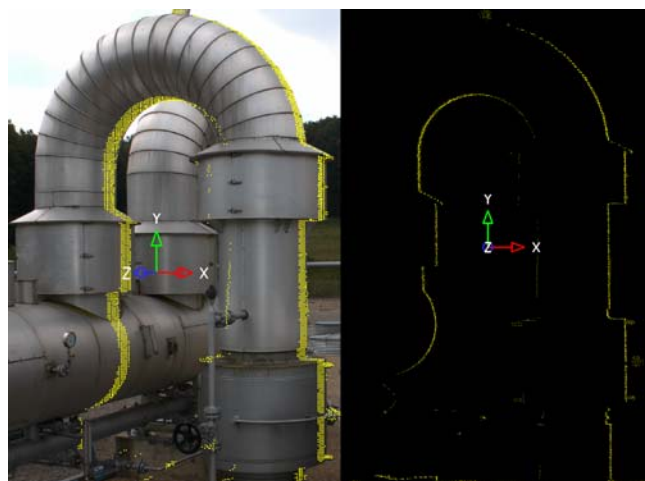


Fig. 17: Visualization of a section of the point cloud

The entire expenditure of time for the modeling of the plant amounted to approx. 60 hours. It is thereby clearly under the time, which purely photogrammetric modeling would have needed. The largest time advantage arose as a result of the omission of the orientation calculation, since PHIDIAS takes over the orientation parameters of the photographs and point clouds automatically from the software RiSCAN Pro of RIEGL. The difference to total station measurement

turns out still more clearly, since in PHIDIAS measurement and modeling are done in a single working procedure. A total station measurement with following 3D-modeling would not have only multiple cost of time, but also would not be so simply checkable on completeness and correctness and would have smaller information content.

The accuracies of the two combined systems are different. The laser scanner measures the running time of the reflected light pulse. The distance measuring accuracy is conditioned by the measuring principle only slightly distance dependent. Against it the distance accuracy of the photogrammetric measurement depends strongly on the angle of intersection of the photogrammetric light rays. The standard deviation of the photogrammetric measurement is on short distances better than the laser scanner measurement, however rises faster with increasing distance (fig. 18).

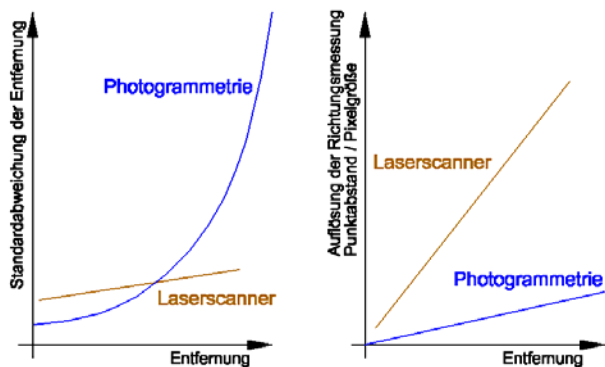


Abb. 18: Accuracies of the measurement techniques lengthwise and resolution crosswise

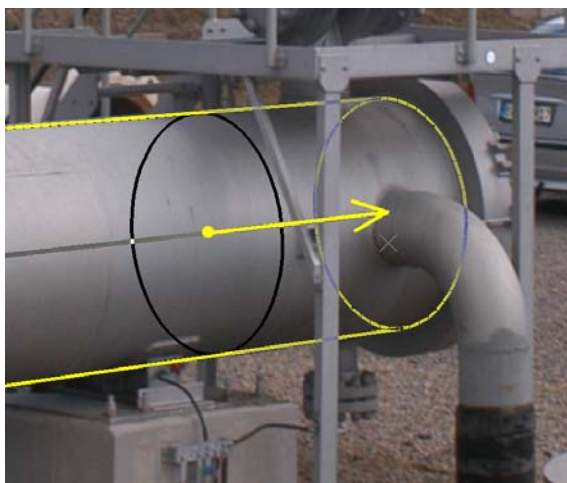


Fig. 19: Axial extension of an automatically extracted cylinder by single photograph measurement

Consequently the distance and/or the position of a surface would be constructed from the point cloud and the border and/or the edge of an object from the photograph. For example for the measurement of the

position of a manhole covers a least square estimated plane is extracted from the point cloud and the edge is drawn in a single photograph (fig. 3). Automatically extracted cylindrical pieces of pipelines are extended in the photograph up to the end or up to a break (fig. 19).

4.3 Results

The first quick result of the measurement was a three-dimensional point cloud given true color from the digital photographs, in which one can navigate freely. It is available immediately after conclusion of the local work. In similar way one can use the oriented photogrammetric images as a data bank of photographs. In contrast to the point cloud the point of view for the photographs is fixed. One cannot move freely as one would wish. The point cloud is suitable for an overview of the object and it can be overlaid with existing 2D or 3D-plans (fig. 20). It is conceivable the fact, that in many cases an immediate 3D-modeling is not at all necessary, but that it is only checked, whether all relevant construction units are completely measured and modeling is possible. Modeling of components on the basis of the archived data can take place if necessary, e.g. before planned extension or structural alteration begins.



Fig. 20: Visualization of the dyed 3D-pointcloud together with the modeled elements

The 3D-surface or volume model can be universally used. In relation to the point cloud it has the advantage, that it structures only the substantial construction units and presents them generalized. In comparison to the point cloud the data sets are very small and can be processed by different program systems.

Ground and view plans as well as schematic plans are derived from the 3D-model and produced partly automatically. In combination with program systems for plant planning, e.g. PlantSpace for MicroStation an intelligent plant model can be developed, which offers far more than an as-built-documentation, and supplies

valuable information for planning and operating of complex plants.

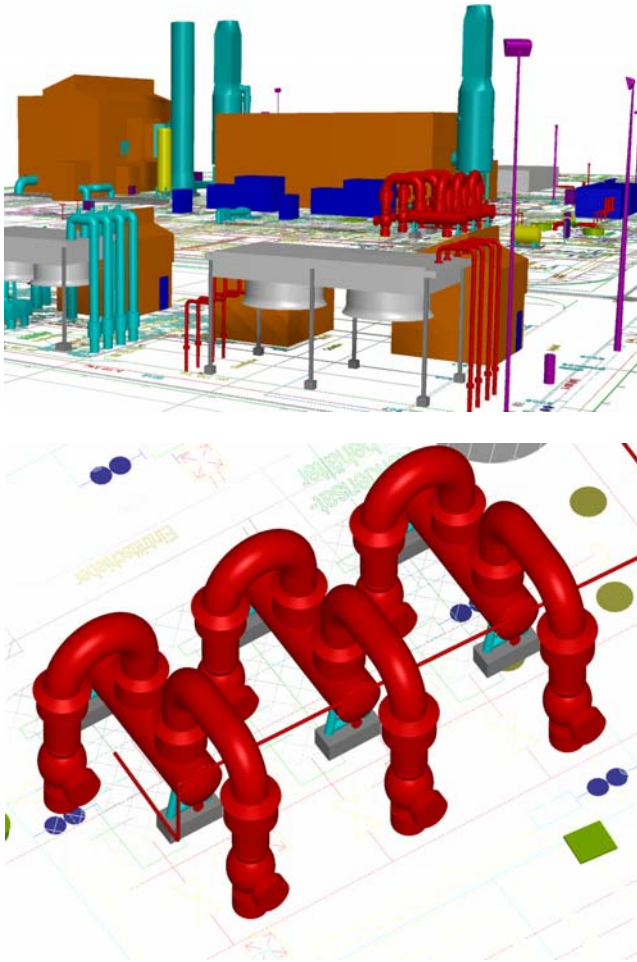


Fig. 21: Shadowed surface models with 2D-as-built-plan in the background

5 Conclusions and Outlook

Combination of photogrammetry and laser scanning in data acquisition and data evaluation supplies the basis for simultaneous object modeling from both types of data.

The modeling system PHIDIAS was supplemented for combined modeling around methods for the automatic definition of local coordinate systems, for the extraction of pieces of planes and cylinders as well as for the extraction of corners, edges and profiles. The methods are based on the automatic plane and cylinder extraction from point clouds of scanner data and supported by photogrammetric images. Using as many points measured on the regular surfaces as possible increases the accuracy of the surface extraction and of the evaluation of the volume of data. The automatic point search and point selection as well as the combination of evaluation methods for photogrammetric and for

scanner data reduce the expenditure of time needed for the evaluation.

The example of chapter 4 clarifies the advantages of this combined data evaluation for the user. Not only time is gained while modeling from the point cloud, but also a substantial increase in reliability and correctness of the topology results. To that extent the future belongs to the combined use of different raw data types. Expansion of the modeling from scanner data on further line and surface forms lines up. The information from the photograph is to be included more strongly into the extraction from scanner data.

Literature

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Links:

- <http://www.gia.rwth-aachen.de> Geodätisches Institut der Rheinisch-Westfälischen Technischen Hochschule Aachen
- <http://www.phocad.de> PHOCAD Ingenieurgesellschaft mbH
- <http://www.riegl.com> RIEGL Laser Measurement Systems

Address of the authors

Dipl.-Ing. Ralf Becker
 Univ.-Prof. Dr.-Ing. Wilhelm Benning
 Dipl.-Ing. Christoph Effkemann
 Geodätisches Institut der Rheinisch-Westfälischen Technischen Hochschule Aachen
 Templergraben 55, 52062 Aachen
ralf.becker@gia.rwth-aachen.de
benning@gia.rwth-aachen.de
effkemann@gia.rwth-aachen.de