International Archives of Photogrammetry and Remote Sensing. Vol. XXXII, Part 5. Hakodate 1998

CAD-BASED PHOTOGRAMMETRY FOR 3-D RECONSTRUCTION OF LARGE OBJECTS*

Thomas Luhmann
Professor and Head of the
Institute for Applied Photogrammetry and Geoinformatics
University of Applied Sciences Oldenburg
Ofener Str. 16, D-26121 Oldenburg
E-mail: luhmann@fh-oldenburg.de
GERMANY

Commission V, Working Group V/2

KEY WORDS: multi-image photogrammetry, image scanning, image database, CAD-based photogrammetry

ABSTRACT

The photogrammetric reconstruction of large buildings is normally characterized by difficult environmental conditions, complex image configurations and large numbers of images. In this paper a hybrid photogrammetric system is presented which consists of well-proven analogue imaging devices in combination with a low-cost image scanner and a CAD-integrated digital multi-image compiling system. Practical results of large engineering projects are used to discuss experiences and system performance.

1 INTRODUCTION

1.1 Objectives

The photogrammetric reconstruction of large engineering objects such as manufacturing plants, power stations, buildings or bridges is not a new application. Various examples have been published showing the successful use of photogrammetry for the measurement of complex environments (e.g. Kotowski et.al. 1989). However, it is still an ambitious engineering task due to the complexity and structure of many objects, and the general technological and economical situation.

This report presents practical experiences using a hybrid low-cost photogrammetric system. The system has been applied to a number of projects which can be characterized as follows:

- recording of large objects
- processing of natural, non-targeted object structures
- medium accuracy requirements
- hidden object areas
- difficult environmental conditions
- results processed as 3-D CAD data

The spatial dimension of the objects varies between approx. 10m to 200m. The required accuracy is about 1:5.000 to 1:20.000 of the maximum object dimension. The object surfaces can not be marked by artificial targets and image processing is mostly performed manually.

Due to practical conditions and the complexity of many objects, variable imaging configurations are required. The photogrammetric network is always designed as a convergent multi-image configuration whereby local restrictions often lead to non-optimal ray intersections. As a result, multi-image orientation is performed by bundle adjustment. The datum problem is normally solved by locally provided control points. The configuration of control points and camera stations must enable simultaneous camera calibration.

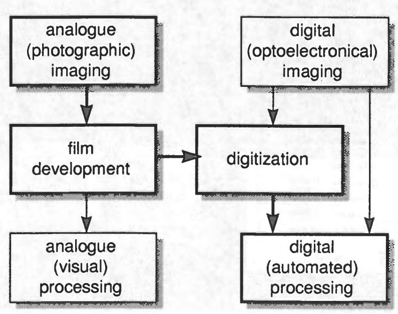

Figure 1: Principles of photogrammetric data acquisition and processing

1.2 Solutions

The highlighted sequence in Figure 1 describes the hybrid photogrammetric process used in the following applications. It is based on analogue photogrammetric image acquisition. Using low-cost desktop image scanners enlarged paper prints can be digitized with sufficient geometric resolution and accuracy. Finally, the photogrammetric image evaluation is performed with interactive digital processing systems that are integrated into a CAD environment. This method combines the advantages of a well-proven imaging technology with those of digital image and CAD processing.

* Modified version of (Luhmann 1997)

2 SYSTEM DESCRIPTION

2.1 Image Recording and Digitization

All projects have adopted the Rollei 6006 medium-format metric camera, with focal lengths between 40mm and 150mm using ILFORD FP4 b/w film. Its geometric resolution is estimated around 100 lp/mm. The original negatives have been enlarged to paper prints of 18cm x 18cm (scaling factor 3).

A simple desktop scanner, the HP ScanJet, has been used for image scanning. Geometric resolution (400 dpi), radiometric resolution (8 bit) and geometric accuracy (30-50µm) do not match the performance of the camera/film system. However, scanning of enlarged reseau images yields to an appropriate pixel size (approx. 21µm in the original film negative) and enables the numerical correction of almost all geometric failures down to image accuracies of 10µm (Bendler 1994).

Recently a second image scanner, the Agfa DuoScan, has been used (600 dpi, 8 bit). As compared with the HP ScanJet is shows a significantly worse accuracy with a strong non-linear behavior. Later results of bundle adjustment have shown that the Agfa system does not fulfil the requirements even for reseau images.

2.2 Image Archiving

Large and complex image configurations (e.g. >100 images) require systematic management and archiving of the images. For this purpose an image data base has been developed using MS-ACCESS which allows the storage of relevant image information either during image acquisition on-site, or during later scanning. The situation in the field is described by relatively simple imaging attributes (e.g. *north, south, top, bottom* ...) and the parameters of exterior orientation. The object itself is defined by a number of predefined object attributes such as *'main arch'*, *'west entrance'*, *'dome'* and so on.

Figure 2 and Figure 3 show examples of data structures and report generation.

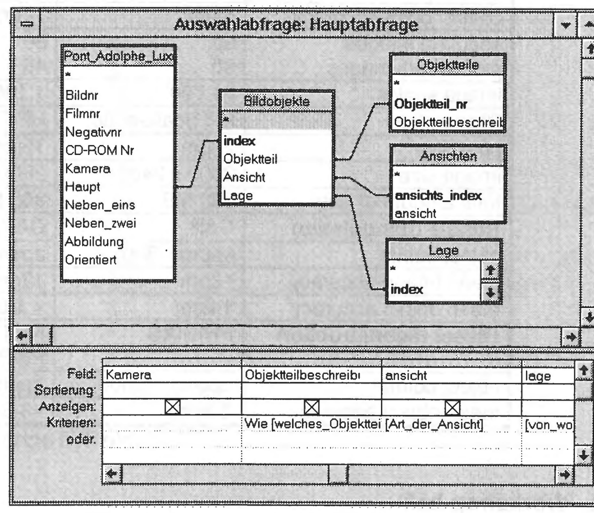

Figure 2: Example of data relations of the image data base

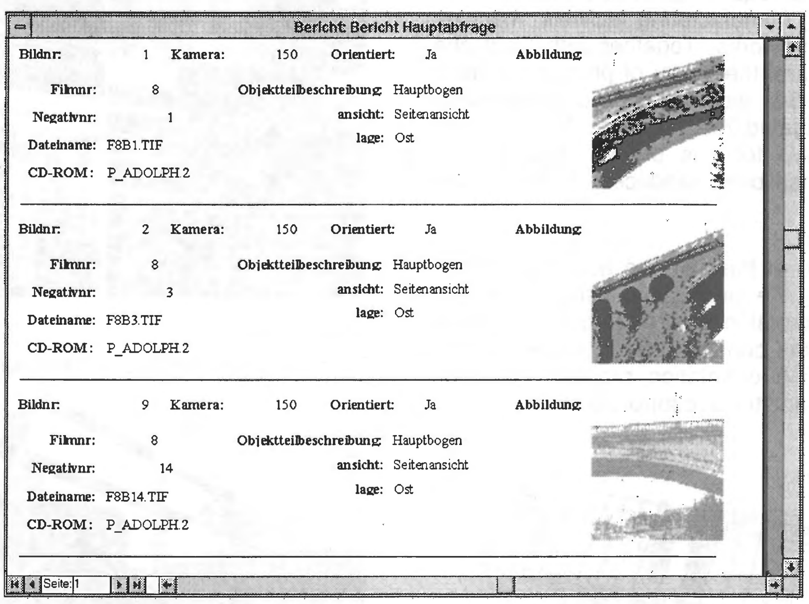

Figure 3: List of images matching the query statement

2.3 Photogrammetric Processing

The interactive multi-image compiling systems PHIDIAS (Benning & Effkemann 1991), PHIDIAS-MS (Benning 199???) and Rollei CDW (Godding & Fellbaum 1995) have been used. In order to transfer data between both systems special data conversion programs have been developed. The first version of PHIDIAS was restricted to a two-image compiling mode.The newer version of PHIDIAS-MS is integrated into the Microstation 3-D CAD environment and is suited for interactive processing of up to 8 images at once. The CDW package benefits from robust estimation of approximate values which is otherwise an extremely time-consuming task in complex applications with a large number of images (Godding & Fellbaum 1995).

3 PROJECTS

Table 1 summarizes the technical data of three practical applications. The relatively high number of established control points, as well as the number of acquired images have been chosen to provide a safety margin. In all projects access to the object was limited to a few days so that possible problems in orientation and object reconstruction had to be avoided in advance.

	Workshop hall	Powder Tower	Pont Adolphe	Main Station
Local object recording				
dimensions [m]	100 x 60 x 8	12 x 12 x 10	180 x 15 x 60	120 x 30 x 38
Year	1994	1994	1995	1997
Lenses	40mm	40mm	60mm, 150mm	60mm
control points	29	40	80	34
control point accuracy	5mm	1-3mm	10mm	2-3mm
acquired images	60	96	250	96
processed images	60	48	155	45
image scales	>1:700	1:100 - 1:300	1:300 - 1:500	1:470 - 1:650
Digitization	HP ScanJet IIc	HP ScanJet IIc	HP ScanJet IIc	Agfa DuoScan
pixel size	23µm	19µm	21µm	13µm
image size	2400 x 2400	2800 x 2800	2700 x 2700	4320 x 4320
total amount of data	330 MB	368 MB	1080 MB	1710 MB
Bundle triangulation	CAP	CAP	Nawe-Opt, CAP	PHIDIAS-MS
object points	approx. 300	approx. 60	approx. 330	40
mean image accuracy	12µm	12µm	16µm	7.5µm
mean object accuracy	1-2cm	< 1.5mm	< 10mm	5mm
Object reconstruction	PHIDIAS	PHIDIAS, P3/PHOCUS	PHIDIAS	PHIDIAS-MS
object points	approx. 10000	approx. 32000	approx. 4500	approx. 800
mean object accuracy	2-3cm	<3-5mm	2-4cm	3-6mm

Table 1: Technical project data

3.1 Workshop hall

CAD-oriented information and planning systems for workshop management require geometric data of the workshop environment, manufacturing facilities, machine positions and supply networks. Together with Deutsche Aerospace DASA at Varel the ability of photogrammetric data collection for the 3-D reconstruction of a workshop floor has been investigated (Harms et.al. 1994). Using PHIDIAS 1.0 / InfoCAD for this project (Figure 5) a complete 3-D model has been produced (Figure 4 and Figure 6).

Due to the architecture of the hall, the acquired images were mainly taken from the longitudinal aisles in the hall. The final image configuration was therefore laid out in strips, leading to a weak configuration in some parts of the block. The following orientation problem could be solved by a number of additional control points.

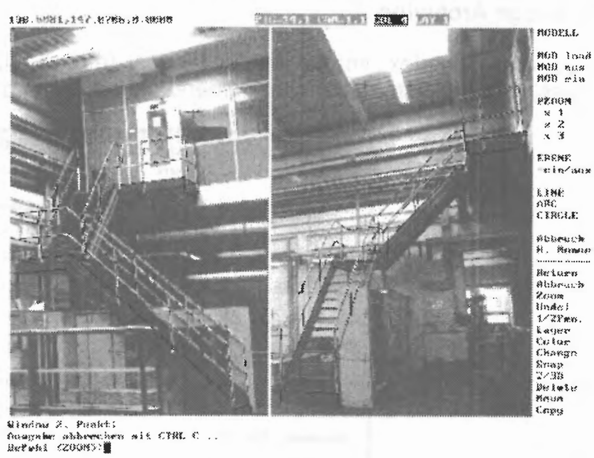

Figure 5: User-interface for photogrammetric processing

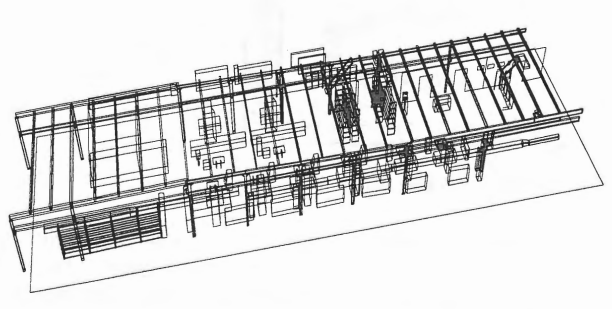

Figure 4: CAD model of the processed workshop hall objects

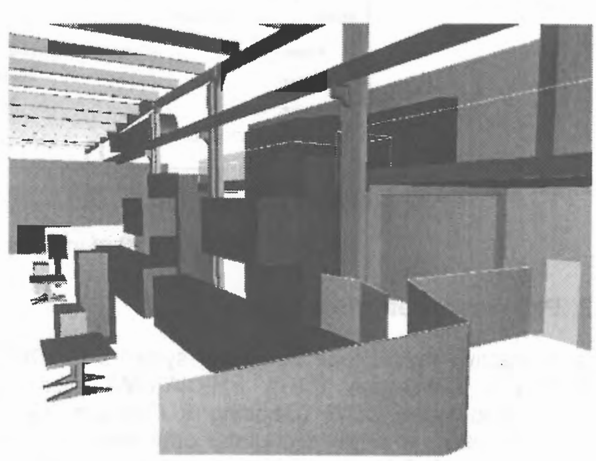

Figure 6: Rendered view of the workshop floor

3.2 Powder Tower

For momument preservation purposes detailed plans of the historic Powder Tower of Oldenburg had to be generated. The final results will include a stone-by-stone registration of the exterior and the interior walls in the form of a complete 3-D CAD model. A geodetic net of control points has been established inside and outside the building. Images were taken from all around the object including camera stations from higher positions using a hydraulic lift (Figure 7: Example image of the Oldenburg Powder Tower Figure 8).

3-D Point determination of the exterior walls was performed by intersection in the PHIDIAS program. The total facade consists of approximately 32000 object points (4 to 8 points per stone). This task could only be handled by a direct superimposition of graphical data onto the images (Figure 7: Example image of the Oldenburg Powder Tower Figure 8). In the interior a stereoscopic reconstruction of the untextured wall of the dome was nessecary. This data was collected on a Zeiss P3 analytical plotter running PHOCUS software. The measuring results of both systems were transfered to AutoCAD for further processing. As a result two-dimensional drawings and a cylindrical projection of the exterior facade have been produced (Figure 9) (Tecklenburg 1995).

Figure 7: Example image of the Oldenburg Powder Tower

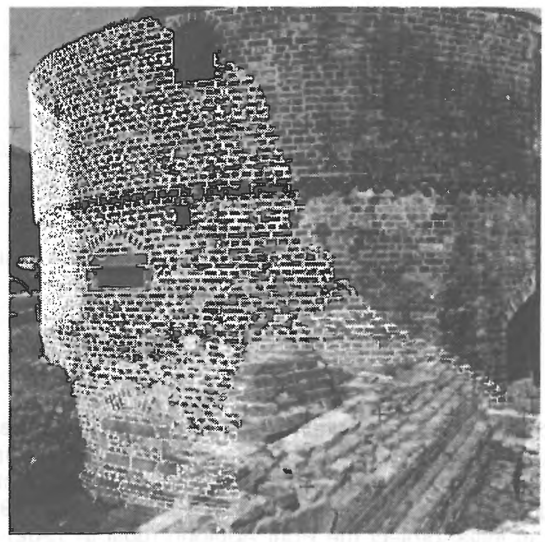

Figure 8: Superimposition of 3-D CAD data

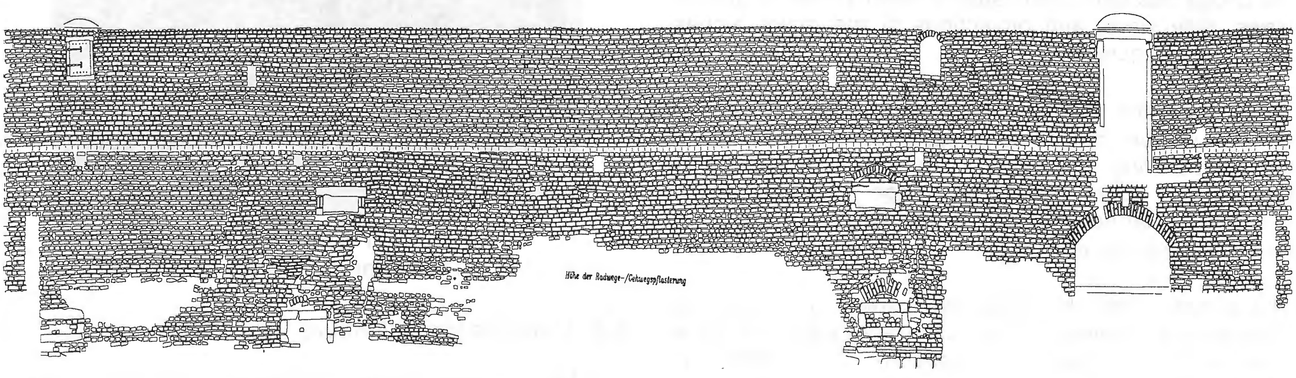

Figure 9: Cylindrical projection of the facade

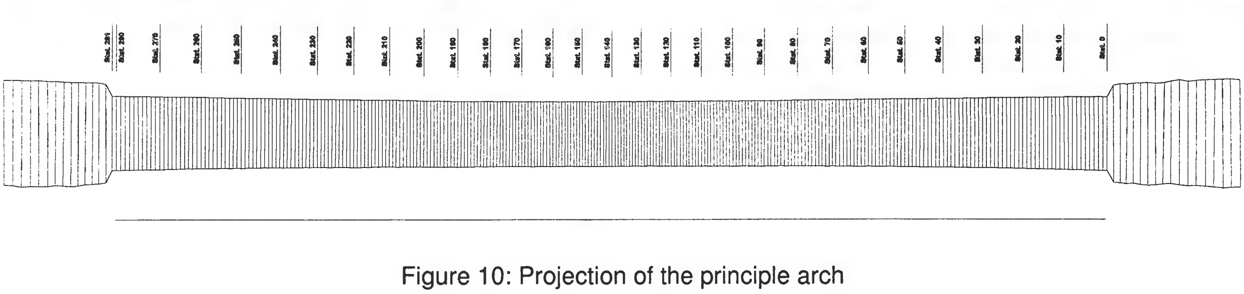

Figure 10: Projection of the principle arch

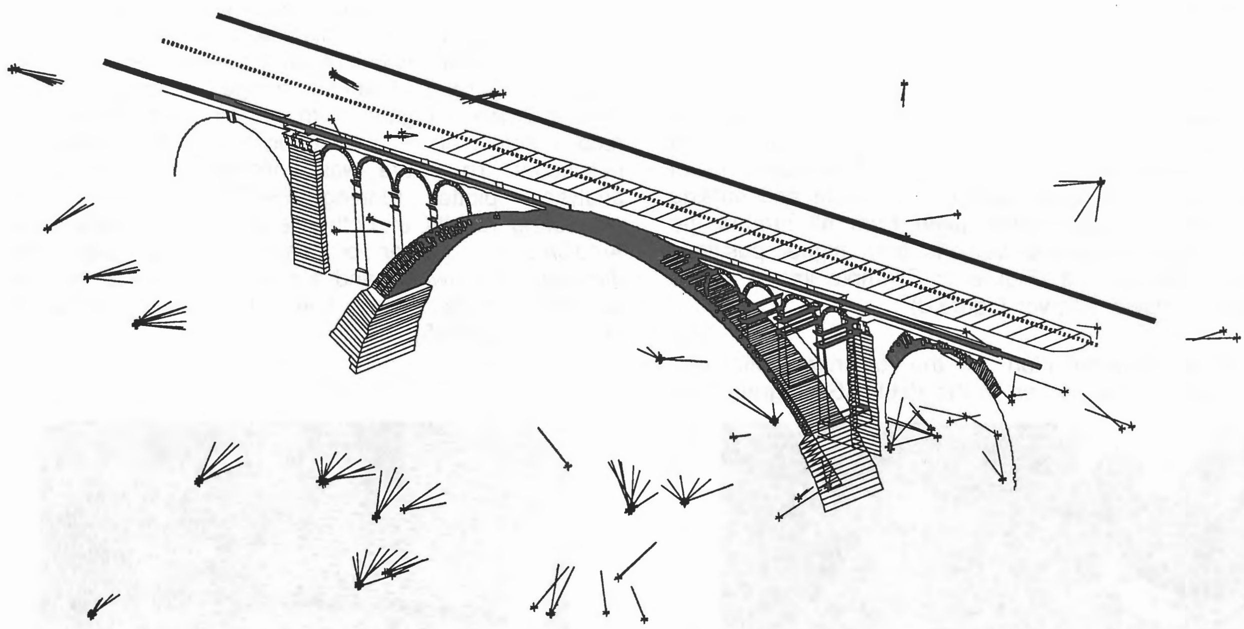

Figure 11: 3D-CAD model with camera stations and viewing directions

3.3 Pont Adolphe

In co-operation with Administration Ponts & Chaussées of Luxembourg the suitability of low-cost photogrammetric systems for the documentation and measurement of bridges has been investigated (Gay &Hartenstein 1995). As an initial project the Pont Adolphe (built in 1902) has been chosen. At one time this was the largest stone bridge in the world (Figure. 12). A complete 3-D model of the bridge has been requested in order to derive ground views, side views and projections of the major arches (example in Figure 10).

Especially in this project a lot of images look very similar so that unique image identification is only possible if image archiving has been carefully done. For this purpose the above mentioned image database was a helpful tool that enables even a second operator to work easily with the image material.

The bridge spans the Petrousse canyon in the city of Luxembourg. It consists of two separate longitudinal parts covered by a common roadway. The bridge is approximately 180m long and 60m above the river, with a maximum span of 80m. The steep slopes of the canyon, the river and the vegetation on the slopes create very complicated environmental conditions. Numerous photographs must be taken from a 30m hydraulic lift. Due to very limited camera stations a number of overlapping images must be taken by panning the camera. Figure 11 shows the configuration of those images used for final data collection.

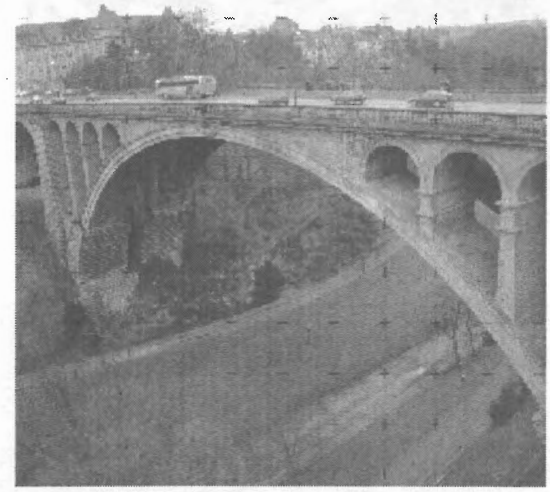

Figure. 12:
Pont Adolphe, Luxembourg

3.4 Main Station Oldenburg

The Main Railway Station of Oldenburg has been chosen as a test object for a student's diploma thesis (Bahn & Krite 1998). The major topic of the work deals with the superimposition of real images onto the CAD model in order to generate ortho-images of the facade (texture mapping) (Streilein 1995, Pomaska 1996).

Figure. 13: PHIDIAS-MS with project Main Station (Oldenburg)

4 REFERENCES

Bahn, W., Krite, S. (1998): Photogrammetrische Erstellung eines 3D-Modells und digitale Texturüberlagerung am Beispiel des Oldenburger Bahnhofs. Unpublished diploma thesis, Fachhochschule Oldenburg.

Bendler, O. (1994): Untersuchungen zur Genauigkeit eines einfachen Bildabtasters (Desktop Scanner). Unpublished diploma thesis, Fachhochschule Oldenburg.

Benning, W., Effkemann, Ch. (1991): PHIDIAS - Ein photogrammetrisches interaktives digitales Auswertesystem für den Nahbereich. Zeitschrift für Photogrammetrie und Fernerkundung, 3/91.

Benning, W., Schwermann (1997): PHIDIAS-MS - Eine digitale Photogrammetrieapplikation unter Microstation für Nahbereichsanwendungen. Allgemeine Vermessungsnachrichten, 1/1997.

Gay, O., Hartenstein, B. (1995): Photogrammetrische Bestandsaufnahme von Brückenbauwerken in Luxemburg. Unpublished diploma thesis, Fachhochschule Oldenburg

Godding, R. , Fellbaum, M. (1995): New Solutions in Close-Range Photogrammetry through a Combination of Digital Systems and Modern Estimation Techniques. In Gruen/Kahmen (ed.): Optical 3-D Measurement Techniques III, Wichmann Verlag, Heidelberg.

Harms, K., Keilmann, J.-U., Luhmann, T., Tecklenburg, W. (1994): Photogrammetrische Aufnahme einer Werkhalle für dreidimensionale CAD-Anwendungen. Publikation der DGPF, Band 3, Dresden, pp. 135-141.

Kotowski, R., Meid, A., Peipe, J., Wester-Ebbinghaus, W. (1989): Photogrammetrische Bauaufnahme der "Kirchen von Siena" - Entwicklung eines Konzepts zur Vermessung von Großbauwerken. Allgemeine Vermessungsnachrichten, 4/1989, pp. 144-154.

Luhmann, T. (1997): Hybrid Interactive Photogrammetry for 3-D Reconstruction of Large Objects. In Gruen/Kahmen (ed.): Optical 3-D Measurement Techniques IV, Wichmann Verlag, Heidelberg.

Pomaska, G. (1996): Implementation of Digital 3-D Models in Building Surveys Based on Multi-Image Photogrammetry. International Archives of Photogrammetry and Remote Sensing, Vol. 31/B5, Vienna, pp. 487-492.

Streilein, A. (1995): Videogrammetry and CAAD for Architectural Restitution of the Otto-Wagner-Pavillion in Vienna. In Gruen/Kahmen (ed.): Optical 3-D Measurement Techniques III, Wichmann Verlag, Heidelberg, pp. 305-314.

Tecklenburg, W. (1995): Photogrammetrische Aufnahme des Pulverturms in Oldenburg. In Vermessung im Wandel, VDV Schriftenreihe, Band 9, Chmielorz Verlag, Wiesbaden.