DIGITAL PHOTOGRAMMETRIC TECHNIQUES FOR ARCHITECTURAL DESIGN

André Streilein, Horst Beyer, Thomas Kersten

Institute of Geodesy and Photogrammetry
Swiss Federal Institute of Technology
ETH-Hönggerberg, CH-8093 Zurich, Switzerland
phone: +41-1-3773047, telefax: +41-1-3720438
e-mail: andre@p.igp.ethz.ch

ABSTRACT

Rapid advances in digital imaging sensors and the availability of powerful workstations make a fully digital system for architectural photogrammetry feasible. Such a system must be able to derive geometric and semantic information from the architectural object in such a way, that it can be directly used for CAAD (Computer Aided Architectural Design). Therefore it must provide a sensor-resolution comparable to traditional film-based systems. A system for Digital Photogrammetry and Architectural Design (DIPAD) is under development at the Institute of Geodesy and Photogrammetry in cooperation with the chair of Architecture and CAAD, both at the Swiss Federal Institute of Technology in Zurich.

A practical project is used to demonstrate the methods and performance of DIPAD. The processing steps from image acquisition to the three-dimensional geometric and semantic description of the architectural object in a CAAD-model are presented. Emphasis is placed on novel techniques for the semi-automatic measurement of architectural features. A comparison of the results for images taken by a camera using a solid-state sensor and a film-based camera is carried out.

KEY WORDS: Architectural, CAD/CAM, Close-range, Digital system, Feature Extraction.

1. INTRODUCTION

Improvements and new developments in the fields of sensor technology and computer technology allow the acquisition of digital images in video-realtime, without developing and digitizing a photographic film. A system for Digital Photogrammetry and Architectural Design (DIPAD) consists of a Digital Photogrammetric Station (DIPS) and a system for Computer Aided Architectural Design (CAAD). The aim of DIPAD is to make the photogrammetric data acquisition and processing easier and faster, to create a three-dimensional geometric and semantic object description, and to allow visualization and architectural processing. Therefore the system must be capable to acquire imagery with sufficient resolution, process the data with a high level of automation, and pass the results to a data structure useful for CAAD. This can be achieved using solid-state sensors and semi-automatic or automatic measurement techniques. The current status of DIPAD being developed in a joint project of the Institute of Geodesy and Photogrammetry in cooperation with the Chair of Architecture and CAAD at the Swiss Federal Institute of Technology in Zurich is outlined.

2. PROCESSING STEPS IN DIGITAL ARCHITECTURAL PHOTOGRAMMETRY

Image data for digital architectural photogrammetry can be acquired with film-based cameras as well as with cameras using solid-state sensors. Conventional film-based cameras still provide for an unsurpassed photographic resolution. For example, images with over 6000 by 6000 pixel would be required to match the resolution of a medium format film camera. But the difference between film-based cameras and cameras using solid-state sensors concerning the photographic resolution shrinks more and more. On the other hand the disadvantage of film-based cameras is that the film must be developed and digitized before the data is available for processing in a digital system. Whereas the image data of solid-state cameras is immediately accessible. This offers, among others, the advantage of quality control for image acquisition on the spot.

Figure 1 depicts the processing steps in digital architectural photogrammetry. After image acquisition, orientation and calibration, the geometric relations among all images and between images and object are known. The semi-automatic and automatic measurement techniques are used for the measurement of image coordinates. Herein, the identification of architectural features and the semantic classification is performed. The three-dimensional object coordinates are determined within a bundle adjustment. The result of the photogrammetric processing is a three-dimensional geometric and semantic object description, which can be passed automatically to the CAAD-system for further architectural processing.

The photogrammetric processing with the Digital Photogrammetric Station (DIPS II, *Grün and Beyer, 1990*) is meaningful because of the capability using semi-automatic and automatic measurement techniques. Some of these measurement techniques are described in chapter 5. DIPS consists primarily of a network of workstations from SUN-Microsystems, to which special purpose systems like an image acquisition workstation, an analytical plotter, personal computers with interfaces for special

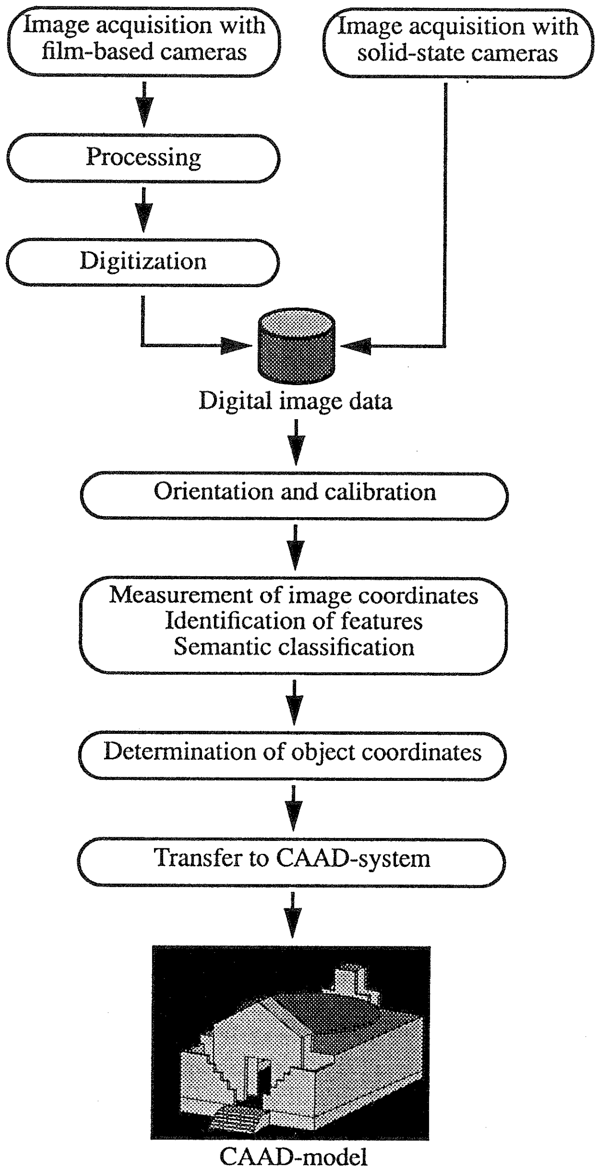


Figure 1: Processing steps in digital architectural photogrammetry.

cameras, and other input and output devices are connected. It must provide ample storage space for the large amount of imagery, a tremendous processing performance for semi-automatic and automatic measurement techniques, and a high resolution display for visualization of imagery, processing steps and results.

The major software component of DIPS is DEDIP (Development Environment for Digital Photogrammetry). All tasks, from image acquisition to the three-dimensional geometric and semantic object description, are performed with this software package, which was developed in our group. Major functional modules are: image acquisition with solid-state cameras, input and output of image data, image handling and display, semi-automatic measurement techniques, radiometric and geometric image analysis, bundle adjustment with self-calibration, model extension with semantic object information, automatic data transfer to CAAD-system.

3. ARCHITECTURAL OBJECT

The church "Chiesa di Nostra Signora di Fatima" in Giova (Switzerland) was chosen to demonstrate the functionality and efficiency of DIPAD. Giova is located in the southern alps near Bellinzona. The church was designed by the architects M. Campi and F. Pessina and built in 1984-88. It stands in a privileged and dominating position, nearly 800 metres above the valley Mesolcina at the edge of a plain. The church is 14 m in length and 10 m in width and height. A detailed discussion about the architectural design and construction of this church is given by Gazzaniga *(Gazzaniga, 1989)*.

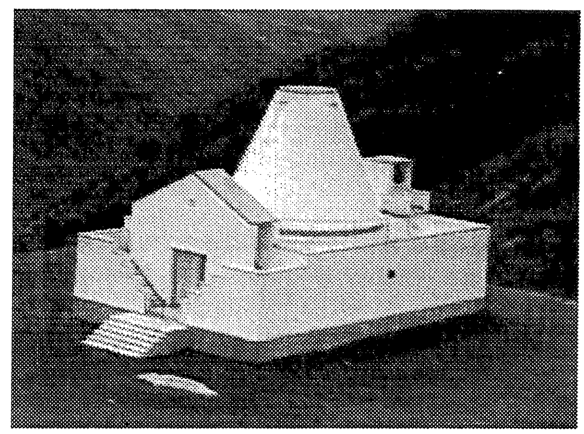


Figure 2: "Chiesa di Nostra Signora di Fatima".

4. DATA ACQUISITION

The imagery of this project was acquired with a film-based camera (Rollei 6006) and a camera using a solid-state sensor (Canon CI-10). Additionally, two images taken with the Rollei 6006 were digitized to compare the results of the digital and the analogue photogrammetric system under similar conditions.

The data acquisition took place during a campaign with several imaging systems. Thus the camera arrangement was planed for stereophotogrammetric tasks. Furthermore the arrangement was restricted by the dimensions (14x10x10 m^3) and the surrounding of the church (see

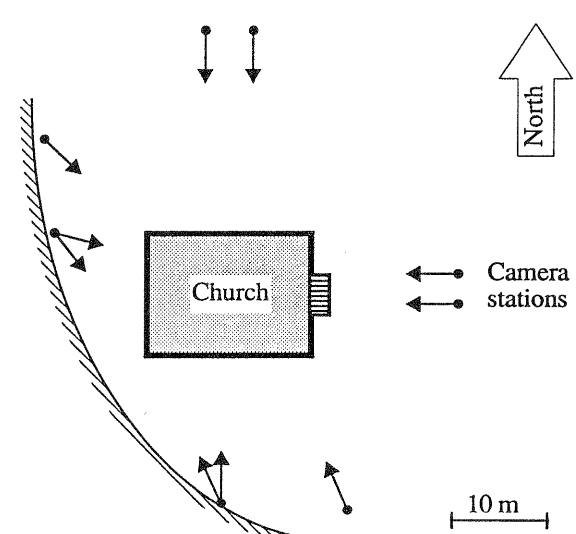


Figure 3: Object and camera configuration.

Figure 4: Rollei 6006.

figure 3). A steep slope to the south and the west makes an ideal camera arrangement impossible. So a stereo pair was taken of the north and east facade each, and three images had to be used to cover the west and south facades due to the smaller object distances.

4.1. Rollei 6006

Because of sufficient accuracy, flexibility in handling and ease-of-use, terrestrial cameras like the Rollei 6006 metric (see figure 4) play an important role for tasks in architectural photogrammetry. The Rollei 6006 metric is an one-eye, medium format (6 x 6 cm^2), full automatic Motor-SLR camera system equipped with automatic shutter

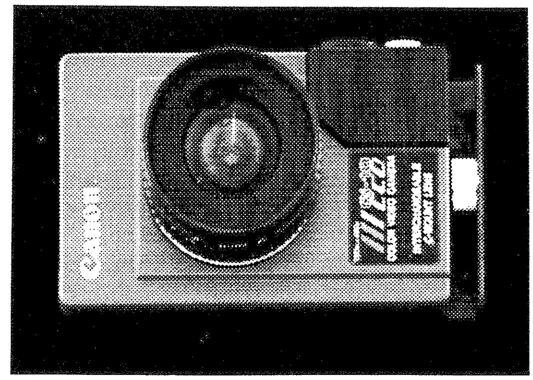


Figure 5: Canon CI-10.

and flash. Exchangeable magazines for roll films (12 exposures) and a selection of lenses make the camera system flexible for many applications. In this project, the images were taken with a 40 mm lens and a high speed colour slide film.

4.2. Canon CI-10

For the image acquisition with a camera using a solid-state sensor, a Canon CI-10 colour still video camera with a 9 mm lens was taken (see figure 5). It employs a CCD image sensor of 8.8 x 6.6 mm^2 with nearly 380'000 sensor elements (for red, green and blue) and records the images on still video floppy disks. The digitized images have a size of 508 x 466 pixels. This results in a pixel spacing of 15.3 µm in horizontal and 12.9 µm in vertical direction.

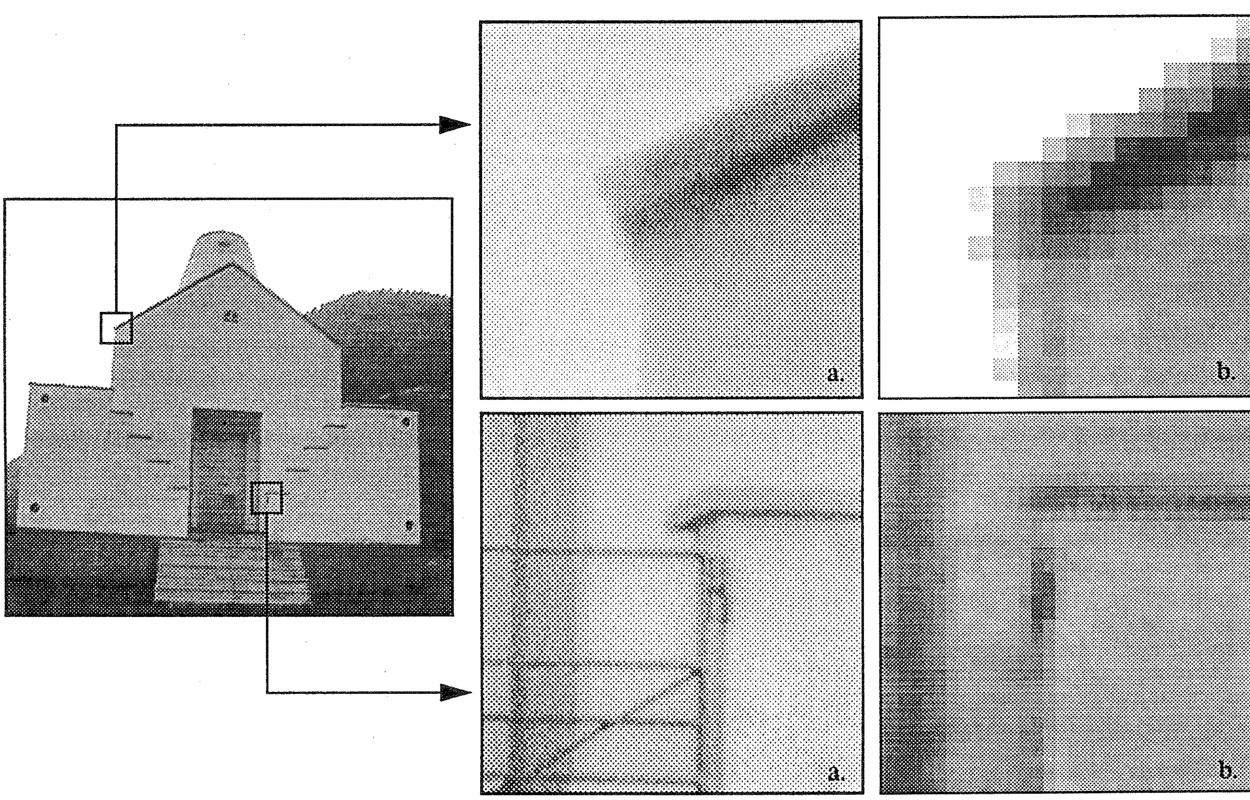


Figure 6: Zoomed image parts of the church Giova.
(a.) scanned images of Rollei 6006, (b.) images of Canon CI-10.

4.3. Digitized Rollei 6006 images

For the comparison of the results derived with the digital photogrammetric system and a conventional system under similar conditions, a stereo pair of the front facade was digitized with the scanner Optronics 5040. The 6 x 6 cm^2 colour slides of the Rollei 6006 were enlarged to 24 x 24 cm^2 colour prints. This was necessary, because the used scanner accepts only opaque media. The print was scanned with a resolution of 50 µm. This corresponds to scanning the slide with a 12.5 µm resolution. The resulting digital image has 5000 x 5000 pixel, which is comparable to the resolution of a medium format film-based camera.

The difference in resolution between the Rollei 6006 and the Canon CI-10 is demonstrated in figure 6. It shows zoomed parts of the front facade. The big difference of these two imaging systems is conspicuous. This demonstrates the need for high-resolution solid-state imaging systems for architectural photogrammetry.

5. MEASUREMENT TECHNIQUES IN DIGITAL ARCHITECTURAL PHOTOGRAMMETRY

A system for digital photogrammetry offers various methods for the measurement of image coordinates. When using semi-automatic methods, the operators task is only to judge the scene qualitatively, whereas the quantitative statement (measurement) is done by computer. The result is not affected by the subjective human measurement. Furthermore the operator is supported in such a way, that all measurements and other known informations are visualized on the screen. This is comparable with the super-imposition technique used by analytical plotters. Double measurements or confusion of points are reduced to a minimum.

Three different measurement techniques are currently implemented in DEDIP: manual point location (chapter 5.1.), point location using Least Squares Template Matching (chapter 5.2.), and feature location via line tracking (chapter 5.3.).

5.1. Manual point location

The simplest method to determine the location of architectural features in the images is to use the cursor as a manual measuring device. This is basically identical to the measurement technique used in many systems employing a digitizer (e.g. Rolleimetric MR2, Elcovision 10). In DEDIP the regions of the images, in which the coordinates have to be determined, are displayed on the screen and the operator measures the coordinates of corresponding points with the cursor. The images are usually zoomed to improve the precision of the manual measurements. Several regions of interest can be viewed simultaneously. The measured coordinates are indicated with crosses and their respective point numbers. This measurement technique does not exploit the additional capabilities offered by semi-automatic measurement methods.

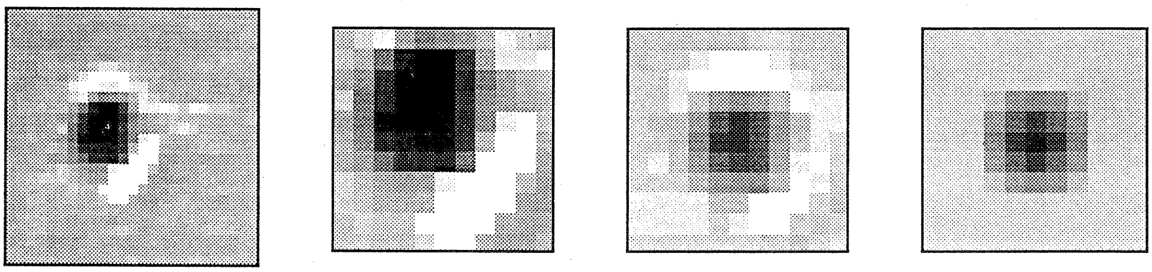
5.2. Point location using Least Squares Template Matching

In this project Least Squares Template Matching (LSTM, *Gruen, 1985*) was applied to measure the precise position of signalized points. It uses a template (artificial image of the signalized point) as reference and determines the position via an iterative procedure through the least squares fit of an affine transformation between template and patch (image region). Initially, the patch is taken at the approximate position from the image. In general this can be indicated by the operator in an interactive mode. In subsequent iterations the patch is resampled from the data of the image using updated values for the affine transformation from an interpolation algorithm. Figure 7 shows an enlargement of a part of the original image, the patch at the initial position, the patch after convergence of the algorithm, and the template. Point location using LSTM provides a very high precision. In practical applications an accuracy corresponding to $1/10^{th}$ of the pixel spacing can be achieved. Under laboratory conditions accuracies of a few hundreds of a pixel have been achieved.

5.3. Feature location via line tracking

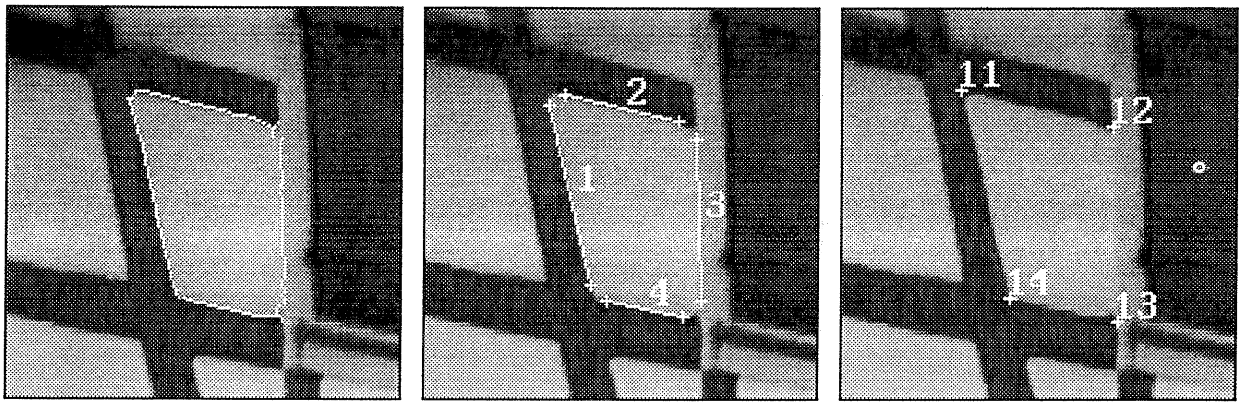
Looking at images for architectural photogrammetry one can see that in the most cases linear boundaries of an architectural feature contain more information than the vertices of this feature. The measurement technique shown here, takes advantage of this knowledge. It first locates the linear elements of the feature to be measured and then derives the vertices as intersections of these lines.

The geometric and semantic information of the object is thus generated together during the measurement process, which is important for architectural processing. Beside a list of three-dimensional object coordinates a surface



Part of image with signalized point — Patch at initial position — Patch at final position — Template

Figure 7: Image with point and number at final position, patches at initial and final position, and template of a target measured with Least Squares Template Matching.



a. tracked lines. b. extracted straight lines of feature. c. extracted vertices of feature.

Figure 8: Example for feature location via line tracking.

model of the object is created without any additional interference in the measurement process.

Figure 8 shows an example of feature location via line tracking. The approximate position of the feature is indicated by the operator in the shape of a polygon with the cursor. Starting from that positions, the linear boundaries of the feature are tracked by an algorithm using the first partial derivatives of the image (see figure 8.a.). A straight line is fitted onto each segment of the polygon (see figure 8.b.). The coordinates of the vertices are computed automatically as intersections of the appropriate straight lines (see figure 8.c.). Thereafter the geometric and semantic information of the feature is known. The operator needs only to judge the scene qualitatively while indicating the initial values for the algorithm. In principle this could be provided by a suitable CAAD-model of the object. The measurement itself is performed by the computer. This measurement technique delivers image coordinates for the vertices of architectural features with a precision of $1/10^{th}$ to $1/20^{th}$ of the pixel spacing.

6. PHOTOGRAMMETRIC ANALYSIS AND RESULTS

The photogrammetric analysis of the analogue and digital image data was performed with different hard- and software. The Digital Photogrammetric Station was used for processing the digital images and the analytical plotter Wild AC3 was used for measuring of the analogue images. The image data of the Canon CI-10 and the analogue images of the Rollei 6006 were used to determine the geometric and semantic information of the church. The Rollei images of the front facade were digitized to compare these results with the results of the analogue technique.

The reference data for the photogrammetric network was determined by theodolite. Therefore 20 signalized points were fixed on the facades and used as control points. Each facade with the ideal camera arrangement (see figure 3) includes four signalized points and each facade with the non-ideal arrangement has six signalized points. The precision of the geodetic reference coordinates is 1.2 mm in plane and 4.0 mm in height.

6.1. Calibration

To obtain precise calibration parameters for the cameras a testfield calibration was performed beforehand. For the Canon CI-10 ten additional parameters were determined using 35 images and 162 object points. The additional parameters are the three parameters of the interior orientation, a scale factor in x-direction, a shear, and parameters for the radial and decentering distortion. The relative accuracy of this testfield calibration is 1 : 10'000. The Rollei 6006 was calibrated using 8 images and 58 object points. The relative accuracy of this calibration is 1 : 7'000. The higher relative accuracy attained with the CI-10 is attributable to the high redundancy of 26 rays per object point. The results of the testfield calibration were then used for the photogrammetric analysis of the church.

6.2. Measurement

Within DIPS the image coordinates of the signalized points were determined by point location with LSTM (chapter 5.2.). The coordinates of architectural features were determined by feature location via line tracking (chapter 5.3.). In some cases, due to the insufficient resolution of the images taken with the Canon CI-10, these measurement techniques could not be used. Then it was necessary to measure these coordinates by manual point location (chapter 5.1.).

The analogue images were measured with the analytical plotter Wild AC3. All relevant colour slides which pictured the facades of the church have been processed on the stages of the AC3 for stereo measurements without exchanging the slides. The signalized points were used to determine the orientation of the stereo pair. The acquired data was displayed on a workstation, which is connected to the AC3. Moreover, the operator was able to edit the current measurements at any stage of the 3D-interpretation. For architectural processing the photogrammetric results can be transformed into a standard format and transferred to AutoCAD.

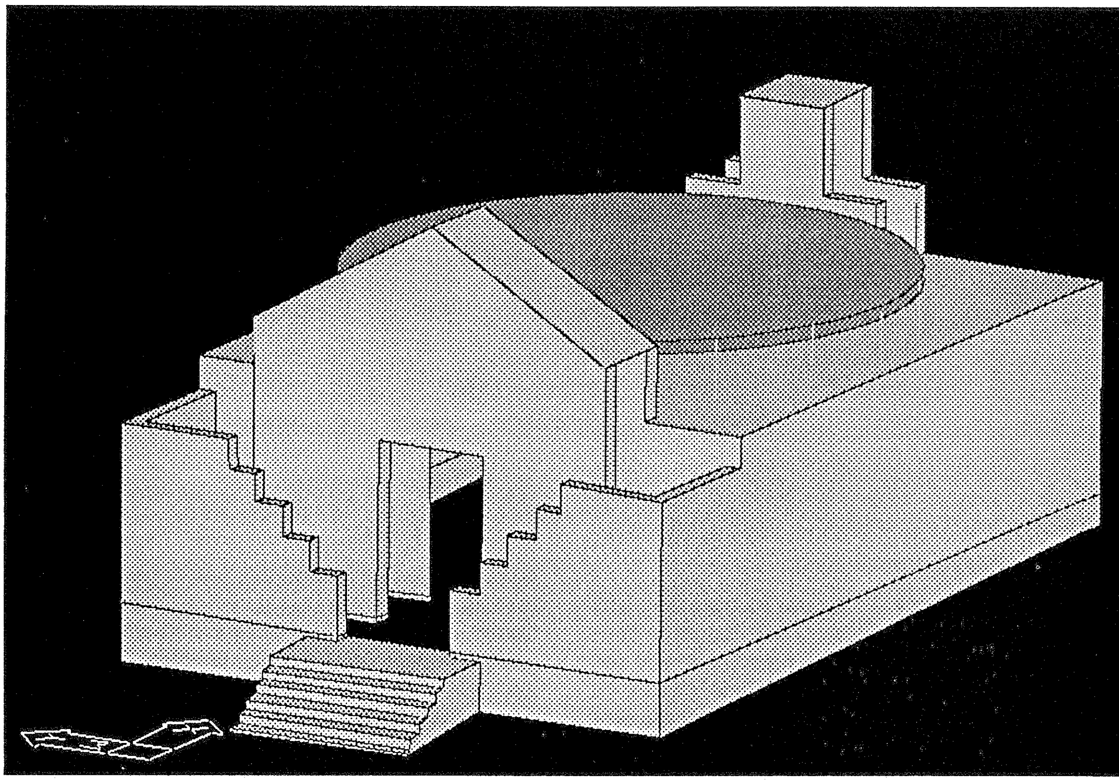


Figure 9: CAAD-model of church Giova (imagery from Canon CI-10).

6.3. CAAD-model

The result of the photogrammetric processing is a three-dimensional geometric and semantic object description, which can be passed automatically via LISP-files to the CAAD-system. This system is able to preprocess the data and store it in data structures adapted to architectural purposes. The system is capable to find efficiently special data in a huge data base. It allows data transformation into other representations in an easy way. The task of the architect is just the creative finding of new solutions or to judge the current solution. The CAAD-system is important for documentation and visualization, and for complex simulations, manipulations and analysis of the object. This could be used in art history, in preservation of historical monuments and sites, in regional and local planning, as well as in renovations and reconstructions. Figure 9 illustrates a parallel perspective view of the photogrammetric generated CAAD-model of the church. The existence of a surface model is demonstrated with the shaded representation.

6.4. Precision of photogrammetric analysis

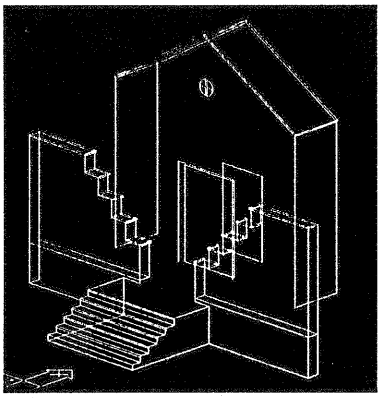
The precision of the photogrammetric analysis is assessed in two ways. First the theoretical precision of object coordinates was determined with a bundle adjustment. The results of the adjustment are given in table 1. The coordinate system was defined with X- and Y-axis in the plane of each facade and Z-axis in depth. The results indicate for the Canon CI-10 a precision corresponding to 1/3rd of the pixel spacing in image space. The theoretical precision of the object point coordinates is 2.1 cm within the plane of each facade and 4.0 cm in depth. The Rollei 6006 imagery delivers a theoretical precision of the object point coordinates of 1.3 cm within the plane of each facade and 1.3 cm in depth. This corresponds to 3.1 μm in image space. Here the analogue system seems to be superior, but this solely due to the much higher resolution of the imaging system. The results of the digital system are very encouraging when considering the low resolution of the still video camera used.

Table 1: Precision of photogrammetric analysis

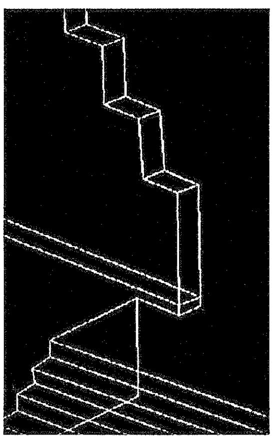
Imaging system	# of points	σ_X [cm]	σ_Y [cm]	σ_Z [cm]
Canon CI-10	100	1.8	1.0	4.0
Rollei 6006	112	0.9	0.9	1.3
Digitized images	112	0.8	0.9	1.2

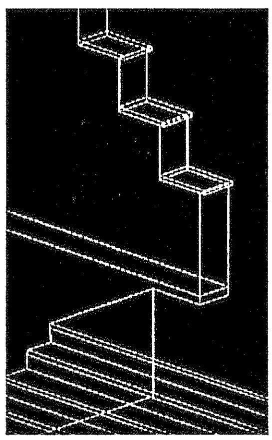
The main difference between the digital and the analogue system is not the precision of photogrammetric processing, but the architectural details which can be measured. This was demonstrated in figure 6 and can also be shown in zoomed parts of the resulting CAAD-models. Figure 10 shows the front facade generated with the analogue Rollei images (figure 10.a.) and comparable parts of the models generated with digital (figure 10.b.) and analogue techniques (figure 10.c.).

What is to be expected with a digital imaging system providing a resolution comparable to analogue film is demonstrated with the digitized images of the Rollei 6006. The theoretical precision of the object point coordinates



a. Rollei 6006.





b. part of Canon CI-10. c. part of Rollei 6006.

Figure 10: CAAD-models of the front facade.

is 1.2 cm within the plane of each facade and 1.2 cm in depth. This is comparable to the results of the analogue technique. That the results are even slightly better could not be expected, because the stereo measurement mode of the analogue technique has the advantage that the architectural details can be identified easier and better. The root mean square difference of 112 object points on the front facade between analogue and digital images of the Rollei is 2.8 cm in X-direction, 3.4 cm in Y-direction (both in the plane of the facade) and 4.1 cm in Z-direction (depth). The large size of this differences as compared to the precision of object coordinates is attributed to differences in the interpretation of the features by the operator and the digital measurement system.

Furthermore distances of the photogrammetric generated CAAD-models were compared to the corresponding distances of the object. Thirtyseven distances, ranging from 0.5 m to 13.8 m, were chosen. The average relative distance error between CAAD-model of the Canon CI-10 and the object is 0.52%, whereas the analogue technique delivers 0.44% for the same distances. For distances over 7 m the average relative distance error for the digital system is 0.27% and lower than the one for the analogue system with 0.35%. This demonstrates the accuracy of the photogrammetric processing and the influence of the sensor resolutions.

7. CONCLUSIONS

An overview of the current status and prospects of a system for digital photogrammetry and architectural design (DIPAD) was given. Advantages and current limitations of the system are shown. Conventional film-based cameras still provide for an unsurpassed photographic resolution, but the imagery must be developed and digitized before it is available in a digital system. The photogrammetric processing in a digital system is easier and faster than in an analogue system by using semi-automatic or automatic measurement techniques. The processing with more than two images at a time is possible. Digital processing is controlled by additional graphic information. The current limitation is the low resolution of the digital imaging systems. The number of architectural details which can be measured is not sufficient. This demands high-resolution solid-state sensors for architectural photogrammetry. With the automatic data transfer of the photogrammetric results to the CAAD-system a flexible three-dimensional geometric and semantic object description is given. An interaction between the Digital Photogrammetric Station and the CAAD-system is conceivable and desirable for the future. Furthermore DIPS could be supported by information from the CAAD-system. This includes knowledge on architectural styles, the construction of features, and objects build of several lower level features. Measurement routines adapted to special characteristics of features could be automatically selected. The features already measured could be used to reconstruct the object through CAAD and to support the interactive measurement or guide the automated recognition and measurement through visualization.

8. ACKNOWLEDGEMENTS

We would like to thank L. Hurni from the Institute of Cartography at ETH Zurich for the digitization of the Rollei images. The research project "Digital Architectural Photogrammetry and CAAD" is funded by ETH Zurich.

9. REFERENCES

Gazzaniga, L., 1989. Chiesa di Nostra Signora di Fatima. Domus, monthly review of architecture interiors design art. No. 703, March 1989, pp. 29-35.

Gruen, A., 1985. Adaptive Least Squares Correlation: A Powerful Image Matching Technique. South African Journal of Photogrammetry, Remote Sensing and Cartography. Vol. 14, No. 3, pp. 175-187.

Grün, A., Beyer, H., 1990. DIPS II - Turning a Standard Computer Workstation into a Digital Photogrammetric Station. International Archives of Photogrammetry and Remote Sensing, Vol. 28, Part. 2, pp. 247-255 and ZPF - Zeitschrift für Photogrammetrie und Fernerkundung, No. 1, pp. 2-10.