RECORDING OF MONUMENTS WITH HAND OPERATED CAMERA SYSTEMS

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1. Introduction

In architectural photogrammetry today not only metric, but also semi-metric and sometimes non-metric cameras can be applied, because bundle block adjustment programs and analytical plotters are available which allow for the evaluation of non-metric images and unconventional photogrammetric arrangements.
The field of architectural photogrammetry has been one of the activities undertaken by the Chair for Photogrammetry of the Technical University of Munich. In 1985, both the Omayad Mosque and the Citadele of Damascus had to be recorded by means of photogrammetry. During those projects it was one of the aims to test unconventional recording and evaluation procedures.

2. The Project

The Omayad Mosque of Damascus (figure 1) - sometimes called the Big Mosque - is the oldest mosque still in use. The building project was started by the Kalif AL Walid I in 707 A.D. and was finished in 715 A.D. It was constructed on the location of an ancient roman temple of Jupiter.

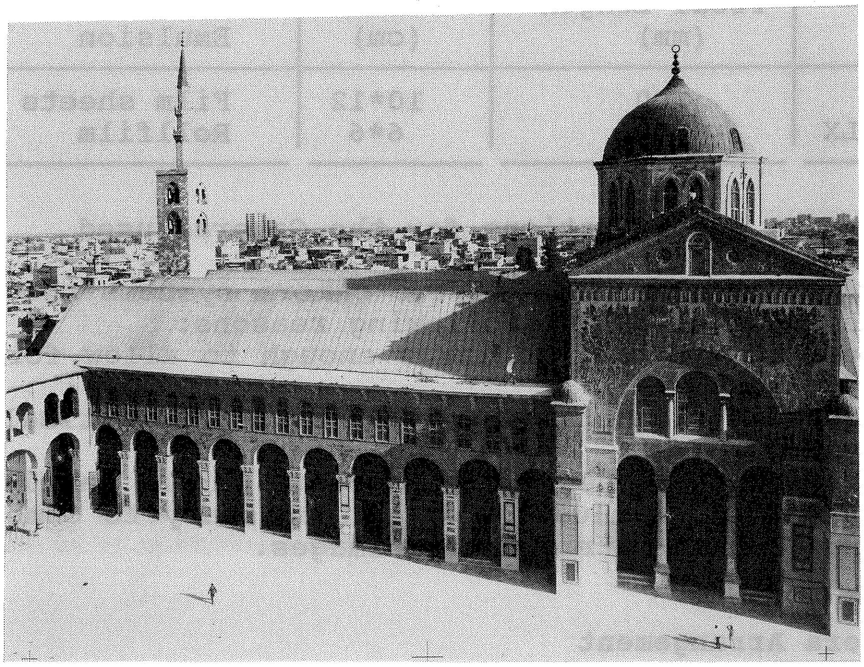

Figure 1: Omayad Mosque, Damascus. Main building with south-eastern part of the courtyard.

The prayer hall consists of three parallel naves each roofed by wooden trusses. In the middle the naves are crossed by a higher lateral nave with a central dome, where the main Mihrab is located. The interior of the prayer hall was completely renewed in 1893 after it was damaged by fire. A rectangular-like courtyard of about 123m x 49m size in front of the mosque is surrounded by double arcades in West, North and East. Besides the fontain in the centre the so called "treasure house" and the Kubbet es sa'a ("clock-house") are located in the marble covered court.

Compared with conventional metric camera systems, hand operated cameras offer the obvious advantage of more flexibility, because of less weight and therefore more efficiency in field work. But one has to consider, that its application needs a special procedure for the treatment of the data and images.
It is important to take into account, the instability and the lack of information of the interior orientation of the hand operated camera, in the evaluation of the final data.
Therefore it is interesting to compare the accuracy potential of a hand operated camera with the one of a modern metric camera during a practical project. Furthermore the handling of both systems should be investigated and the suitability for graphical evaluation of non-metric camera images should be proven.
For this project the modern ROLLEI SLX system was chosen and compared with the well known highly accurate WILD P31 terrestrical metric camera. Within this investigation the wide angle objective (DISTAGON) of CARL ZEISS was adapted to the ROLLEI SLX camera, therefore the following camera specifications were obtained:

Camera	Focal Length (mm)	Format (cm)	Carrier of the Emulsion	Tripod
WILD P31	100	10*12	Film sheets	yes
ROLLEI SLX	40	6*6	Rollfilm	no

Table 1: Camera Specifications for the Cameras used

For the comparison between the two camera systems the courtyard was choosen, because of the following reasons:
- The project is typical and large enough to allow for an informative test.
- The photogrammetric arrangement can be set up optimal for both camera systems.
- A comparison with geodetic check points can be carried out.
- For the graphical evaluation it is necessary to combine the metric and the non-metric camera images.

3. The Camera Arrangement

The arcades around the courtyard were photographed completely with both camera systems, consequently it was possible to perform a bundle block adjustment for each camera system. For accuracy and reliability reasons attention was payed to the fact that each object point was measured at least within three images

to assure for an optimal block arrangement. In order to perform a solid comparison of the accuracy achieved it was necessary to aim for similar image scales. On the other side the whole image format should be used for the final graphical evaluation. To account for these factors, camera positions along lines which are parallel to the facades have been used. On each camera station three photographs were taken, a perpendicular one and an averted one to the left and to the right.
Apart from some stations, were the exposure axis had to be changed because of the structures on the courtyard, the arrangement is rather regular. Figure 2 shows the camera positions and the exposure axis schematically. For the graphical evaluation additional photographs had to be taken from intermediate stations. The complete effort whith both camera systems is presented in table 2.

Camera	Total Amount of Photographs	Average Image Scale	Average ω-Tilt	Time Effort[h]
WILD P31	111	1:250	0^g	18
ROLLEI SLX	115	1:350	$+20^g$	4

Table 2: Total Effort for both Camera Systems

The tilt of the exposure axis of the ROLLEI SLX camera resulted from the selected camera position and the height of the arcades.

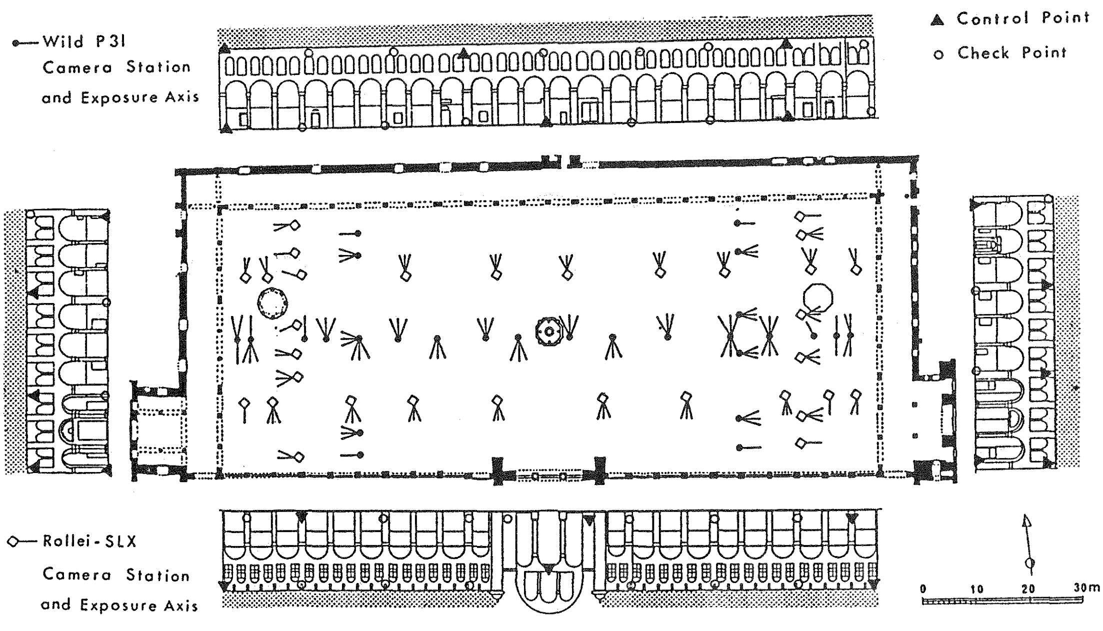

Figure 2: Camera Stations, Control and Check Points along the surrounding Arcades of the Courtyard.

For the orientation of a bundle block only the datum (positioning, orientation and scale) is necessary under the condition that the rigidity of the block is good enough. In this case the block consists of four stripwise joined image formations. To compensate the poor stiffness of the block either enough control

points (figure 2) or additional control information (figure 3) is necessary.
Additional control information such as distances, horizontal and vertical angles, local elevation systems or characteristics of the object such as plumblines, points along any spatial straight line or at plains can be used. Additional control information leads either to a reduction of the number of control points or to an improvement of the condition of the block.
A simulation with only 6 control points but additionally 6 distances along the lower part of the facades and 19 vertical angles to different points at the facades demonstrates an effective way to obtain enough control information.
In addition to the control points about 30 check points have been measured (figure 2). The estimated accuracy after the adjustment for the control and check points was 6mm in X,Y and Z.

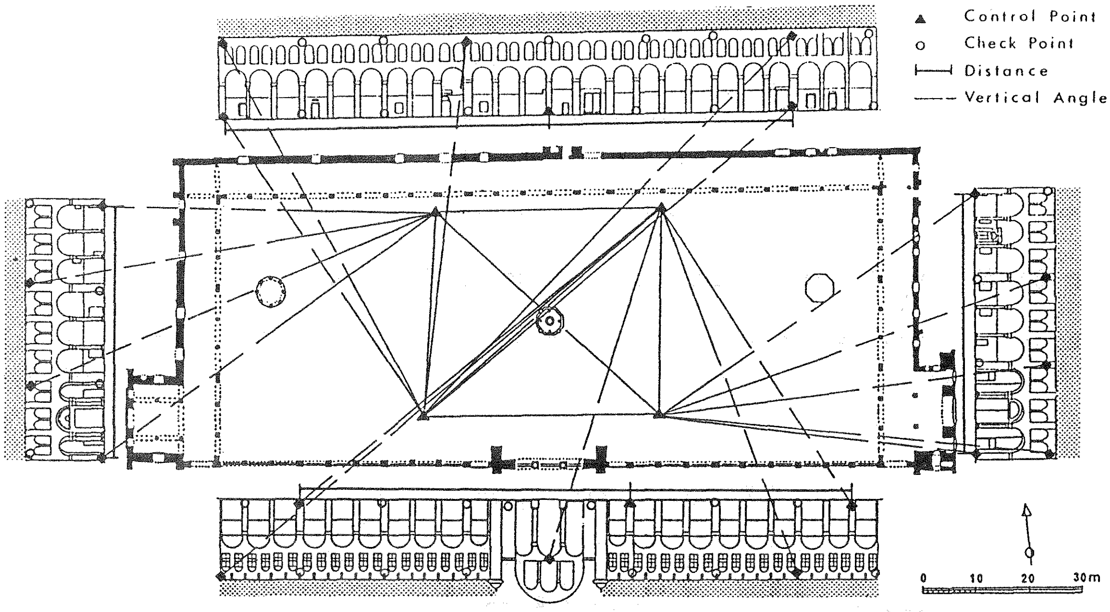

Figure 3. Additional Control Information

For an optimal photogrammetric documentation not only the camera arrangement but also the time for taking the photographs is important. According to the location of the facades within the four cardinal points, the photographs should be taken when the sun inclination angle is optimal. That means, that the procedure for taking the photographs should be as short as possible. This is an important aspect for the judgement of the camera system to be used.The metric camera has to be set up on a tripod and the exposure axis is adjusted by using a ground glass plate. Additionally the exposure time has to be measured and the film cassette has to be changed for each photograph. All these points result in the fact that only half of the long facades could be photographed under optimal exposure to the sun.
With the hand operated camera ROLLEI SLX approximately the same amount of photographs were taken. But the system offers the advantage of a reflex camera with exposure time automatic and motoric film winder. This is not only very comfortable in field work, but also saves a lot of time. This project showed that The ROLLEI SLX camera was 4 times as fast as the WILD P31.

4.1 Numerical Results

Within the preparation work care was taken that identical object points were determined from the images of both camera systems. The image coordinates were measured with an analytical plotter (ZEISS Planicomp C100) with an estimated accuracy of 4-5 microns.
For the photogrammetric point determination the bundle block adjustment program CLIC, developed at the Chair for Photogrammetry, Munich Technical University /2/ was used. It offers the possibility to use additional control information and the ability to determine the interior orientation parameters (selfcalibration) of the camera used, both essential for the project.
The results of the WILD P31 camera had a high accuracy level, as expected. The standard deviation of the image coordinates after bundle block adjustment is 5.9 microns, the theoretical standard deviation at the object points is 3mm in X, Y and Z and the rms values (root mean square) at the check points were 6mm in X, 4mm in Y and 6mm in Z. There was no significant improvement of the interior orientation parameters. This indicates a good state of adjustment of the WILD P31.
Studying the results of the ROLLEI SLX one has to distinguish different computing versions:

- Version 1: bundle block adjustment with a given control point configuration (figure 2) and measured image coordinates. The interior orientation parameters were not included in the adjustment process. As camera constant the focal length of the lens (f=40mm) was used.

- Version 2: bundle block adjustment according to version 1, but with 5 additional parameters for the camera constant the principle point and the radial symmetric distortion.

- Version 3: bundle block adjustment like version 2. Only 6 control points, but 6 object distances and 19 observed vertical angles (figure 3) were included.

The additional parameters of version 2 and version 3 were treated as block invariant.
Table 3 represents the results of the computed versions described above. It becomes obvious that the consideration of the interior orientation parameters leads to an essential accuracy improvement.The accuracy level of a metric camera is nearly reached.
Version 3 in comparison with version 2 shows that the loss of accuracy is not significant but the effort for surveying control points can be reduced considerably by using additional control information. The standard deviation of the image coordinates after block adjustment increases to 6.6 microns and the rms values at the check points are 13 mm in x, 9 mm in y and 16 mm in z.

ROLLEI SLX	Version 1	Version 2	Version 3
Images Control Points Object Points	78 20 299	78 20 299	78 6 299
Additional Parameters Additional Control Information Redundancy	0 0 1565	5 0 1560	5 25 1543
Standard Deviation of the Image Coordinates σ_o [µm]	47.7	6.4	6.6
Mean Theoretical Stand. Deviation after Block Adjustment $\sigma_x, \sigma_y, \sigma_z$ [mm]	33, 31, 47	4, 4, 6	8, 5, 16
RMS Value μ_x, μ_y, μ_z at Check points [mm]	27, 15, 48	9, 6, 8	13, 9, 16

Table 3: Results of the ROLLEI SLX camera

In version 2 the following values for the interior orientation parameters and their standard deviations were obtained:

Camera Constant	40.742 [mm] ±0.005 [mm]
Principle Point in X	0.177 [mm] ±0.004 [mm]
Principle Point in Y	0.178 [mm] ±0.004 [mm]
Distortion Parameter A1	-24.561 $[m^{-2}]$±0.181$[m^{-2}]$
Distortion Parameter A2	17047.9 $[m^{-4}]$±145.5$[m^{-4}]$

With the values A1 and A2 of version 2 the distortion of the DISTAGON objective and its standard deviation can be computed using the formulas:

$$dx = (dr/r) * x \quad \text{and} \quad dy = (dr/r) * y$$

with: $dr = A1*(r^3 - r*r_o^2) + A2*(r^5 - r*r_o^4)$ and $r^2 = x^2 + y^2$
dx,dy.... Displacement of image coordinates x,y
r_o....... Radial distance for dx= dy= 0 [20 mm]

Radius R [mm]	0	5	10	15	20	25	30	35
Distortion [µm]	0	32	48	36	0	-40	-36	90
Standard Dev. [µm]	0	0	0	0	0	0	1	2

Table 4: Radial Distortion of the DISTAGON Objective

Obviously the main part of the systematic errors are caused by the distortion of the objective and the wrong camera constant. However the displacement of the principle point also shows significant values.

4.2 Graphical results

For the graphical documentation different procedures have been investigated. The traditional "on-line" drawing results in plans still favoured by archeologists, architects and other experts. One of the main advantages is, that the lines and edges are drawn exactly according to reality. The disadvantage of this procedure is that it is very time consuming and it does not use modern mapping facilities offered by analytical plotters and CAD systems.

Consequently digital mapping is more effective because the operator is supported by the system. The plot file produced can be edited at any time and the plot may be easily reproduced at any scale on different plotting materials. Finaly the desired plot windows may be defined by the operator.

The collected data may be introduced into a CAD system. This offers the posibility of manipulating the data and of various graphical representations of the whole structure.

The problem with digital mapping in architectural photogrammetry is, that the operator has to decide whether straight line connections, splines, circles, squares ect. may be applied to represent the real shape of a structure line. Otherwise a sequential "tracing mode" has to be used. An optical superimposition like the ZEISS Videomap system proved to be a very good tool to control the plotted lines and the completeness of the plot.

Figure 4 shows a part of the eastern arcades, produced with the ZEISS Planimap digital mapping program. Two plains have been plotted, the front facade of the arcade and the interior wall. For a better impression to the observer the two plans have been overlayed in figure 4. While observing the plan another problem appeares: Large areas of the interior wall are hidden by the front of the arcades. The only possiblity to complete those areas is to use additional stereo pairs taken between or inside the arcades. For this task the ROLLEI SLX camera turned out to be very useful, too. Of course the state of calibration obtained with the bundle block adjustment was introduced for the graphical evaluation.

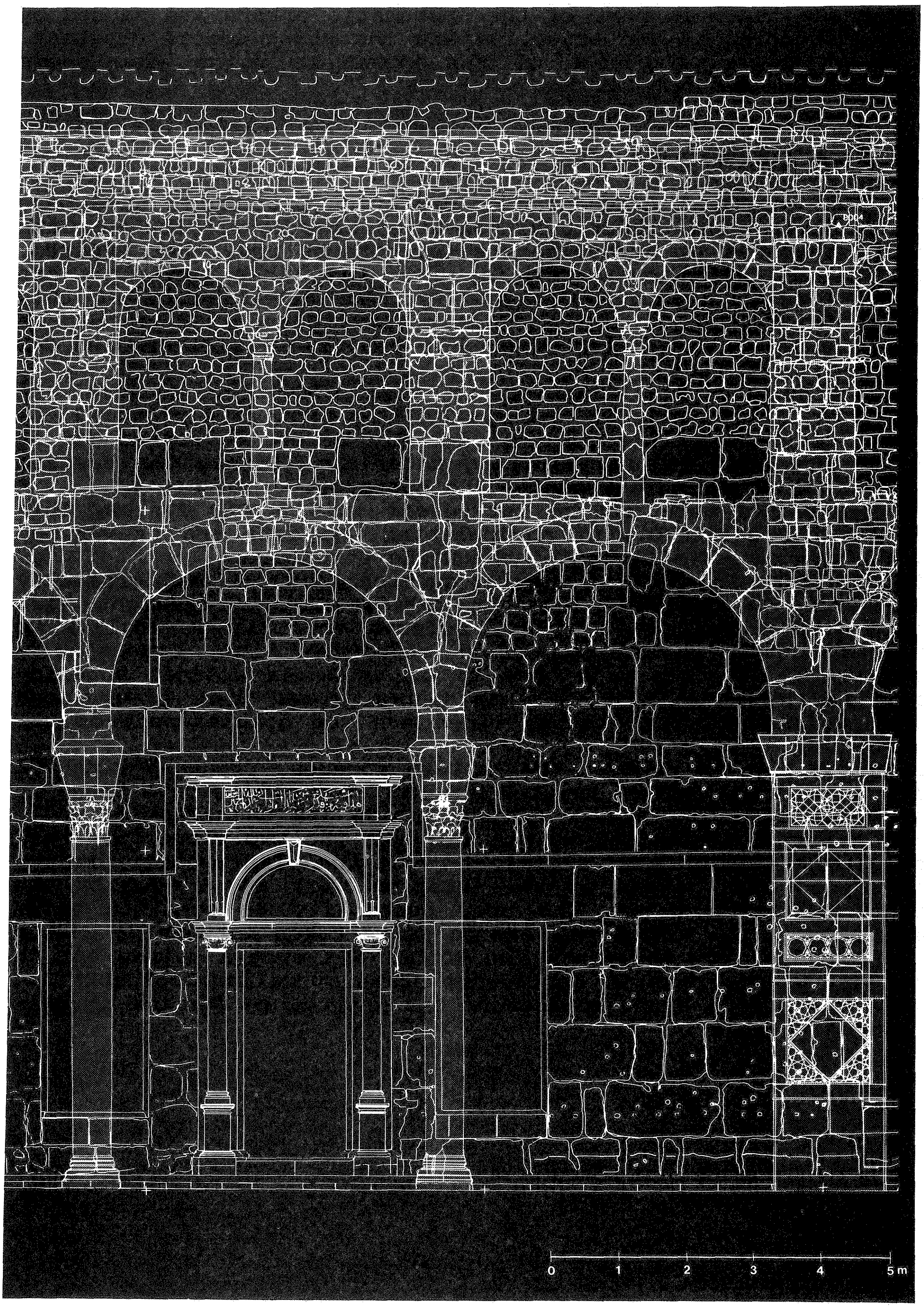

Figure 4. Graphical Evaluation of a Part of the Eastern Arcades.

At an evaluation scale of 1:50, small but important details like mosaics, marble inlaid work, wooden carvings and parts of the masonry are not represented properly. For this task either the evaluation scale must be enlarged or another evaluation technique has to be applied. If the facade is flat, a rectification may give good results. For spatial structured facades however, only a differential rectification is possible. Stereo orthophotos may support a detailed interpretation.
As an example for orthophoto production, the mosaic at the main portal to the prayer hall of the Big Mosque was choosen. Within a student work, a three dimensional digital surface modell was established using a P31 model. For the computation the program package HIFI /1/ of the Chair for Photogrammetry was used. The program is able to compute a regular grid (resp. profiles) from arbitrary distributed reference points, break lines and skeleton lines. This grid with a mesh size of 0.4 m supplied the scanning profiles for the orthoprojector ZEISS Z2. Figure 5 shows the digital surface model projected in an oblique photograph of the portal.

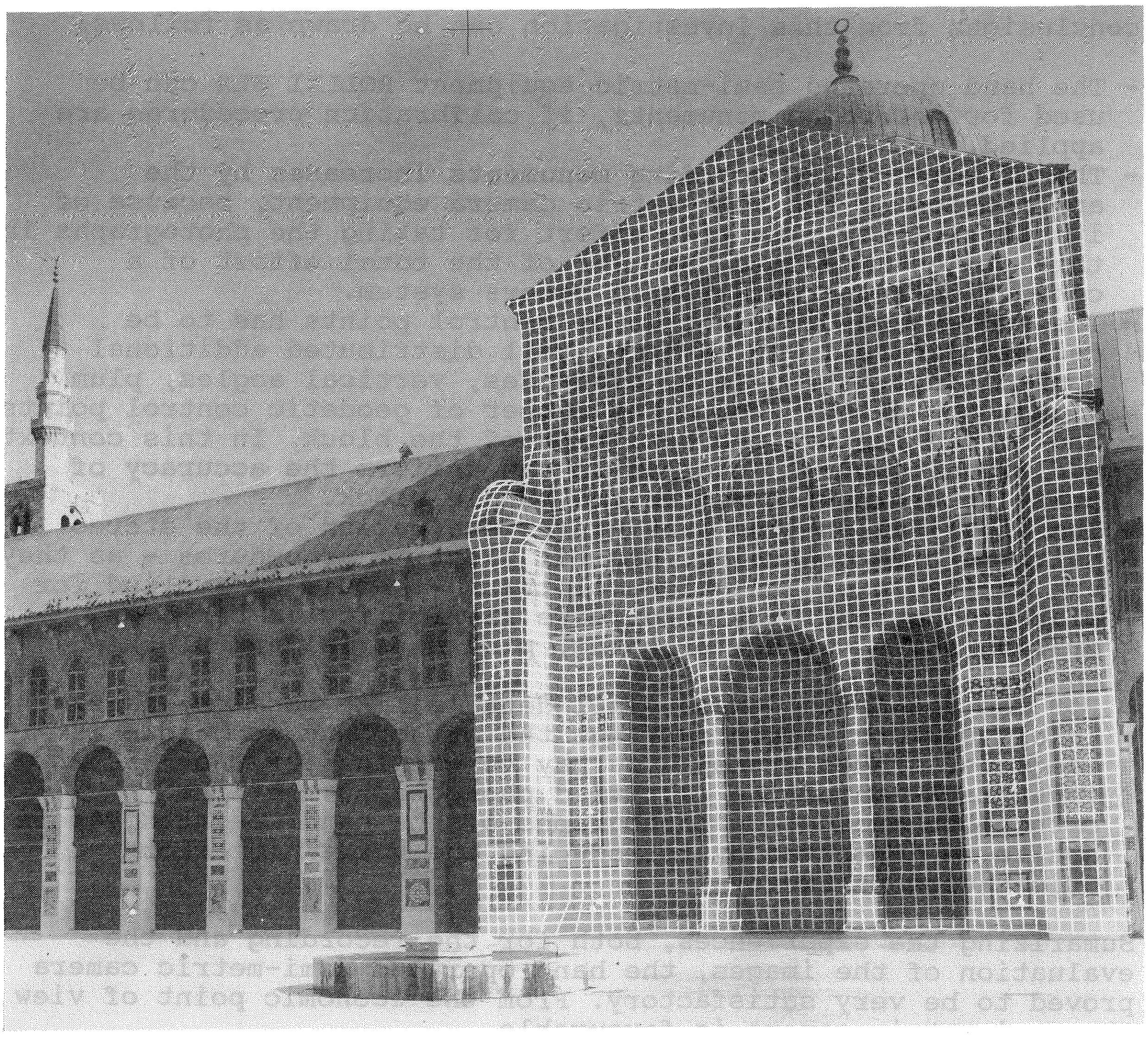

Figure 5. Digital Surface Model, projected in an oblique Photograph.

An orthophoto based on ROLLEI SLX images of the famous "Barada Mosaic" which extends at the upper western arcades was produced. During the orthopoto production, the state of calibration of the camera obtained from the block adjustment was introduced. In order to get a complete orthophoto of the mosaic, a digital surface model is necessary which covers the mosaic entirely. Now for each part of the mosaic, the concerning photograph of the hand operated camera is rectified /3/. This way a coherent documentation of this important cultural heritage was obtained. The condition of the mosaic now can be studied in detail, since it was documented years ago in a photoplan by IGN-UNESCO /4/.

5. Conclusions

The potential of a hand operated camera system (ROLLEI SLX) for recording architectural monuments was compared with that of a highly accurate photogrammetric equipment (WILD P31)in an extensive practical test. In order to evaluate the accuracy reached with both systems geodetic control was used. The main conclusions from this investigation can be drawn as follows:

- The hand operated semi-metric equipment ROLLEI SLX can be used for recording monuments, if calibration procedures are applied.
- The efficiency of recording monuments increases by the application of the semi-metric camera equipment, because of its flexibility. The time effort for taking the photographs in this project was less than 25% of the total effort of a conventional photogrammetric camera system.
- The number and distribution of control points has to be decided carefully in advance. Well distributed additional control information (e.g. distances, vertical angles, plum lines) may either reduce the number of geodetic control points and/or may improve the condition of the block. In this context additional control information can uniform the accuracy of point determination within the bundle block.
- The classical on-line drawing for evaluation of the stereo pairs is time consuming. Digital plotting procedures - as they are available on analytical plotters - should be applied for plan production. They offer more flexibility in terms of drawing scale, window plotting, plot material and plotting tools.
- For the documentation of small details like mosaics, marble inlaid work or wooden carvings the orthophoto technique is adequate. Stereo orthophotos may be helpful for the interpretation of the rectified photographs. For the orthophoto production photographs of the hand operated camera are to be corrected by introducing the actual interior orientation parameters.

Sumarizing the experiences, both for the recording and the evaluation of the images, the hand operated semi-metric camera proved to be very satisfactory. From the economic point of view the semi-metric camera is favourable.

Literature

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