USING KNOWLEDGE ABOUT SHAPE AND POSITION OF PLANT ELEMENTS IN PHOTOGRAMMETRIC AS-BUILT-DOCUMENTATION

Thomas Bürger, Wolfgang Busch
Technical University of Clausthal-Zellerfeld, Germany
Institute of Geotechnical Engineering and Mine Surveying
thomas.buerger@tu-clausthal.de, wolfgang.busch@tu-clausthal.de

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ABSTRACT

While as-built-documentation of process plants has been performed manually until now, modern survying technics like close-range photogrammetry and electronic tachymetry offer advantages for this task. The present paper reports of recent experiences using close-range photogrammetry for *as-built-documentation*. They show that the survyer's work will be significantly easier if he uses information from the developer's catalog-data and the design-rules from plant-engineering.

RÉSUMÉ

Jusqu'à aujourd'hui la documentation "tel que construit" s'est réalisée encore fréquemment manuellement. Pourtant les techniques modernes de la photogrammétrie terrestre et de la tachymétrie électronique ont de nombreux avantages. Cette publication donne un compte rendu d'expériences de l'utilisation de la photogrammétrie terrestre pour la documentation "tel que construit". Celles-ci montrent que le travail du géomètre peut-être largement facilité par l'utilisation des normes industrielles et des règles de construction spécifiques à la technique des installations industrielles au cours de l'interprétation des images.

KURZFASSUNG

Bis heute wird die As-Built Dokumentation einer verfahrenstechnischen Anlage häufig noch händisch durchgeführt. Moderne Techniken der Vermessung, wie die Nahbereichsphotogrammetrie und die elektronische Tachymetrie haben demgegenüber einige Vorteile. Diese Veröffentlichung berichtet über Erfahrungen beim Einsatz der Nahbereichsphotogrammetrie für die As-Built Dokumentation. Die Erfahrungen zeigen, daß die Vermessungsaufgabe erleichtert werden kann durch Einbeziehung von Normdaten und Konstruktionsregeln des Anlagenbauers in den Auswerteprozess.

1 INTRODUCTION

It is necessary to have a documentation of chemical and process plants after the construction phase is completed and to update the documentation repeatedly during the entire time the plant operates.

As far as the plant's geometry is concerned, this was formerly documented by drawings and is today mostly presented in 3D CAD models. This is called *as-built-documentation*.

In recent years the use of close-range photogrammetry has become increasingly popular as a means of as-built-documentations, because it offers a number of advantages over manual measuring especially in chemical plants (Przybilla, 95) and power plants (Kamsties, 92):

- Only a very short time in situ is needed to record the images.

- Photogrammetric results are reliable and can easily be verified.

- The total plant geometry can be easily described in a series of images that allows the reconstruction of CAD models on every desired level.

A great amount of research is still needed to make the relatively new technique of close-range photogrammetry a suitable tool for the reconstruction of these objects. Recent approaches that link photogrammetry with digital image processing hold a great potential that has not yet been fully realized.

This paper explores the individual steps of a photogrammetric as-built-documentation and aims to optimize the procedure. The documentation process is based on the assumption that universally accepted industrial standards of shape and position of typical plant elements have been met. This knowledge has been applied to the orientation phase as well as to the reconstruction phase of the documentation process. The optimization lead to a prototype close-range photogrammetric system for as-built-documentation of process plants.

As a new documentation tool this digital photogrammetric system has been made compatible with existing CAE tools that demand certain CAD-model structure and data management facilities.

It is the object of digital photogrammetry to find a way to deal with data acquisition and data interpretation in a highly automated way. This paper presents tools that support actually an interactive reconstruction with standard data of process plants. Using these tools the design of an automatic as-built-documentation system should be around the corner.

2   RECONSTRUCTING PLANT ELEMENTS IN ORIENTED IMAGES

Actually two different kinds of tools exist to perform photogrammetric as-built-documentation:

1. Tools based on CAD-systems with highly optimized modelling capabilities. Those systems are still lacking a number of photogrammetric measurement features. Some systems allow only "modelling on top of the photo".

2. Digital photogrammetric systems permit the measurement of some (not yet all) features needed to model the plant elements. The data of those systems must be imported into CAD-systems in order to perform the plant-modelling.

In general the *reconstruction* of process plants and its components always consists of two steps which should be ideally combined into one interactive system:

$$Reconstruction = Feature{-}Measurement + Modelling.$$

2.1   Feature–Measurement

The components of process plants are typically *pipes, valves, pumpes, elbows, flanges,* etc.: Standardized components, hardly to be measured by single, homologous imagepoints. The features to measure are points on lines, edges, points on circles or directly circles, cylindric and conic forms. The following methods measure those features:

First of all the epipolar-line method is an important tool in as-build measurement of points on arbitrary edges.
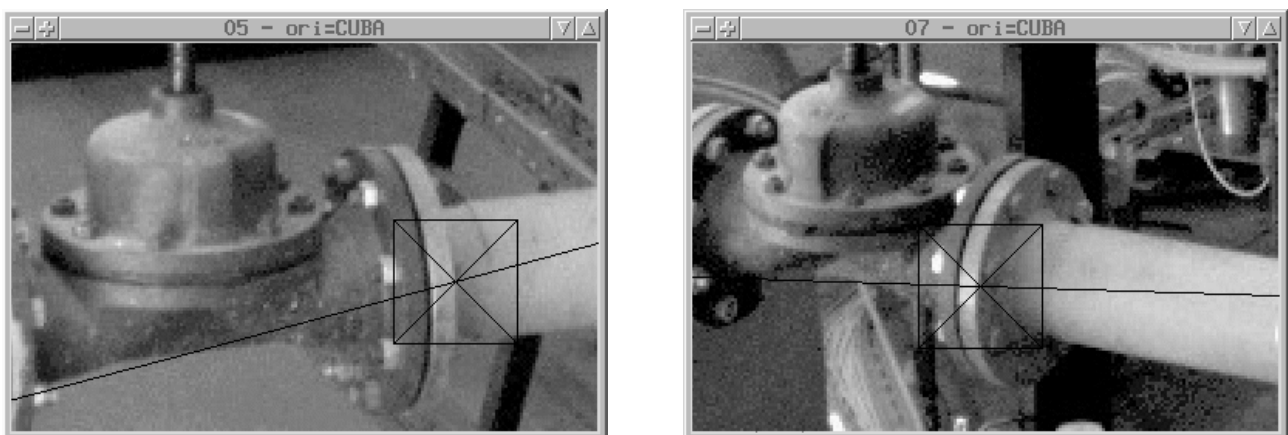

Figure 1: Measurement of point on flange-edge

The location of a point on a flange-edge relativ to the pipe's centerline defines position and shape of the flange. In this article we will see that methods with a higher accuracy are not neccessary in this case.

Straight lines (e.g. body edges, steel beam edges) are initially identified in space as the intersection of two planes (**Fig. 2**). If more than two images and more than two points per image are used the position of the line in space is found by
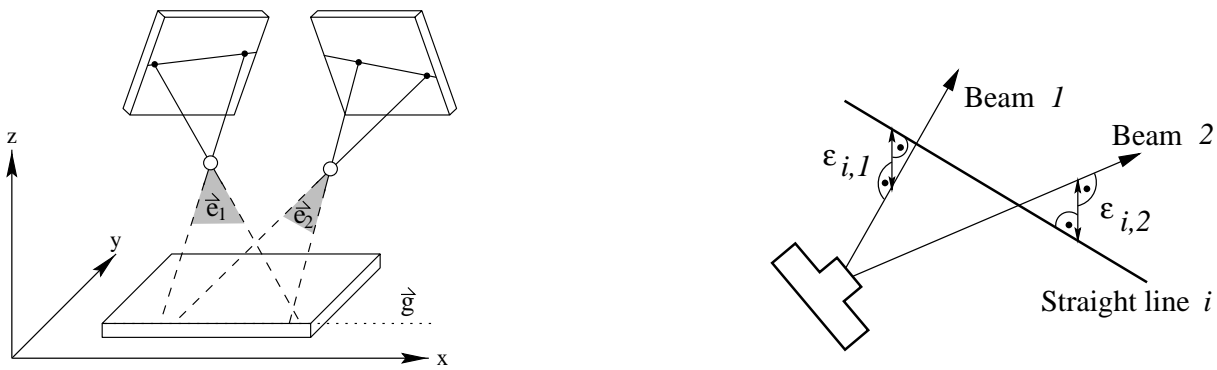
Figure 2: Measurement of straight lines

minimizing the sum of the square distances of projection beams of points on this line and the line itself (Andresen, 91). Initial values for the non-linear minimizing problem are generated with the two-plane intersection method.

The two approaches of straight line measurement are easily extended to aquire position and shape of cylindric objects (e.g. pipes and vessels):

Two points of the visible edge of the cylindric object lead to a plane in space touching tangentially the object. The two planes at either side lead to a *center-plane*. The centerline of the cylindric object falls into this center-plane, so the center-planes of two images have to be intersected to obtain the objects centerline (**Fig. 3 A**). Assuming errorless data the object's radius is the perpendicular distance to the tangential planes. A reasonable radius from eight edge-points in two images is obtained as the mean-value of the distances of the eight projection-beams to the centerline. The edges are found using Hough-transformation in manually selected rectangular segments (**Fig. 3 B**).
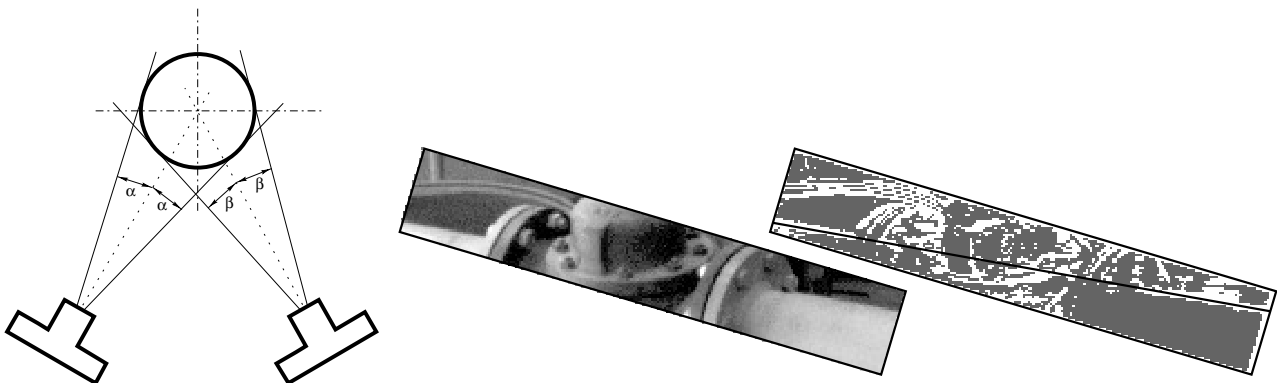

Figure 3: Measurement of cylindric objects (A) and digital edge detection (B)

The statistically exact solution to measure shape and position of cylindric objects has been shown by ANDRESEN in (Andresen, 91). It minimizes the residuals of the radius and the projection-beam–centerline–distance directly leading to a radius and centerline-coordinates for the cylindric object.

While ANDRESEN's method has been successfully used for measurement of large-scale cylindric objects (vessels) it failed frequently for low-scale objects as pipes due to deficient orientation and imagepoint data. The simple method of intersecting centerplanes proofed to be stable in either case.

The method of intersecting centerplanes is easily extended to measure position and shape of conic objects (**Fig. 4**). While the centerline of the object is calculated analogously the radius of the cone is a linear function of the centerline-position. The parameters of this funtion are obtained from eight (or more) projection-beams in two (or more) images by linear regression.

This set of feature-measurement-technics is used to obtain position and shape information which are completed to the entire plant-model with CAD–modelling-technics.

2.2 Modelling

The modelling of process plants with computer-aided-design technics (CAD) is highly dependend from design rules for this plants. Design rules determine the choice and position of plant-components. This will be illustrated by the following examples:
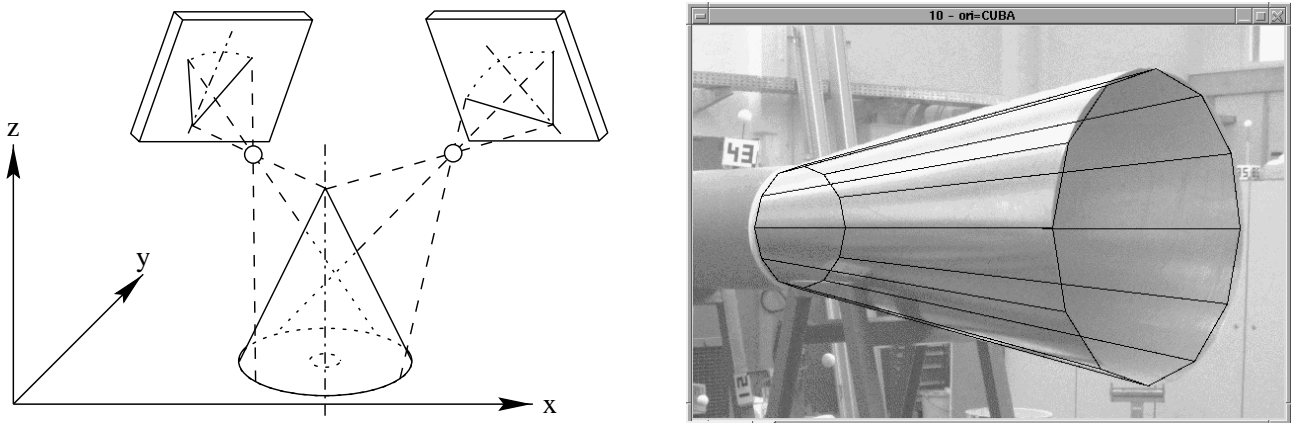
Figure 4: Measurement of conic objects

Piping components are positioned *coaxially* into the pipe. While this might not be exactly true in reality it is a reasonable assumption for as-built-documentation. This assumption leads to an easy modelling procedure for pipes and its components:

1. Measurement of the pipe (or a straight part of the pipe) as a cylindric object.

2. Measurement of points on flange-edges, center-points on handwheels etc.

3. Calculation of the component's geometry resulting from the point-positions and the pipe's centerline.

4. Coaxial insertion of the pipe-components at the given positions.

At this point not only position and shape of the components are known but also the pipe's topology which is an important information for documentation of chemical processes.
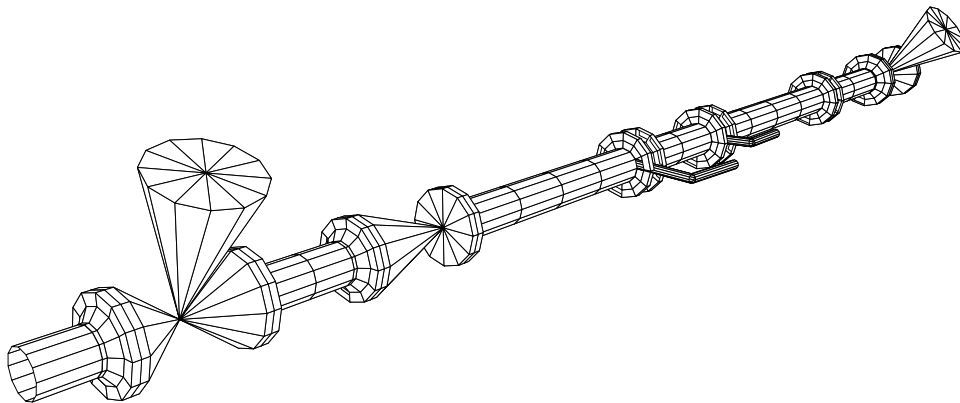

Figure 5: As-built documented pipe segment with coaxially included piping components

Piping components of process plants are not designed individually but choosen from component-catalogs. Catalogs contain information about all components which may be used in one pipe of a given *specification* which depends on the chemical process. The relevant parameters for the component-choice are the *bore size* which is approximately the inner diameter of the pipe and the *pressure rate*. All geometrical parameters of tubes, flanges, valves and other components depend on these parameters and can be found in the catalog-data.

Using this catalog-data the feature-measurement for piping-components need only be enough accurate to obviously identify the component in the catalog and to replace optionally the measured data by catalog-data. The following table shows examples from the german DIN-catalogs of tube-material (A) and flanges (B):

$D_e[\text{mm}]$	bore size	series	$\Delta D_e[\text{mm}]$	$\Delta D_e[\%]$
44.5	40	R3	-	-
48.3	40	R1	3.8	8.4
57.0	50	R2	8.7	18.0
60.3	50	R1	3.3	5.8
76.1	65	R1	15.8	26.2
88.9	80	R1	12.8	16.8
108.0	100	R3	19.1	21.5
114.3	100	R1	6.3	5.8
133.0	125	R2	18.7	16.4
139.7	125	R1	6.7	5.0
159.0	150	R3	19.3	13.8
168.3	150	R1	9.0	5.7

$D_e\,[\text{mm}]$	bore size	pressure rate
190.0	80	6
200.0	80	40
210.0	100	6
220.0	100	16
235.0	100	40
240.0	125	6
250.0	125	16
270.0	125	40

Table 1: Catalog-data (DIN) of tube-material (A) and flanges (B)

Table (A) shows the exterior diameter, the nominal bore size[1], the difference between two consecutive diameters and the relative differences. The relative differences are large enough to permit the unique identification of tube-material as well as flanges (B) and other piping components using the simple measurement technics shown above.

Using Catalog-data in step 3 of the modelling-procedure not only facilitates the modelling but also leads directly to specified or partially specified plant models which are more valuable than so called "collision models".

The major problem for using the knowledge about the component's shape is the availability of electronic catalog-data for older paper documented process plants.

3 USING POSTION INFORMATION IN THE ORIENTATION PHASE

The planning of an image-series of a process plant is a rather complex task. The orientation of the series and the reconstruction of every important plant-component must be taken into account. Even if the orientation succeded there might be components which are impossible to reconstruct if they appear in one image only or if there is a poor intersection only. So it might be important to take additional images at a later time and to succeed an orientation even if auxiliary orientation material (numbered targets, plumblines) are removed from the plant.

One approach of this task is to revert the straight-line reconstruction method presended in section 2.1 (**Fig. 2**) using known straight line information and searching for the parameters of the exterior orientation:

Straight lines i in space are defined as

$$\vec{g}_i = \vec{g}_i^0 + \lambda \cdot \vec{g}_i^R. \tag{1}$$

The projection beams j of imagepoints lying on the line i are represented in terms of the parameters of the exterior orientation $\vec{X}^0$, $\mathbf{D}(\varphi, \omega, \kappa)$, distorsion corrected imagepoint coordinates $u'_{i,j}$, $v'_{i,j}$ and the focal length c_k:

$$\vec{s}_{i,j} = \vec{s}_{i,j}^0 + \mu \cdot \vec{s}_{i,j}^R = \vec{X}^0 + \mu \cdot \mathbf{D}(\varphi, \omega, \kappa) \cdot \begin{pmatrix} u'_{i,j} \\ c_k \\ v'_{i,j} \end{pmatrix}. \tag{2}$$

Residuals $\varepsilon_{i,j}$ are defined as the perpendicular distance between straight lines i and projection beams j as:

$$\varepsilon_{i,j}^2 = \frac{\left((\vec{g}_i^R \times \vec{s}_{i,j}^R) \cdot (\vec{g}_i^0 - \vec{s}_{i,j}^0)\right)^2}{(\vec{g}_i^R \times \vec{s}_{i,j}^R)^2}. \tag{3}$$

The sum's minimization of the residual's squares

$$\sum_i \sum_j \varepsilon_{i,j}^2 = \text{Min} \tag{4}$$

leads to the parameters of the exterior orientation. Orientation succeeds with initial parameters for the exterior orientation and at least two imagepoints on three different known straight lines.

Using the centerline of pipes as straight lines requires the calculation of fictive imagepoints using imagepoints of the visible edges and defining a centerplane as in section 2.1. The following images (**Fig. 6**) illustrate the steps of this orientation using pipe-segments in a pilot-plant:

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[1] Bore size defined without unit in DIN!

Figure 6: Orientation of image using visible pipe-edges and known position of pipe-segments

- Onscreen digitizing of exterior orientation in a *space assignement plan* of the plant.

- Onscreen digitizing of points near the pipe-edges and searching for the edges with Hough-transformation (**Fig. 3**).

- Selecting the correspondant pipe-segments from the as-built-model superimposed in the image.

- Starting orientation procedure.

- Superimposing the plant-components after orientation as a visual verification of the process.

This orientation method should be applied only to single images using reliable geometric data from edges or pipes. It would be preferable in future to integrate orientation of images by plant-features directly into bundle adjustment algorithms. This will reduce also the amount of passpoint and tiepoint targets to be fixed in the plant and consequently reduce the time to spend in the plant.
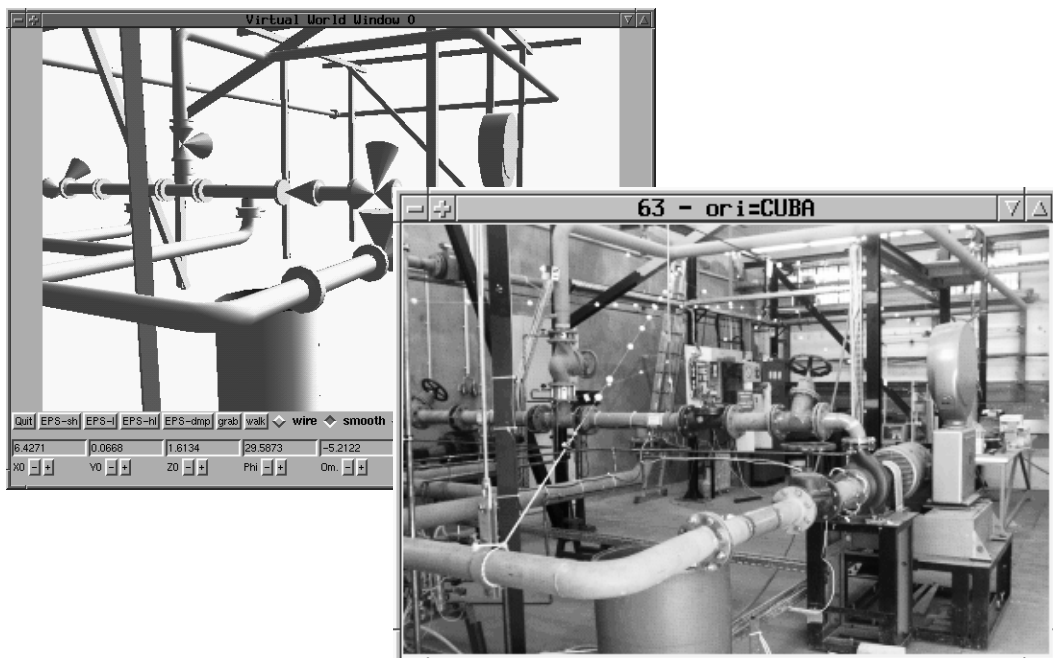
4 THE PROTOTYPE SYSTEM

Figure 7: Digital image and shaded as-built model with same orientation generated from ABANICO

The methods and tools presented in this paper are integrated into a prototype close-range photogrammetric system called ABANICO[2] developed at the Technical University of Clausthal. The tools have been proofed to be valuable in various pilot projects within the University and also within plants of the chemical industry (Bürger, 99).

[2]*As Built Acquisition of Non-documented Industrial and Civil Objects*

Images where taken with photogrammetric equipement (ROLLEI-3003 METRIC) as well as a medium resolution digital camera (KODAK DCS 420 B/W). Image series contain between 40 and 200 Images. Space assignement plans of the plant are digitized and loaded into the system to facilitate orientation of the images and to compare finally the as-built status of the plant with its design status presented by the plan by means of superimposition.

Pre-orientation of images is performed in ABANICO using resection, DLT, intersection of tiepoints and the straight-line orientation method shown above. Tachymetric data can be imported and assigned to individual imagesets. Pre-orientation data will be exported either to ROLLEI MR2 or to the bundle adjustment program CUBA from City University in London. Final data of inner and exterior orientations are imported from the two systems into ABANICO.

Virtual walking and grabbing of exterior image orientations is possible within the shaded model (**Fig. 7**) The reconstructed as-built model as well as the plant's catalog-data are stored in a relational database which permits access to individual parts of the plant. Until today the export of model-data has been realized for AUTOCAD and VRML-1.

5 CONCLUSION

Close-range photogrammetry is a powerfull tool for as-built-documentation of chemical and process plants. The oriented images itself are documentation and an important supplement to the virtual model.

The success of the close-range photogrammetry in this area will depend on the degree of adaptation to the plant-engineers necessities. Quick and reliable tools for reconstruction are more important than a high accuracy as needed in other domains of photogrammetry. The result of as-built modelling must be compatible to results of other CAD-tools used by plant-engineers. Therefor a maximum of data about the plant should be integrated in the measurement and modelling process and even in the orientation phase of an image series.

In future as-built documentation would be more frequently the update of virtual electronic models than an initial modelling of old paper-planned process plants. Further steps might go toward a higher degree of automation, which could be realized as a comparison between the design state and image-features found in oriented images of the realized plant.

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