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Architecture with Analytics

Application of analytic photogrammetry and an amateur camera to architectonic mapping.

ABSTRACT: *Analytical methods can be applied successfully to photogrammetrical problems in architectonic mapping. The continuous process of facade drawing on stereoplotters is replaced by the numerical evaluation of coordinates of individual points. Photographs are taken with an amateur camera.*

INTRODUCTION

ARCHITECTONIC MAPPING has been accomplished to date with analogue instruments, stereocameras and phototheodolites. However, stereoplotters are slow to operate, and specially trained operators are required. Moreover, as the same instrument serves both for measurement and plotting, expensive equipment is used inefficiently in simple graphic work.

The mapping process may be simplified and improved by applying the techniques of analytical photogrammetry. The idea of separating the measurement and plotting procedures, the latter performed with simple drafting instruments and based on numerical information derived from the photographs, is due to the second author[1]. This technique has been applied by the second author over a considerable period of time, to numerous projects, using phototheodolites and stereocameras. Collaboration between the authors led to additional improvement and to a technique based on the use of a roll-film amateur camera.

The following is based on some of the authors' relevant experiences; they believe that their work is one of the few attempts made in this particular field, and hope that it will prove of interest to specialists in architectonic mapping.

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NUMERICAL MAPPING SYSTEM

Analytic photogrammetry consists mainly in determining the space coordinates of a certain number of points within the reference frame of the photographed object. Although the task seems simple enough when presented in this form, in practice this is not the case. An analytic approach to this type of mapping involves a complex of instruments and manpower which have to derive answers to a series of problems, including what kind of camera to use, what to measure, what instrument to use for measuring how to compute, and how to present the results graphically. In addition, the procedure must compete successfully with *classical* mapping techniques in terms of accuracy, cost, convenience in operating the equipment, trained manpower requirements, output, etc.

WHAT CAMERA TO USE

The camera is required to yield information of superior quality. Where numerical processing of the data is concerned, it is mainly the photographic quality that counts. Details recorded by the camera should be as sharp, as clear, and as abundant as possible. Geometrical requirements are secondary here for two reasons: for one thing, as the camera is calibrated, no difficulty is involved in taking the calibration data into consideration; secondarily, photographs scales are large (1:400 to 1:200) in view of the short ranges involved.

Another feature required from the camera is facility and flexibility of operation. Architectonic mapping frequently contains problematic objects: photographs have to be taken in narrow streets and at short range,

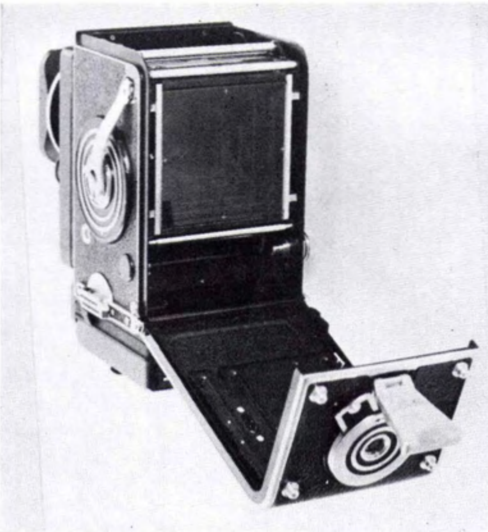

FIG. 1. A Rollei amateur camera was equipped with a glass plate which bore the fiducial marks and which also served as a pressure plate for film flattening.

sometimes from roofs or through windows of nearby buildings, or at unusual angles; a large building photographed close-up must be covered by a large number of pictures. In these circumstances, the roll-film amateur camera, hand-carried and operated without a tripod, is best suited for the above purposes. The advantage of such a camera are obvious. It is inexpensive compared with the stereocamera; its output is high; the need for transportation of cases with glass plates, and for recharging cassetes under field conditions, is avoided; and also one has complete freedom in choosing photo bases and camera directions. As for photographic quality, amateur cameras which are in no way inferior to a stereocamera are available.

Obviously, the camera must be adapted for measuring purposes: fiducial marks must be added in the negative plane, the principal must be located, and the focal length and radial-distortion curve must be determined. Flatness of the film throughout the photography process must also be ensured.

In the present study, a *Rollei* camera was used with a wide-angle objective and a plane-parallel glass plate in the image plane with fiducial marks engraved on it (see Figure 1). The camera was calibrated by the three-dimensional test field method developed at the Institute of Photogrammetry in Stockholm. During exposure the film is flattened against the plane-parallel glass plate; experience showed that it remain sufficiently plane.

WHAT TO MEASURE AND WITH WHAT

Substitution of analytic for analogue processing means intermittent instead of continous plotting. Hence the importance of choosing a representative set of points which describe fully the object mapped. In the instance of a front elevation of buildings, the points should define and determine all necessary and characteristic details such as openings, brick courses, gutters, roof elements, or decorative details, etc. Although not excessive, their number should still suffice for a comprehensive description. Hence, the selection should be entrusted to a trained specialist capable of judicious and economic choice. Once the points have been chosen and marked on an enlarged photograph, the measurement can be made by an operator without special training in architectonic mapping.

The scale of the negatives being large, a relatively simple measuring device—a small stereocomparator with a standard deviation of the order of 0.01 mm—would suffice. The photographs are frequently very convergent or oblique, so that the stereoscopic effect in the comparator may be lost. As the measured points refer to defined details on the photograph, such as corners of intersections, it may be assumed that separate measurement of each picture on a monocomparator, or even on a precise coordinatograph, would be possible.

The small size of the negatives (6×6 cm) permits a rapid rate of measurement, two models per hour on the average.

COMPUTATION

The program (see flow chart, Figure 2) which was prepared for processing the measured data permits a model to be constructed from any arbitrary pair of photographs. It entails no assumptions as to the size of orientation angles, the number and position of the orientation points, or depth differences.

A few remarks are in order with regard to the routines of restituting the model and of the absolute orientation. Relative orientation is effected with the aid of angular elements only. The orientation solution is based on series expansion of the coplanarity condition of corresponding rays, with the expansion coefficients determined from sets of angles obtained in successive iterations. For the first iteration, the angles are taken as zero. Convergence is rapid, and five iterations suffice even if the angles are of the order of tens of degrees. All measured points are included in the solution process; this is advantageous, as it provides uniformity in the accuracy of the coordinates determined in the model system, all of which are of equal importance. Frequently, the mapped object does not cover the entire model and the zone of interest is only a part of the model. In this instance, points outside the zone have to be included with a view to a distribution which will permit a more accurate solution of the relative orientation.

For the absolute orientation and the determination of the final coordinates in the object system, control points determined with the aid of in-situ measurements are necessary. Analytic processing permits a convenient reduction of the amount of field work by recourse to available object data. A building usually containes a considerable number of symmetric configurations of lines and elements which may be utilized for orientation purposes. When planning the photographic procedure at the site, one has to consider how the object is to be presented graphically. This implies the selection of the plane (or planes) on which the object is to be projected and subsequently plotted. In these circumstances, every identifiable point in the photograph lying in that plane becomes a *height* control point with known Z-coordinate. In addition, all points along a horizontal line are of the same Y-coordinate, and all points along a vertical line are of the same X-coordinate. With this information included in the program, the amount of in-situ work is minimized and, in fact, a single horizontal distance between a pair of points in the drawing plane suffices in each model. Analytic processing also permits convenient data matching between models and improved integration of separate models into one system.

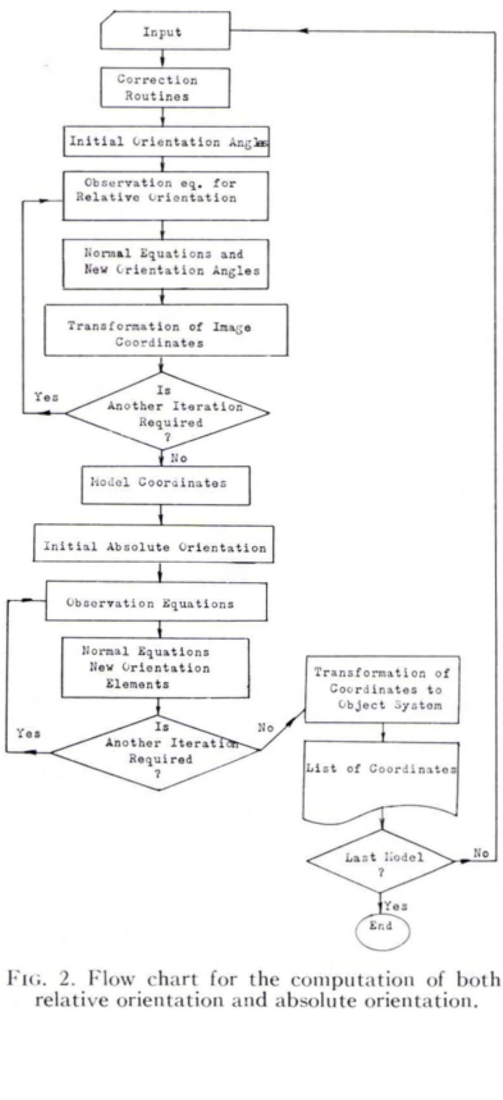

FIG. 2. Flow chart for the computation of both relative orientation and absolute orientation.

The proposed technique was successfully applied in a number of projects. An explicit description of the computation process is given in Reference 2.

PLOT AND ACCURACY

The coordinates of measured and computed points are plotted to the required scale and form the skeleton of the object containing all the characteristic details in their correct interrelationship. Completion of the map is realized with the aid of conventional drafting instruments, missing details being reproduced from enlargements and marked within frames plotted according to coordinates. The technique in general resembles graphic rectification.

The accuracy of measured point coordinates is high and suitable for large-scale drawings (1:50). This accuracy is due to several factors: the large scale of the negative; the analytic procedure used, based on general projective relations; large bases, and convergent photography providing ray intersections at convenient angles; uniformity of the model, secured by inclusion of all points in the relative orientation; and, finally, exhaustive utilization of object data.

As for the accuracy of unmeasured details, all plotted lines are straight lines connecting measured points, in disregard of the real situation (such as irregularities due to wear or to faulty construction)—in other words, the final drawing represents the building in an

FIG. 3. A curved street including the fronts of 10 small buildings.

idealized form. It may be assumed that the result corresponds to the designer's original plan and reflects his idea to a greater extent than the building itself. Where irregularities are of special interest (as in the instance of reconstruction or repair), the desired data are obtainable by a denser coverage of the negatives.

EXAMPLES

Figures 3 and 4 show a curved street block comprising 10 frontages of small buildings.

Due to the close quarters, convergent photography had to be resorted to, with roof details taken from windows of opposite buildings. The time required for covering the whole object, using the Rollei camera, totalled one working day. Actually, the work was performed intermittently as dictated by lighting conditions. A view of the frontages is shown in the upper part of Figure 4, and the lower part shows the control points used for the numerical processing (a total of 21, i.e., only two per frontage). The points were referred to a local coordinate system, the XY-plane passing through the first control point on the left and the next-to-last on the right, with the X-axis horizontal and the Y-axis vertical.

The control points were marked at the bottom of the elevations near the pavement. Above them, additional control points were subsequently chosen on the photographs with only their Z-coordinates known (taken as identical to that of the control point in the corresponding vertical section).

Over 500 points (an average of 50 per model) were chosen and marked on the enlargements, measured with a stereocomparator on the negative, and used for preparing the skeleton of the drawing. Some of the points common to adjoining models were measured and computed twice, thereby providing an accuracy check both for the continuity of the models and for the procedure as a whole. Matching of the models was satisfactory, as was the accuracy of the coordinates from the viewpoint of the drawing scale. The processing rate on a large computer was about 30 seconds per model.

The drawing was prepared as described previously in the form of a projection on a vertical plane parallel to the XY-plane. This projection was chosen in reference to a development in order to secure a single comprehensive view of the whole object. It is worth noting that the analytical processing permits one to prepare such a projection easily, and it follows from the choice of the reference frame to which the control points are related.

The correctness of the applied procedure

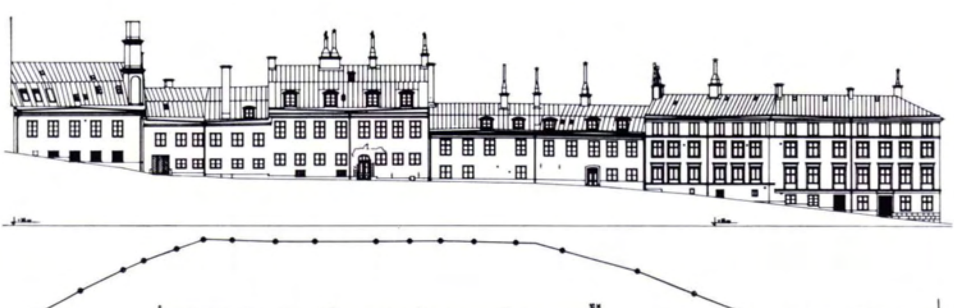

FIG. 4. A drawing of the building fronts shown in Figure 3. The lower part shows a traverse of the control points.

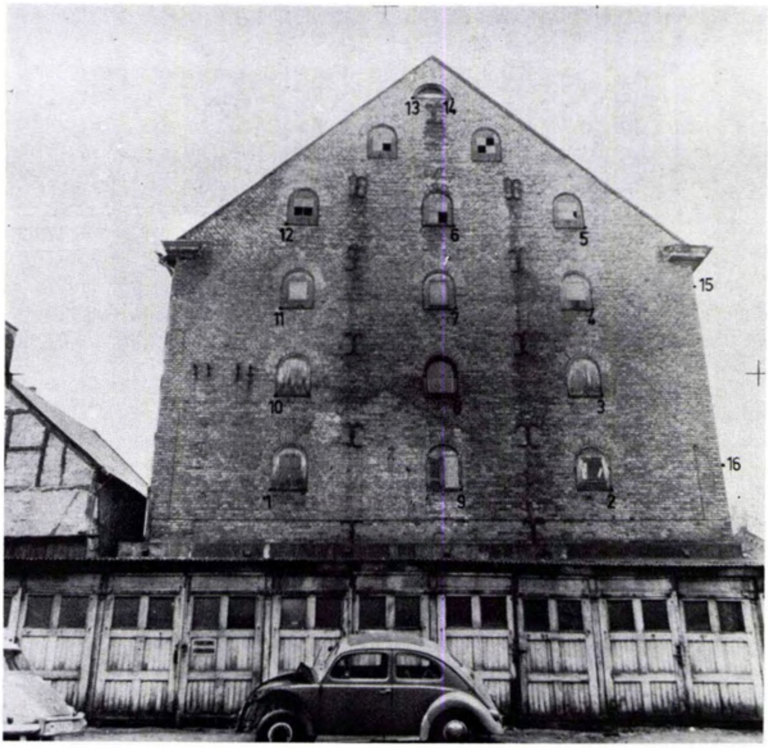

FIG. 5. Façade of an old storehouse showing numerous numbered points selected on the wall.

may be demonstrated by a numerical example.

Figure 5 shows the façade at an old storehouse in Malmö, Sweden, taken with the Rollei camera without a tripod (distance about 20 m, negative scale about 1:400). A number of points were selected on the wall; some of them are indicated on the photograph. The only measurement made was the distance 1–2. Points 1, 2, 5, 12 were assumed to be coplanar and used as control points, and coordinates were assumed for them as shown in Table 1.

The Y-coordinates for points 1, 2, were chosen arbitrarily; as line 1–2 was taken as horizontal, the Y-coordinates are the same for both points.

TABLE 1. COORDINATES ASSIGNED TO COPLANER POINTS ON THE FACE OF A BULIDING

Point	*X* *meters*	*Y* *meters*	*Z* *meters*
1	0.00	7.76	0.00
2	8.87	7.76	0.00
5			0.00
12			0.00

For relative orientation all points were used. The iterative process comprised four steps. The standard deviation of the discrepancies in the coplanarity condition was 0.005 mm in the negative plane. For the absolute orientation three steps were required.

TABLE 2. COMPUTED COORDINATES OF ALL POINTS

Point	*X* *meters*	*Y* *meters*	*Z* *meters*
1	0.00	7.76	0.016
2	8.87	7.76	−0.016
3	8.88	5.19	0.006
4	8.86	2.60	0.007
5	8.86	−0.02	0.016
6	4.92	−0.02	0.008
7	4.93	2.61	0.016
8	4.92	5.21	0.030
9	4.93	7.76	0.008
10	−0.01	5.22	−0.012
11	0.00	2.67	−0.055
12	0.02	0.00	−0.016
13	3.76	−4.56	0.000
14	5.00	−4.54	−0.001

The computed orientation angles were relatively large, the ω-tilt was -22.7653^g.

The computed coordinates are summarized in Table 2. As the points are assumed to lie on common straight lines, the coordinate values illustrate the validity of the method very clearly.

Summary

The paper deals with some aspects of the application of analytical photogrammetry to architectonic mapping. It discusses the equipment, computational scheme, and drawing technique to be used.

The advantages the method offers are reflected in the required amount of site measurements for determining control points, in the flexible and rapid photography process, in the high rate of measurement and processing, and in the use of simple drafting devices. Examples demonstrate the efficacy of the method.

An additional development in the application of analytic methods is a recourse to strip triangulation. A strip can cover a large object and provides a uniform system of control points for mapping purposes. Rapid photography and use of roll film permits the object to be photographed twice, once with suitable overlapping of the models for triangulation puposes and once for measurement of details and for plotting, in the event the first strip be unsuitable for the plotting.

References

1. Redelius, "Application of Photogrammetry to Architecture," *Report*, Stockholm 1968.
2. B. Shmutter, "Triangulation with Independent Models," *Photogrammetric Engineering*, June 1969.