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Orthophotography in Architectural Photogrammetry

Orthophotography preserves more detail and can be prepared more rapidly than conventional stereo-plotted line drawings.

(Abstracts on next page.)

INTRODUCTION

PHOTOGRAMMETRIC STEREO PLOTTING is the technique usually practiced for graphic representation of architectural objects. This method has been found to be both accurate and applicable to objects of any type, shape, and size. The result of stereoplotting is a line map which shows the recorded object in the form of elevations and plan views.

The efficiency of the method, however, becomes questionable if richly decorated or painted surfaces must be plotted. The time expended increases rapidly with the quantity of details and it is possible that analogue plotting of baroque fresco - paintings or classicistic façades requires drafting times of, for example, several weeks per model. This problem demands other representation techniques, especially for the application of continuous - tone processes.

In some institutions elevation maps of façades have been produced by rectification of simple enlargement of photographs. If the objects are extended in depth, radial displacements caused by central projection are found in the off - axis areas. Thus, rectification methods can be applied only to plane or almost plane surfaces. A better adaptation to the object is made possible by improving the degree of rectification. Separate transformation of parts and zones of the object can reduce the displacements, but causes more extensive mosaicking.

In order to revise topographical maps a method for differential convertion of central - perspective photographs to an approximate parallel projection has been applied for years. It can be expected that this technique, called "ortho-projection", will have uses in architectural work as well. The first experiments made by several institutions have supplied good results and have encouraged continuing research in this field. In the following a description of the special process for producing orthophotos in architectural photogrammetry is given here together with results of accuracy and efficiency tests. Examples of orthophotos give an idea of possible applications.

ORTHOPHOTO PRODUCTION IN ARCHITECTURAL PHOTOGRAMMETRY

Because of the heterogeneity of different objects, the production of orthophotomaps in architectural surveys requires a detailed design of the project parameters for photography and orthoprojection. All terrestrial cameras and orthoprojection systems are qualified more or less for architectural purposes.

PHOTOGRAPHY

Project planning begins with the selection of a suitable camera. Here the focal length, i.e., the angular field, is of special importance for the accuracy and image quality of the resultant photomap. From the ortho-

ABSTRACT: *Stereoplotting of richly decorated or painted surfaces is the most time - consuming part of an architectural survey. Photographical representation methods based on simple enlargement or rectification can be applied only to plane or almost plane objects. An improved rectification process is possible by application of the orthophototechnique which is well established in topographical photogrammetry. Before differential rectification, the parameters of photography and orthoprojection should be coordinated as nearly as possible. In this process great importance must be attached to the selection of the optimal scan width and of the proper profiling speed. The accuracy of architectural orthophotomaps averages approximately ± 15 mm, in reference to the object, and is sufficient for architectonic tasks. If the client calls for line representations, the orthophoto can be used as a base for direct tracing on overlay sheets. This method takes only one third the time needed for conventional stereoplotting. Initial research with the orthophototechnique in architectural photogrammetry has been encouraging. The examples of orthophotos given in this report show the variety of possible applications and demonstrate the qualification of different orthoprojection systems for architectural tasks.*

RÉSUMÉ: *La restitution graphique d'objects richements décorés ou de surfaces peintes à un appareil stéréophotogrammétrique nécessite la plupart du temps pendant un relevé architectural. Les méthodes de représentations photographiques qui basent sur un élargissement ou un redressement d'images, peuvent seulement être appliquées sur des objects à peu près plans. Un redressement différentiel peut être atteint par l'orthoprojection qui est employé dans la photogrammétrie topographique. Pour réaliser une telle tâche on doit coordonner les paramètres pour la prise de vue et la restitution orthophotoscopique. Il faut accorder une grande importance à la sélection de l'intervalle optimal de profils ainsi qu'à la propre vitesse du filage. La précision d'orthophotocartes architecturales se monte à ± 16 mm moyenne en référence à l'objet et est bien suffisante pour le relevé architectural. Si le client demande des dessins au trait l'orthophoto peut être appliqué pour le tracé direct. Ce procédé ne nécessite qu'environ un tiers du temps exigé pour une restitution stéréoscopique. Les premières expériences avec le redressement différentiel dans la photogrammétrie architecturale étaient encourageantes. Les exemples des orthophots ci-jointes montrent bien la variété des possibilités d'application. Pour des tâches architecturales on voit une qualification principielle de systèmes différents d'orthoprojection.*

ZUSAMMENFASSUNG: *Die linienhafte Kartierung reich verzierter oder bemalter Objekte an einem photogrammetrischen Stereoauswertegerät benötigt den zeitlich größten Anteil bei der architektonischen Bauaufnahme. Photographische Darstellungsmethoden, die auf Bildvergrößerungen oder Entzerrungen basieren, sind jedoch nur bei ebenflächigen Objekten anwendbar. Ein verfeinerter Entzerrungsprozess kann durch die Anwendung der aus der topographischen Photogrammetrie bekannten Orthophototechnik erreicht werden. Vor der Durchführung einer solchen differentiellen Entzerrung sind aufnahme- und auswertetechnische Parameter weitgehend aufeinander abzustimmen. Besonderer Wert ist auf die Festlegung des optimalen Profilabstandes sowie der richtigen Abtastgeschwindigkeit zu legen. Die Genauigkeit von architektonischen Orthophokarten beträgt im Durchschnitt ± 15 mm, bezogen auf das Objekt, und ist für Zwecke der Bauaufnahme völlig ausreichend. Werden vom*

Auftraggeber Strichdarstellungen gefordert, so kann in den meisten Fällen das Orthophoto zur direkten Hochzeichnung verwendet werden. Die Hoschzeichnung benötigt nur ca. 1/3 der für eine Stereokartierung gleicher Detailfülle notwendigen Zeichenzeit. Die ersten Erfahrungen mit der Orthophototechnik in der Architekturphotogrammetrie waren ermutigend. Die Bil dbeispiele zeigen die Vieleseitigkeit der Anwendungsmöglichkeiten und lassen eine prinzipielle Eignung verschiedenster Orthoprojektionssystem für derartige Aufgaben erkennen.

projection process a number of errors arise which are caused by the operator, the object, and the rectification system itself. System errors as a result of height differences inside the rectification element, profiling errors, image motion, and radial displacements all depend on the angular field. Smaller aperture angles or larger focal lengths reduce these errors. If small - angle cameras are not available, the image field of wide - angle photography should be restricted.

The arrangement of the photogrammetric survey also influences the subsequent orthoprojection. Large differences in height with regard to the Z - range of the instrumentation later used should be avoided. This problem is resolvable by a greater camera - to - subject distance which, however, can be obtained only in a few cases. One should also take care that protruding parts of the object will not be imaged at the border of the photograph. These arrangements, which improved the quality and the accuracy of the orthophoto, extend on the other hand the number of photogrammetric models. With more experience in this field, a compromise between accuracy and economy will certainly be found.

ORTHOPROJECTION PROCESS

The orthophoto procedure normally begins with the preparation of the image material and adaptation of the camera focal length and the image size to the available orthoprojection system. In most cases copying processes for getting duplicates or enlargements are necessary. This procedure can be done in special transformation printers and rectifiers. However, optical or electronical dodging should be included in order to get even contrast on the photomap.

Preparation also demands planning of the model scale and of the orthophoto scale, dependent on the ranges of the instruments. While the *X*- and *Y*-range for architectural work are generally sufficient, it is difficult to fit the whole depth of the model into the Z range. Thus, the model scale and the orthophoto scale in the architectural field do not represent values to be chosen independently, but are determined by the instruments' limitations. Therefore, in order to obtain the final scale of the photomap, reproduction processes become necessary.

The most important parameters for orthophotoproduction relate to the scanning procedure itself. Almost all orthoprojectors which divide the model into parallel strips admit scanning only in the *Y* - direction, i.e., perpendicular to the base line. This direction seems to be suited to architectural work as well, because many objects are curved mainly in the *Y* - direction. Therefore height must be changed only from strip to strip.

For these reasons the scan width should be selected with care. In stripwise orthoprojection only those points will have exact horizontal position which are situated on the scanning profile. Points off the profile center change their position, depending on the height difference between the model and the approximating surface. So displacements such as gaps, double contours, and mismatches appear in the orthophotoplan. These so - called system errors are greatest if differential rectification to a horizontal plane (zeroth - order differential rectification) is applied, as in most orthoprojection systems. The amount of displacements can be reduced by using a smaller scan width, but scanning time and stress to the photogrammetric operator increase accordingly.

Since particularly in photographs of aesthetic objects (art, architecture), errors displease the viewer, a refined model approximation is required. For this the orthoprojection system Zeiss GZ 1 for off - line operation seems to be exceptionally qualified. Storage of profiles enables an improved model approximation by "electrical interpolation" of intermediate profiles. Projection may be performed in smaller scanning paths without any additional work for the operator. "Optical interpolation (0-Int)" by inclining of the projection surface up to ± 35° is possible in order to reduce the system errors.

Figure 1 shows the effect of decreasing the scan width in the representation of a 45° inclined ledge. It is obvious that the sytem errors must be diminished as far as possible in order to preserve the original shape of the object. An improvement of the model approximation by electronic scanning systems and digital guiding of orthoprojectors is anticipated for the future.

Profiling errors such as displacements between adjoining strips appear if the object is inclined in the scanning direction or if the curvature of the surface changes suddenly, shown in Figure 2 for the border of a cupola. The only way to minimize this kind of displacement is to reduce the scanning speed. For architectural orthophoto work a variable profiling speed should be possible in any case. Moreover the Y-drive should be stoppable during the scanning procedure in order to follow protruding parts of the object with the floating mark. This possibility is available only in a few orthoprojection systems.

SUBSEQUENT TREATMENT OF ORTHOPHOTOS

The pure orthoprojection is followed by reproduction work for the adaptation of scale, for photo - mounting and retouching. Experience has shown that several copying processes do not really affect the quality of the final product if careful photographic treatment is provided. For the preparation of photomaps little retouching is normally necessary.

If line maps are required by the client they can be derived from orthophotos by direct tracing on overlay sheets. This work does not need a photogrammetric operator and should be carried out in architectural style. Methods of transforming continuous - tone photographs to line maps automatically by equidensities, Agfacontour film, or by "pic-

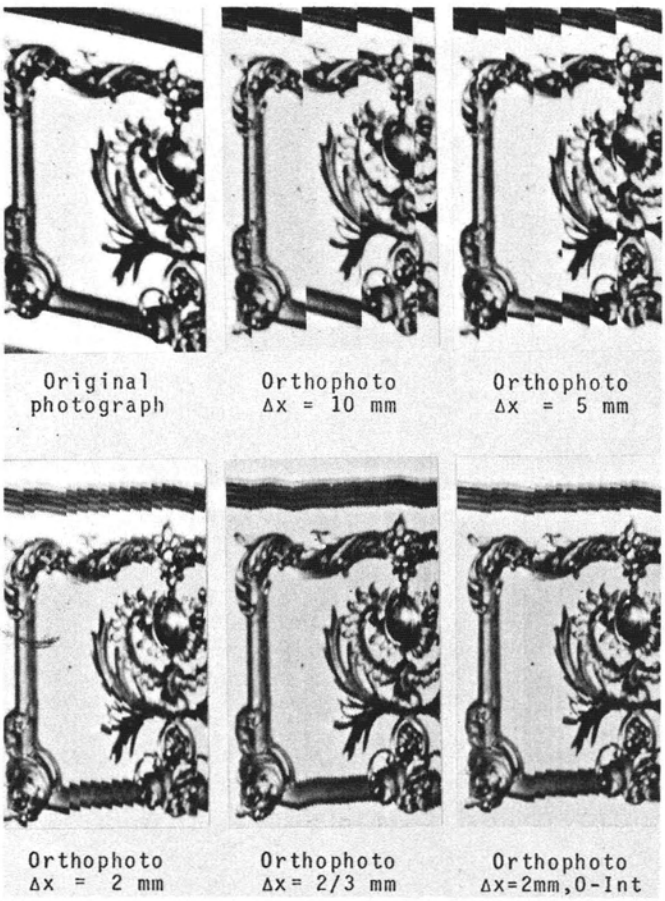

FIG. 1. Reduction of the system errors by decreasing the scan width.

FIG. 2. Displacements at the border of a cupola caused by profiling errors.

toline technique" are in the experimental stage and cannot be considered operational.

Another manner of representation seems to be the graphic combination of photomaps and linemaps; thus, architectonic elements of importance can be restituted by stereoplotting, while painted or decorated surfaces are produced as rectified photographs. Both parts then can be joined graphically. Architectural plans are normally used only in a few copies; therefore photographic reproduction is possible.

PROBLEMS IN APPLICATION OF ORTHOPHOTOTECHNIQUE IN ARCHITECTURAL WORK

Although the scope of application in this field can be extended considerably both by detailed planning and by the best possible utilization of the instruments, there still remains a type of surface to which orthophototechnique should not be applied. These are subjects composed of staggered planes and protruding elements which cover other details. Buildings of this type are antique temples, porticos, Gothic cathedrals or, for example, churches in the Baroque style. They cannot be represented by orthophotoplans in general. Only parts of these objects such as cupolas, frescos, paintings or façades are suited to differential rectification. The decision concerning the type of representation depends upon the object and should be made before starting photogrammetric work.

ACCURACY

The accuracy of orthophotomaps in the architectonic field depends upon the precision

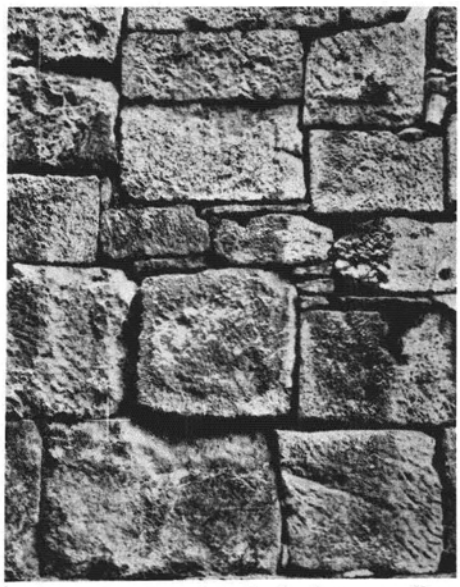

FIG. 3. Regensburg (FRG), the Roman wall; orthophoto, Wild Heerbrugg.

of terrestrial control, on photographic image formation, system and profiling errors in orthoprojection, and on the accuracy of the reproduction processes. The final accuracy is to be regarded as an accumulation of the single influences and can be evaluated in this way. All the figures given here refer to the object scale. They originate from extensive tests carried out at the Photogrammetric Institute of Stuttgart University.

Every photogrammetric work is based on control points. In architectural survey these points can be given within an accuracy of ± 1 to ± 10 mm. Errors of image and model formation amount to ± 1 mm each, again with reference to the object. From ortho-

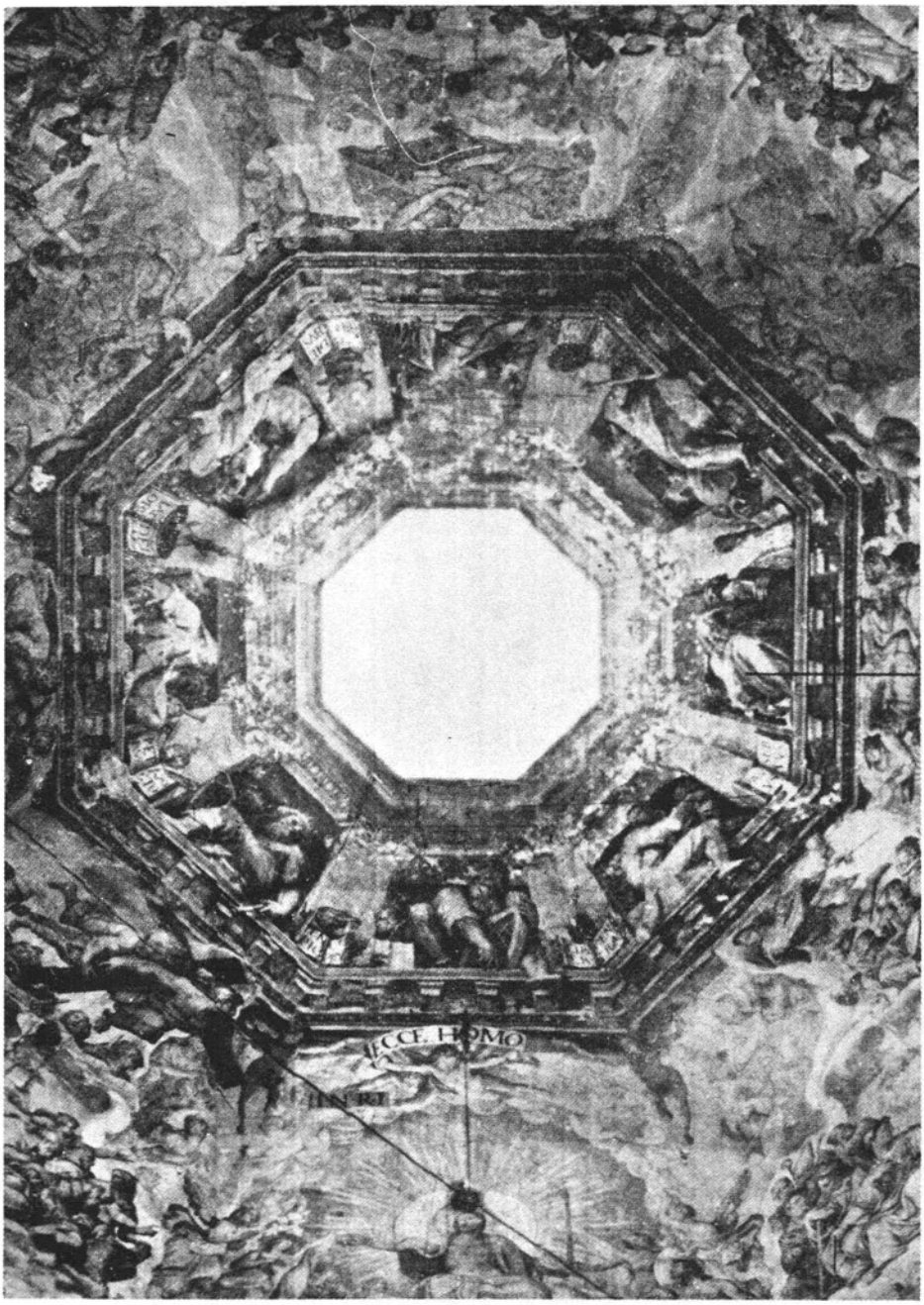

FIG. 4. Florence (Italy), cupola of Sta. Maria del Fiore; orthophoto, Galileo Florence.

projection arise coordinate errors of about ± 10 mm on the average, which is equivalent to 0.15 mm at a mean orthophoto scale of 1:70. This value includes errors of connection and orientation in the orthoprojection system, deviations in profiling caused by the operator, as well as system errors resulting from the degree of model approximation.

If polyester-fortified paper of great dimensional stability is used in the copying processes, errors of ± 1 mm in the object are expected. Regular photographic paper changes its size depending on humidity and temperature so much that it should not be applied to this kind of work. The assembling of image parts into a photo mosaic causes errors of about ± 7 mm in the adjusting and pasting process.

After summarizing all of these factors, there results an accuracy of about ± 15 mm on the average, also with reference to the object. This evaluation is not independent of suppositions such as scale, camera angular field, or the object itself, but the value was confirmed by measuring check points in some final orthophotomaps of different scales. The examination of accuracy obtained by stereoplotting of the same objects amounted to ± 15 mm as well, so stereorestitution has no advantage over orthophotography in accuracy.

Drawing on overlay sheets can be done

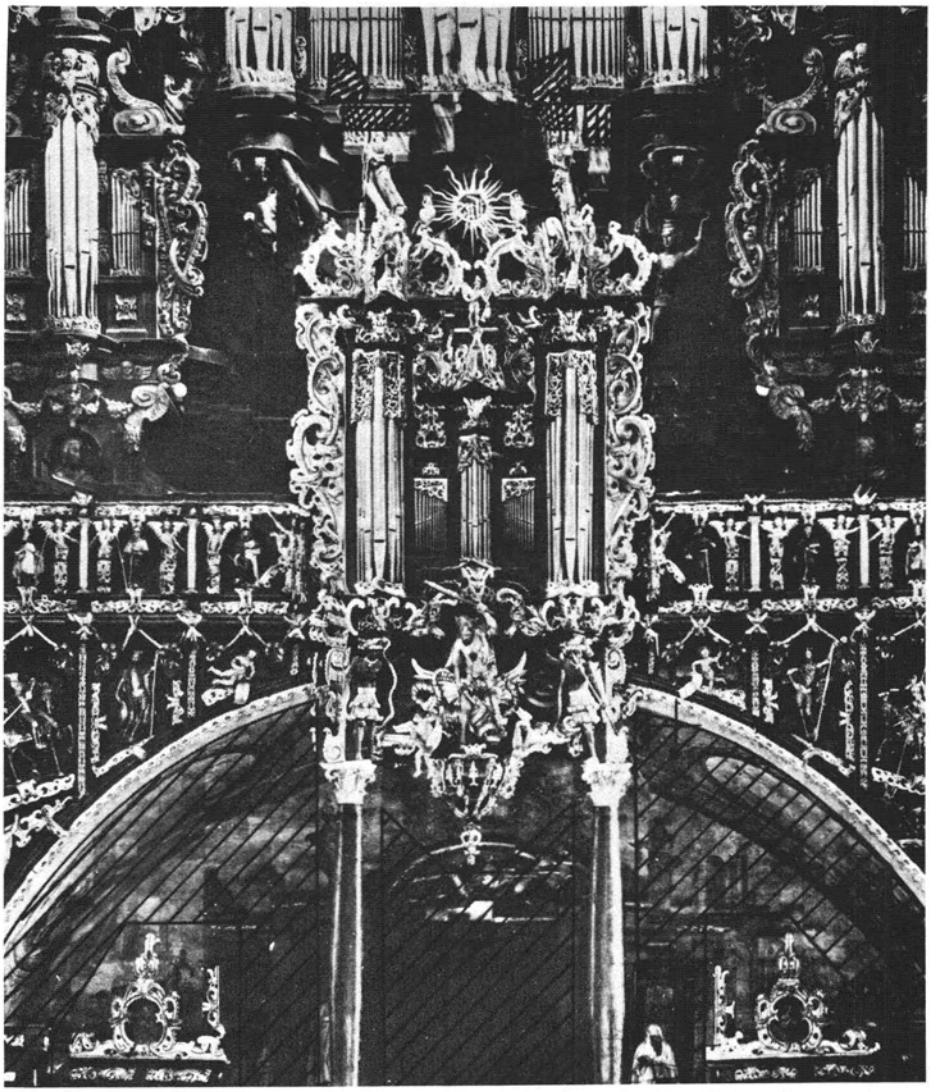

FIG. 5. Lezajsk (Poland), organ screen; orthophoto, Cracow University.

within an accuracy of ± 0.15 mm independent of scale, which means about ± 10 mm in the object, assuming a tracing scale of 1: 70 in accordance with the figures given above. Enlargement of the orthophoto and tracing in a larger scale can reduce the drawing errors in relation to the object.

The accuracy of about ± 15 mm, which can be obtained by orthophotomap production, stereoplotting, or direct tracing, normally meets the requirements of the architect or the art historian.

Comparison of Times

The amount of time demanded for the production of architectural orthophotos is dependent on the size of the model, the profiling distance, and the scanning speed. Because these parameters vary from object to object, it is not possible to give general figures. From experience, which refers to a mean model area of 270 cm² in the Zeiss Planimat, to a scan width of 2 mm, and an on - line profiling speed of 2.5 mm/sec, the following times result:

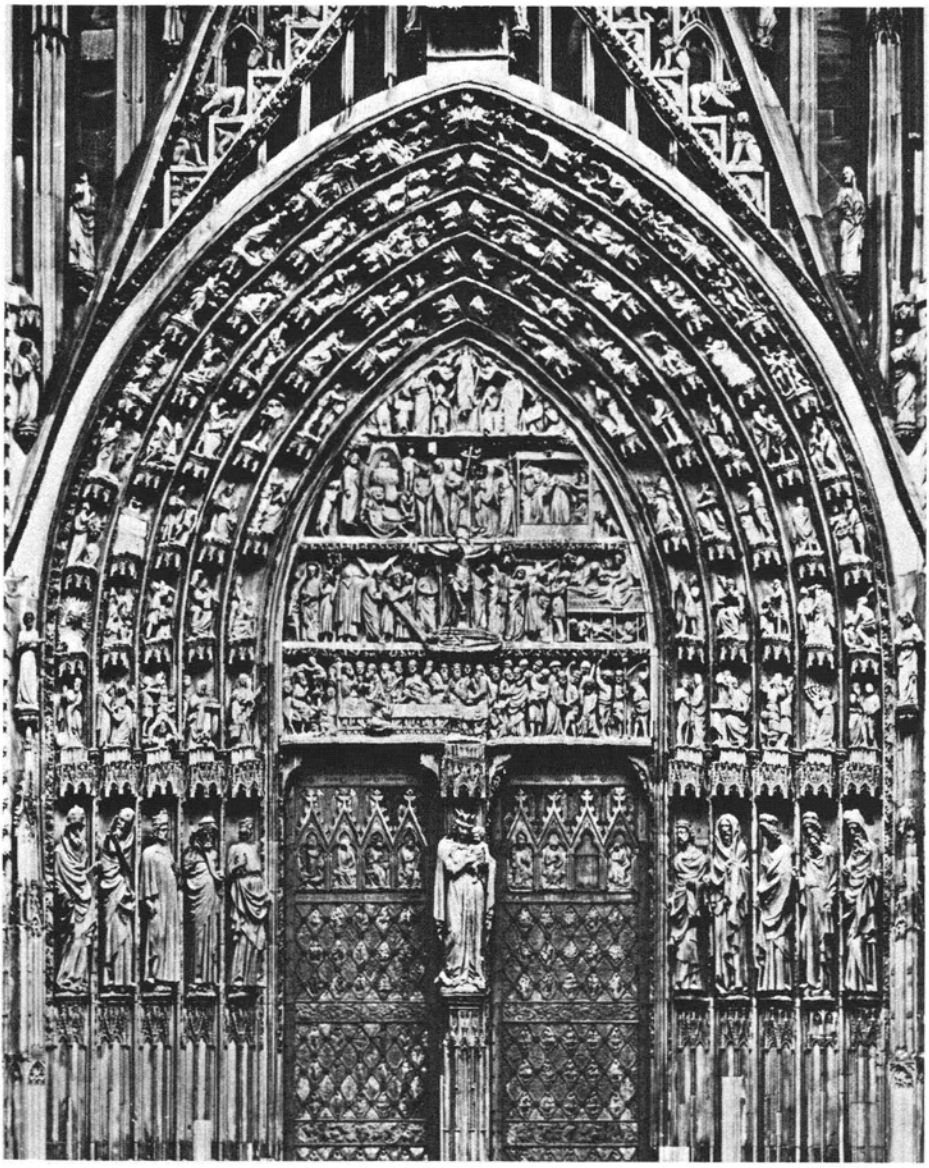

Fig. 6. Strasbourg (France), portal of the cathedral; orthophoto, Stuttgart University.

Preparation	1.5 hours
Scanning (projection)	1.5 hours
Total time	3.0 hours

In off - line operation with the Zeiss Planimat - GZ 1 system the scanning time amounted to 1.5 hours on an average, which also represents a mean scribing time of 2.5 mm/ sec. Projection time in off - line operation depends on electrical interpolation facilities and can take several hours more than profile scribing. This fact can be less important because projection time only occupies the orthoprojector but not the operator.

Direct tracing and stereoplotting require much more time than the production of photomaps. An estimate would be an increase by a factor of 5 to 10, depending upon the quantity of details to be mapped. The same increase in time occurs in topographical applications of the orthophotomap. Providing the same density of detail representation, direct tracing on overlay sheets takes only one third the time needed for conventional stereoplotting. Corresponding results originate from cartographical tests of Commission D of the OEEPE (Organisation Européenne d' Etudes Photogramétriques Experimentales).

Consequently, the most economical method of representation is the photomap, at least as far as production time is concerned. The advantage is diminished by higher instrumentation costs, but remains nevertheless significant.

Present Research and Results

Some institutions have carried out differential rectification applied to architectural

Fig. 7. Ottobeuren (FRG), cupola of the monastery church; orthophoto, Stuttgart University.

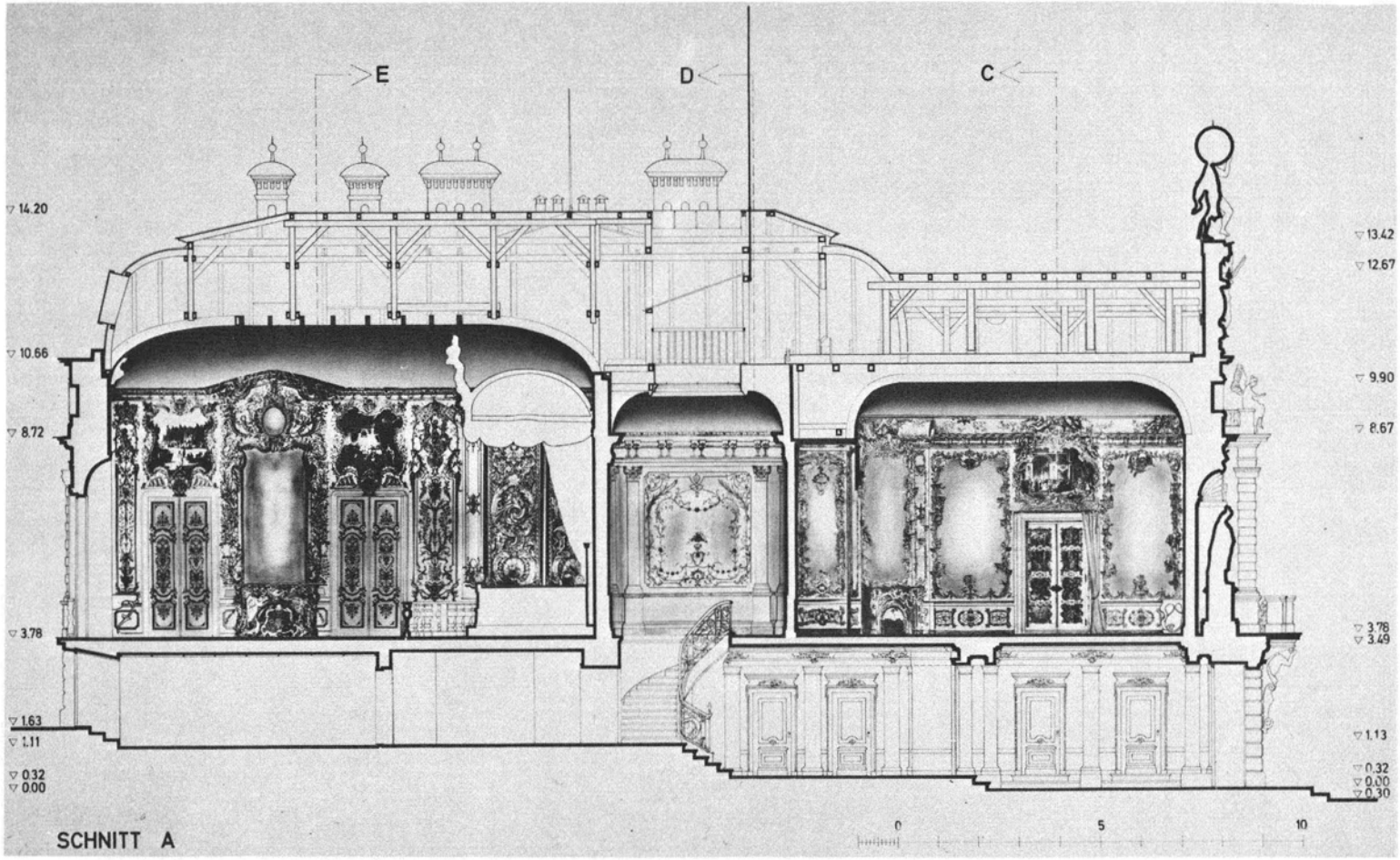

FIG. 8. Linderhof Castle (FRG), combined photo-line map, Stuttgart University.

TABLE 1. PRODUCTION DATA CONCERNING THE ORTHOPHOTOS IN FIGURES 3 TO 8.

Figure	Object	Institution	Orthoprojection system
3	Regensburg, FRG roman wall	Wild, Heerbrugg Switzerland	Wild A 8 + PPO 8 Δx = 3 mm in the scale 1:20
4	Florence, Italy church, cupola	Galileo-Santoni Florence, Italy	Galileo Orthophoto—Simplex
5	Lezajsk, Poland organ screen	Photogr. Inst. Cracow, Poland	Jenoptik Topocart—Orthophot
6	Strasbourg, France cathedral, portal	Photogr. Inst. Stuttgart, FRG	Zeiss Planimat + GZ 1, off-line, 0—Int, Δx = 2 mm in the scale 1:40, profiling time: 1 hour, projection time: 3 hours
7	Ottobeuren, FRG church, cupola	Photogr. Inst. Stuttgart, FRG	Zeiss Planimat + GZ 1, off-line, 0—Int, Δx = 2 mm in the scale 1:58, profiling time: 2 hours, projection time: 5 hours
8	Linderhof, FRG castle, vertical section	Photogr. Inst. Stuttgart, FRG	Zeiss C 8 + GZ 1, on-line, Δx = 2 mm in the scale 1:11, stereoplotting: Zeiss Terragraph

objects. Comprehensive research, however, exists at the moment only at the Photogrammetric Institutes of Cracow, Poland, and Stuttgart, West Germany.

A few examples of architectural orthophotos are given in the Figures 3 to 8. Table 1 contains data concerning them. Importance is attached to the mention of various orthoprojection systems and orthophoto producers. The examples show that it is possible to obtain architectural orthophotos by quite different instrumentation.

For objects having great discontinuities special arrangements such as changing the slit width, the profiling speed, or the degree of model approximation become necessary perhaps. Modification of the instruments by the manufacturers cannot be expected for this field of application. Therefore one must manage for the present with the available instrumentation.

APPLICATIONS OF ARCHITECTURAL ORTHOPHOTOGRAPHY

The orthophoto technique can be applied in architectural photogrammetry to objects which are curved or extended in depth. The advantage of this method becomes evident if these surfaces are painted or richly decorated. In particular there are mosaics, frescos, and ceilings in stucco, and vaults and cupolas of different styles (See Figure 4, 7). Mural decoration (See Figure 8) or paintings can be represented by this technique, too. Façades or parts of churches (See Figure 5, 6), castles, or official buildings come into consideration, as well as stone walls (See Figure 3).

As mentioned before, there are objects like temples, porticos, or cathedrals which are not suited for differential rectification or continuous - tone representation. In those cases, however, in which photographical processing by rectification is applicable, this method is time-saving and equivalent in accuracy to conventional stereoplotting. The greatest advantage of continuous - tone imaging is the preservation of every detail. This advantage should be utilized for architectural representation whenever possible.

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