

## THE INTEGRATION OF CONVENTIONAL AND AUTOMATIC PHOTOGRAMMETRIC METHODS TO THE BUILDING SURVEY IN HISTORIC BUILDING RESEARCH

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### ABSTRACT

In the field of historic building research and archaeology there is a special demand for the application of photogrammetric methods. The architect is used to measure all important building geometry by hand based methods with a very aesthetic ink-drawing as a final result. To combine the modern and traditional methods an integrated surveying strategy is developed by the Chairs of Surveying and Historic Building Research of the BTUC. As an example a project at the Palatine in Rom is presented. Starting from the experiences of the Palatine project consequences for the use of photogrammetry in historic building research are formulated. An idea of a voxel based photogrammetric surveying system is introduced.

### 1 SPECIAL DEMANDS ON THE SURVEYING OF BUILDINGS FOR HISTORIC BUILDING RESEARCH AND ARCHEOLOGY

In building survey the importance of photogrammetric methods increases more and more. Photogrammetry is a successful tool for the survey of complete cities as well as for small building details. In various applications photogrammetric methods are accepted very well, especially the close range photogrammetry is a frequently used technology to determine the geometry of buildings facades. In most cases all visible geometric information has to be measured within the photogrammetric survey. Measuring the main characteristics of a modern building, like doors, windows e.g., is relative easy because of the regular structure of these well defined elements. It is much more difficult to measure the geometry of ancient buildings. Normally these buildings are characterised by an irregular geometry and a very complex surface; very often a deformation of parts of the building or the complete building can be observed. For many applications a simplification of these dense and complex information is accurate enough for surveying purposes. The generalization of complex structures to straight lines or geometrically defined figures is a frequently used method to handle the surveying job of an ancient building in an effective way.

Measuring the geometry of an ancient building is a basic research for an architect who wants to investigate the history of the building. The interpretation of the building normally takes place in a historical or archaeological context to find new information about the former history. The building is a record of the past like historic documents or other written sources (Tomaszewski, 1986). Therefore the architect is not interested in the regular building geometry but in the deviation of the typical building structure. Only this deviation -caused by a special building type or by the influence of time- characterises every individual building for a historical investigation.

To achieve these research aims the architect who is normally doing the survey for historic building research prefers traditional surveying methods by plumb line, level tube instrument and yardstick. With these easy handling instruments the architect is able to survey and to draw the building geometry directly in front of the building. Following this simultaneous working method it is possible to control the surveying part during the plotting and vice versa (fig. 1).



Figure 1: Traditional architectural surveying for historic building research

Because of the time consuming method and the close relationship to the object during the surveying job the architect is able to find many very important constructive information about the building. Constructive or other additional information should be marked in the drawing plan. Another specific demand on the building plan is the high graphic and aesthetic quality. In the architects' opinion only handmade drawings are able to fulfil the necessary requirements; in a CAD system constructed and with a plotter printed plots are not accepted (Schmidt, 1986).

## 2 PHOTOGRAMMETRIC METHODS IN HISTORIC BUILDING RESEARCH

A conventional archaeological or historic building research project is planned without the participation of photogrammetry or geodesy. If there is a participation of photogrammetry, however, it is forced by the object itself. Because of great object dimensions or the missing access architects ask photogrammetrists to participate in their projects. But in most cases the job of the photogrammetrist is done separately from the architect's work without the necessary close co-ordination. Therefore both disciplines do not know enough about each others' aims and possibilities. Very often the photogrammetric experts are visiting the investigation area for just a few days, taking their photogrammetric photographs and measuring the necessary geodetic points. With these information they are convinced to have the basic material for the photogrammetric interpretation which will be done later in the office. The different photogrammetric methods to evaluate the photogrammetric material are well known:

- Simple rectification of plane surfaces, analytical rectification of curved objects, ortho-image generation with detailed object-models including the mapping on a 3D-CAD model (Hemmler, 1997; Wiedemann, 1997).
- Stereoscopic measurement of point or line information (Raslan, 1965), multi-image digital point or line measurement on the base of bundle adjustment (Luhmann, 2000).
- Point, line and area based automatic matching (Maas, 1998).
- Laserscanning (Wehr, 1997).

Results of the photogrammetric methods are rectified images, point co-ordinates, technical drawings (printed by a plotter), 2D or 3D CAD files or animated visualisations. Normally these results are produced by a specialist in photogrammetry who knows the details about photogrammetric algorithm but not even the basics about the buildings history with its characteristic elements. These photogrammetric products are only a base for the revision under the architect's requirements. This revision is so much time consuming that the architect prefers his own surveying in front of the building. It follows that the photogrammetric surveying has to be carried out in a technical and building historical quality. At best the photogrammetrist should be responsible for the technical aspects and the architect for the interpretation task. Maybe with the HICOM principle (Streilein, 1998) this problem could be solved. Herein the computer is responsible for the measurements and the user is responsible for the image interpretation.

Unfortunately the resulting drawings or 3D models of all photogrammetric methods cannot fulfil the demands of the very aesthetic architectural drawings. These drawings have a high dense of information which is nearly impossible to achieve with computer methods. With predefined regular geometric CAD elements it is very time consuming to represent the different information found in a complex building.

From all these reasons follows that at the moment there is only a very small acceptance in using photogrammetry in the field of historic building research.

## 3 PHOTOGRAMMETRIC METHODS IN THE PALATIN-PROJECT

In the large-scale surveying of buildings for the historic building research photogrammetric methods are only used in exceptional cases. The reasons for that poor acceptance were already given and are caused by some requirements which



Figure 2: 'Domus Severiana' at the Palatine in Rome

cannot serve with photogrammetric methods. On the other hand the architect makes demands on the survey for his historic building research which can be fulfilled by photogrammetry perfectly. The building should be completely measured with all its details and mostly with the accuracy of 1 cm for the frequently used drawing scale 1:50. The architect with his hand dominated methods can fulfil these requirements only for a small part of the building but in a

very aesthetic drawing quality. Theoretically, photogrammetry with its image based surveying method is able to measure all visible information. Within the images all information at that recording time is archived for later investigations. On huge dimensioned buildings only the photogrammetric methods are able to guarantee a high relative and absolute accuracy. On the base of a precise geodetic framework the bundle adjustment combines all images so that a homogeneous accuracy can be achieved.

All these advantages of photogrammetric methods have been accepted in the photogrammetric community for many years. But how can the high potential of photogrammetry be used in the field of historic building research?

To solve these problems within the effort of photogrammetry in historic building research at Brandenburg Technical University of Cottbus a very close co-operation between the Chair of Surveying and the Chair of Historical Building Research has developed in the last years. To survey historic buildings a strategy is worked out which combines the photogrammetric and geodetic methods with the handmade architectural survey in an interdisciplinary and integrated way. Photogrammetry as well as geodesy are reduced to a measurement tool without modelling the object in a final drawing or three-dimensional model. Photogrammetry provides the building geometry with high accuracy. In this geometric frame the architect can carry out his interpretation work added by his handmade survey. Finally the architect draws the plans on the base of the provisional photogrammetric drawing in his usual portrait-like way. Because of this interdisciplinary co-operation the survey of historic buildings can be done in a very effective way. It can be guaranteed that the quality of the final drawings fulfil the architect's requirements by using photogrammetric methods. Such a successful co-operation can surely open up new applications of photogrammetry in historic building research.

As an example the author's activities in an investigation project at the Palatine in Rome should be presented here. The survey of the so called 'Domus Severiana', part of the ancient imperial palace located between the 'Forum Romanum' and the 'Circus Maximus', was quite difficult because of the great dimensions and the very complicated structure.

The view from the 'Circus Maximus' to the 'Domus Severiana' (fig. 2) shows the problem for the architects very impressively: How can a building with a length of 120, a width of 110 and a height up to 35 meter be measured with the traditional hand-based surveying methods. It is obvious that these surveying challenge can be managed only with modern surveying techniques.

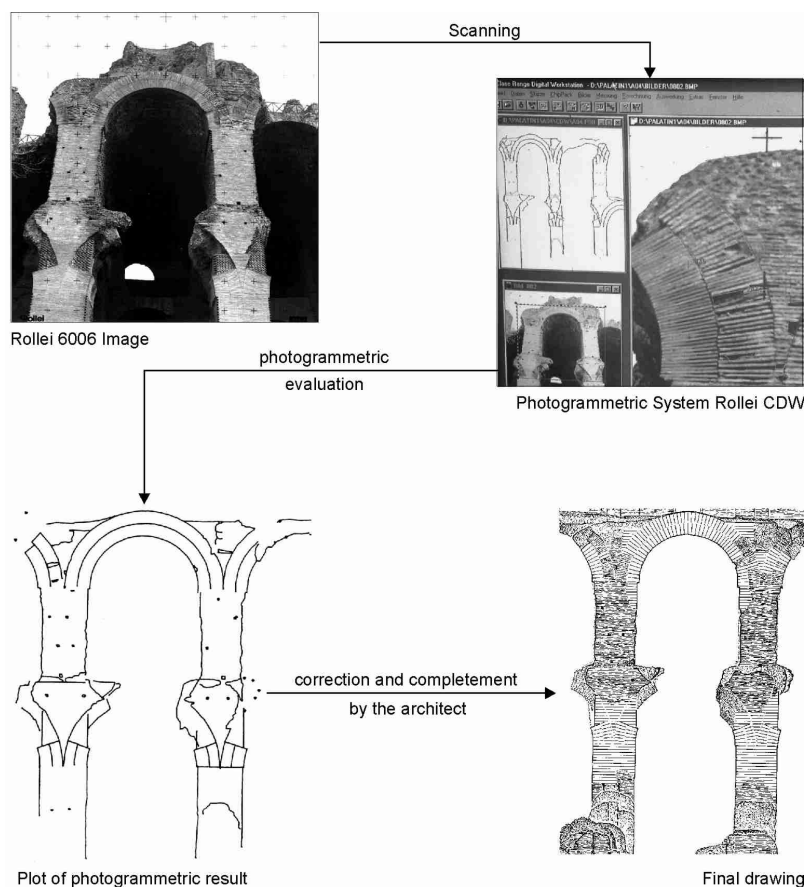


Figure 3: Integration of photogrammetry with traditional architectural surveying

In the year 1998 a joint project between the Chairs of Surveying and Historical Building Research was started in which both disciplines -geodesy and photogrammetry on the one hand and architectural historic building research on the other hand- worked together side by side from the first measured point to the last drawn line. In a combination of various well known photogrammetric and geodetic methods with the hand-based survey of the architect the 300 000 m<sup>3</sup> construction volume was surveyed in ground plans, intersections and drafts of facades. To handle all the object requirements the surveying methods tacheometry, reflector-less tacheometry, architectural photogrammetry and the hand-based architectural surveying were employed together. The photogrammetric evaluation was carried out with the program Rollei CDW (Fellbaum, 1995).

Most of the photogrammetrically measured facades have more or less a plane surface. Within these planes are small areas which do not belong to the main plane. The majority of the walls is built up with bricks in a quite regular form. The architect is not interested in each single brick but in the main geometry with the variation from the regular structure (e.g.: holes from beams, change of the material, etc.). The main working scale should be the scale 1:100. Considering these requirements the CDW-system was nearly perfect to solve the photogrammetric job in a very flexible manner. Many parts of the object were worked out in the single image mode, but all 3D-information were measured in the multi image procedure. The photogrammetric result is a first rough line drawing which has to be revised by the architects to add to these plan all important historic building information. Final product is the ink-drawn plan with a high geometric and building historic quality (fig. 3).

Because of the contribution of students from architecture and civil engineering at the field campaigns in Rome as well as at the photogrammetric measurements in Cottbus the photogrammetric evaluation was carried out in a high quality. The students were experts both in photogrammetry and in the special demands resulting from the historic building situation at the Palatine. With the detailed knowledge of the specific features, of the building history and its typical structure much more information was found and measured by the photogrammetric surveying.

#### **4 CONSEQUENCES FOR THE USE OF PHOTOGRAMMETRIC METHODS IN HISTORIC BUILDING RESEARCH AND ARCHEOLOGY**

The here presented project philosophy is a compromise between the conventional methods of an architect and the available photogrammetric methods. Is the photogrammetrist himself satisfied with this practical result? Without doubt this interdisciplinary project improves the understanding of the involved disciplines. The transfer of these experiences to other photogrammetrist or architects can prove the successful application of photogrammetry in the historic building research. But beyond the improvement of the acceptance of photogrammetry in historic building research projects there is another very important question:

Why is the participation of photogrammetry in historic building research and archeology important for the photogrammetry itself?

##### **4.1 Effects on the acceptance of photogrammetry in the field of architecture**

The traditional architect in historic building research prefers measuring buildings with his well known hand-based methods. If there is no need for modern surveying methods -caused by large building dimensions or inaccessible buildings- the architect would not think about the participation of geodesists or photogrammetrist in his projects. Why should the photogrammetrist want to work in this peripheral area of photogrammetric practise? The methods of the historic building research are not only used for a few historic investigation projects. Many universities are teaching surveying for architectural students in a combination with the historic building research. By the participation of surveyors in historic or archaeological projects a geodetic and photogrammetric basic knowledge can be transferred to the students, so that they are able to use all traditional and modern methods in their daily surveying practise.

##### **4.2 The demands of historic building research a challenge for photogrammetry?**

But there is also a reason for a strong photogrammetric commitment which lies in the very demanding and complex structure of the archaeological objects. To improve the photogrammetric algorithms to the need of archaeology or historic building research is a challenge for photogrammetry in general.

The dense information within a photograph provides all important knowledge about the building's history. But conventional automatic photogrammetric methods reduce this high information level by simplification of the complex building structure. This simplification is sufficient for normal documentation purposes only, but the architect in historical building research is interested in the deviation from the regular geometry. This deviation is the building characterising special quality. A very common approach for automatic photogrammetric measurement in building survey is the extraction of the building characterising lines like corners, windows, doors etc. These automatic algorithms are working with various well known matching algorithms (Gruen, 1996; Streilein, 1998). The derived object-model is normally a 3D volume model, which is defined by the area between the detected building lines; additionally it is possible

to map the taken images on the object model (Streilein 1998; Wiedemann, 1997). In a conventional CAD environment it is quite easy to derive perspective views, intersections and ground plans. But all these different views of the object represent the real building only at the measured lines. There is no geometric information about the area between the building lines. Only the radiometric information can be found in the mapped image. This 3D object representation might be sufficient for a visualisation purpose but surely not accurate enough for the high requirements of historic building research.

#### 4.3 A modelling concept based on a 3D voxel model

To derive real 3D information of the object the description of the geometry by line, area or feature based modelling methods is not very suitable. The basic unit of photogrammetry, the pixel, should be directly used to build up the object model. This could be done by the extension from the pixel structure to a three-dimensional voxel structure (El Hakim, 1998; Li, 1992; Boochs, 1996; Fromherz, 1995; Uray, 1996; Wei, 1996). The geometric information of all voxel elements can be computed with standard matching algorithms. The mean value of all radiometric pixel information can be mapped on the correspondent voxel surface element. With this strategy the high geometric and radiometric information level of the original images can be transferred to a 3D model representation (fig. 4).

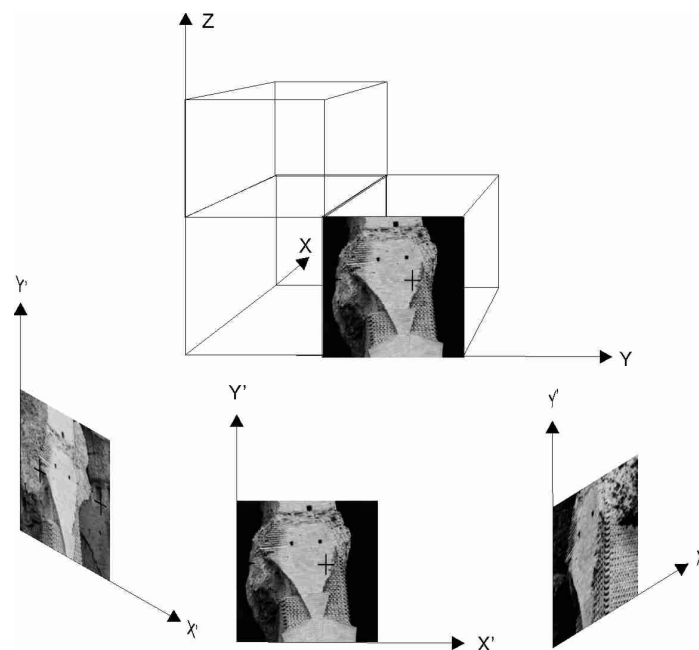


Figure 4: From pixel to voxel

The voxel model is also an excellent object model to describe very complex object structures. Within a voxel representation there is no problem to integrate different building levels or overlapping zones in one consistent model. The voxel model is a real 3D model with the possibility to manage objects with the same ground co-ordinates (X,Y) but different height co-ordinates (Z). In complex buildings with many floors and additional sculptured elements it is very important to use a real 3D model. It is not unusual that for example in one corner of a room you are able to find up to 10 heights above one point in the ground plane: the point on the ground plane itself, bottom and top point of a recess, maybe 2 or 3 points of a bust situated in the recess and the point at the ceiling. In a normal building survey at least the points of the bust are not considered in the object model. It is absolutely necessary to integrate all these points in a comprehensive model to build up a powerful model which should be used in the field of historic building research.

This small example demonstrates that in ancient buildings there is a various dense of information which causes different resolutions of the voxel model. The object representation in various resolutions is one of the characteristics of a voxel model. On the base of one basic voxel size (e.g. 1mm\*1mm\*1mm) the combining of neighbouring voxel has to be carried out until the voxel model is able to describe the smallest object structure. The result of this voxel combining will be a high resolution on the object surface and a small resolution inside the walls where no information can be found with photogrammetric methods.

The representation of huge and complex buildings in a homogeneous voxel model needs a special strategy to take the photogrammetric images and to build up the voxel model. One important element of this strategy could be the sculptor principle (Fromherz, 1995). Within this principle all voxel which are not part of the object are cut away like a sculptor who is removing all superfluous material by hammer and chisel. In a first step a maximum volume has to be defined

which is completely filled in by voxels. On the base of photogrammetric models all unused voxels have to be cut away step by step. To compute all superfluous voxel many photogrammetric models are necessary.

To manage all the photogrammetric data a management system presented by (Chapman, 1997) shall be used. This management system is developed for the application in the documentation of complex plants. A CCD camera is used in combination with a tacheometer to record the complete plant. The images as well as the from the tacheometer given image orientation have to be stored in a data base. Later on it is possible to evaluate the interesting parts of the object in a progressive way. At first a rough object model can be generated which has to be improved in a second step by a detailed sculptor procedure.

The here suggested concept for measuring complex building structures for the purpose of historic building research combines strategies from El Hakim (1998), Fromherz (1995) and Chapman (1997). The main characteristics are

- 3D data of the complete object with a high resolution so that it is possible to derive intersections and ground plans at any place of the object with the necessary accuracy.
- Flexible data structure that enables a flexible construction of the model.
- Radiometric information of all surfaces mapped with high accuracy on the exterior voxel surfaces.

Surely this idea of a comprehensive photogrammetric measurement system is just a first step on the way to a powerful photogrammetric tool for the survey of complex ancient buildings.

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