PHOTOGRAMMETRIC AND GEODETIC DOCUMENTATION METHODS AT St. PETRI CATHEDRAL, BAUTZEN

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ABSTRACT

The interdisciplinary research project for the sustainable restoration of the late Gothic St. Petri cathedral of Bautzen, initiating in 2003, brought together experts and scientists for building preservation and conservation, historical building research, building construction and geodesy from TU Dresden and BTU Cottbus. Within the scope of this project, concepts for restoration and specific usage for the cathedral, built at the end of the 15th cent., should developed.

For the clearance of structural and historical problems an extensive surveying of the whole building is needed for both inner and outer areas. Combined proceedings of geodesy and photogrammetry were applied to create a form-correct and deformation-true documentation of the facades for the scale of 1:50. Additionally several laserscans from different position where made to determine one floor of the roof truss.

The applied measuring methodes and the resultant capabilities for evaluation and analysis, like plane and ortho rectification, stereo processing and 3D visualization, will be presented on suitable building sections. The results of photogrammetric evaluation and laserscanning constitute the groundwork for the following structural and historical analyses. Therefore, methodes for the use of the applied recording techniques should be discussed with regard to the creation of form-correct documentations for historical buildings. In view of scanning measuring methods a usefull combination of automatic preprocessing for filtering and datareduction and conventionally hand measuring for on-site interpretation and evaluation of historical building structure will proposed.

1. INTRODUCTION

The hall church St. Petri with its high facades subdivided by pillars and tracery windows and its high saddleback roof dominates the townscape of Bautzen and is a landmark of the region. The quarrystone brickwork with characteristically granite stones and large plaster areas shows numerous damages like spallings, weatherings, soaked areas and vegetation.

For the reconstruction of the cathedral a documentation of the facades was required. More than 3.000 m² facade area and elevations up to 18 m made the use of hand measuring techniques impracticable, as scaffolding around the cathedral would have been needed.

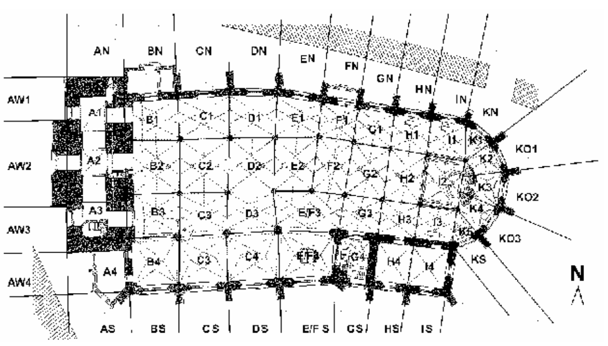

Figure 1. Numbering system for surveying and photogrammetry

Large regions of the facade can be assumed as planar surfaces and be divided in several planes for photogrammetric rectifications. With this proceeding a geometrical correct basis for documentation and a high-quality image archive for further works were created in a short period of time. A combined approach was arranged. The preparation of the complex photogrammetric work was done by specialists of the Chair of Surveying. In a second step students of architecture and urban planning of the BTU Cottbus made elevation drawings on the basis of these image maps. For the building survey and the photogrammetric work a uniform and obligatory numbering system were specified for inner and outer regions of the cathedral (Figure 1).

2. PHOTOGRAMMETRIC WORK

2.1 Photographic Recording and Measuring of Reference Points

During a three-day surveying campaign in May 2004 the photographic records were taken including reference points for the photogrammetric evaluation. To guarantee high quality photographs for the large-size image maps all pictures were done by professional photographer Roland Wieczorek of the Chair of Historic Building Research. A large size camera Linhof 4 x 5 Technika, with an image format of 4 x 5 inch and focal lengths of 75 and 90 mm was used to capture main areas.

For details a medium format camera Rollei 6008 with an image format of 6 x 6 cm and focal lengths of 40, 50 and 80 mm was used. The photographs have been taken in an analogue way due to the high quality necessary for photogrammetric evaluation.

Using a digital SLR camera the small size sensor and low resolution would in comparison result in an increasing effort for additional photographs and additional reference points.

Moreover the lens of an amateur digital SLR camera shows distinct distortions in wide-angle range, which can be corrected only by an additional process of image undistortion (Brown, 1971). Consequently high resolution scanning of large-format analogue images offering unrivalled quality was the method of choice.

Every bay of the south facade was documented with a single large size photograph and therefore simplified postprocessing and reduced prospective errors. The front and side faces of the pillars were captured as well due to visible damages of the stone surface and the masonry in these areas.
In the north of the cathedral the photographic recording and the geodetic measurements were more complicated. The narrow street reduced camera distance to a maximum of 6 m. Here several overlapping exposures for each compartment were needed to capture the whole elevation height. In total approximately 200 large- and medium-format exposures of the cathedrals facade were taken on monochrome negative films. To ensure a sufficient number of reference points for each rectification plane a definition of this planes was done at the beginning (Figure 2).
Reference points can be signal marks or natural points on the object which are precisely identifiable. As large areas of the main facade are plastered, the definition and measurement of natural reference points for the rectification was very time-consuming and error-prone. In these regions marks were put on the facade with the help of an elevating platform truck. Where there were well identifiable edges of stones they were used as natural reference points. All measurements were done in the coordinate- and height-system of Bautzen using a reflectorless total station. In addition a horizontal section of the cathedral was measured on a level of 227 m NN above sea level.

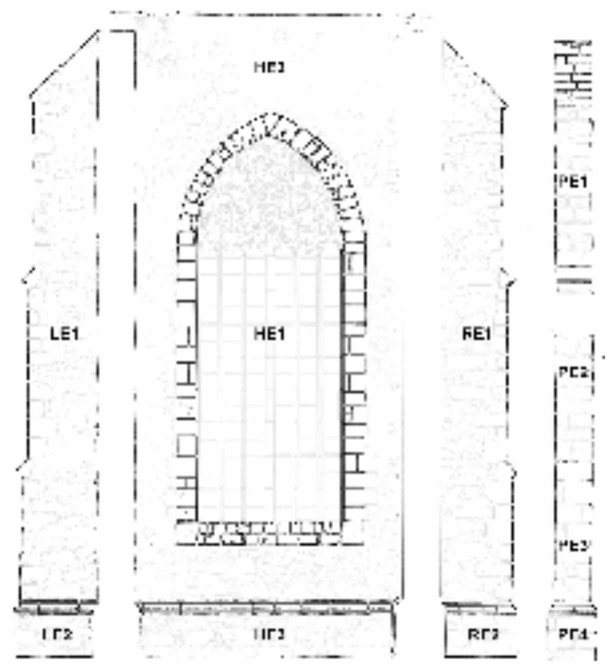

Figure 2. Plane numbering for rectification of facades and flanking pillars

2.2 Image Rectification and assembling of Image Maps

190 monochrome negatives were scanned for the photogrammetric evaluation with a resolution between 1200 and 2400 dpi depending on the format of the image. The result was a data volume of more than 4 GB.
Using the horizontal section measurements 52 local projection systems were defined. The respective reference points were transformed into their vertical elevation systems (Figure 3).

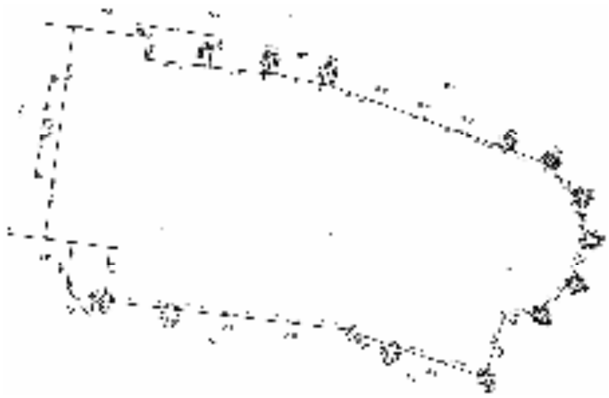

Figure 3. Projection systems for image rectification

For measuring image coordinates and projective transformation of images the metigo2D software by fokus GmbH Leipzig/Germany was used. As a result digital images were generated in correct scale and position of the respective transformation system. Thus complete image-maps including all rectifications of the same transformation system can be composed. For this purpose the software EDDI-Mon by fokus GmbH Leipzig was used. The several image layers were adjusted in the greyscale histograms and consequently merged into single image maps. They were completed by adding a coordinate grid and a legend. Finally the maps were exposed on photo paper to the required scale of 1:50.

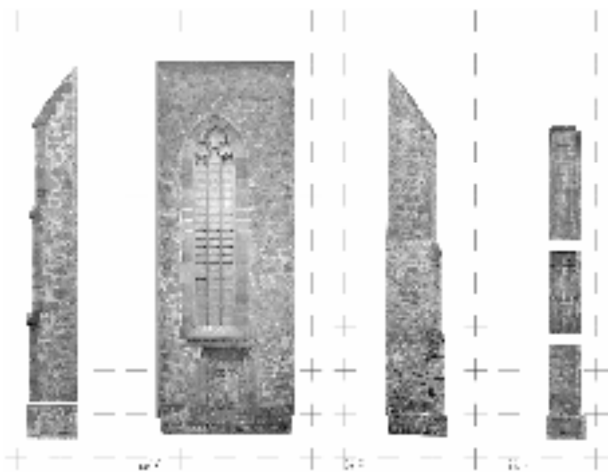

Figure 4. Image map of compartment EN

2.3 Orthoimage Generation

In the bays CN, DN and EN of the northern facade (Figure 1) there is an offset of approximately 10 cm in the upper third of the elevation. Unfavourable oblique camera positions and short camera distances caused significant perspective offsets in the rectified images so evaluation failed in these regions.
A projection of non-planar surfaces into a planar image map is achieved by means of differential rectification or orthoimage rectification (Wiedemann, 1997). For this proceeding a surface model of the object and the inner and outer camera orientation is needed. Therefore subsidiary laserscans of these three compartments were made by the Institute of Photogrammetry and Remote Sensing of the Technical University of Dresden using a LMS-Z420i laserscanner of RIEGL Laser Measurement Systems GmbH.

The 3D point clouds were transformed into the local projection systems by means of photogrammetric reference marks, which are visible in the intensity view of the scan. After this, a digital surface model with a cell size of 1 x 1 cm was created. The resolution of the ortho images was set to 300 dpi by a scale of 1:50 with the result of an object resolution of 4 x 4 mm. The image orientations were calculated with the multi image evaluation software Rollei CDW, the orthoimages were generated with a software developed by the Chair of Surveying. The assembled orthoimage maps showed an orthogonal projection of all object parts in one unitary projection plane, a rectification in several different planes was needed no longer. Finally the orthoimage maps were completed by a coordinate grid and a legend and exposed also to a scale of 1:50.
Additional laserscans of the outer choir compartments and the western portal were measured March 2005 with a Cyrax HDS 2500 by Leica Geosystems to generate subsidiary orthoimages for these areas.
A mapping of the facade only by using scanner data was not intended and seems problematic due to the data quality offered by up to date scanners. The registered intensity information of the reflected signals does not reach the quality and resolution of a real photographic recording at present. On large scales the point cloud images of laserscans resolve into their discrete measured points, whereas photographic images offer continuous greyscale information. Without additional image information a CAD evaluation of scanner point clouds is hardly possible. Many object textures are not derivable from the geometry of the points only, but are visible in photographic images.

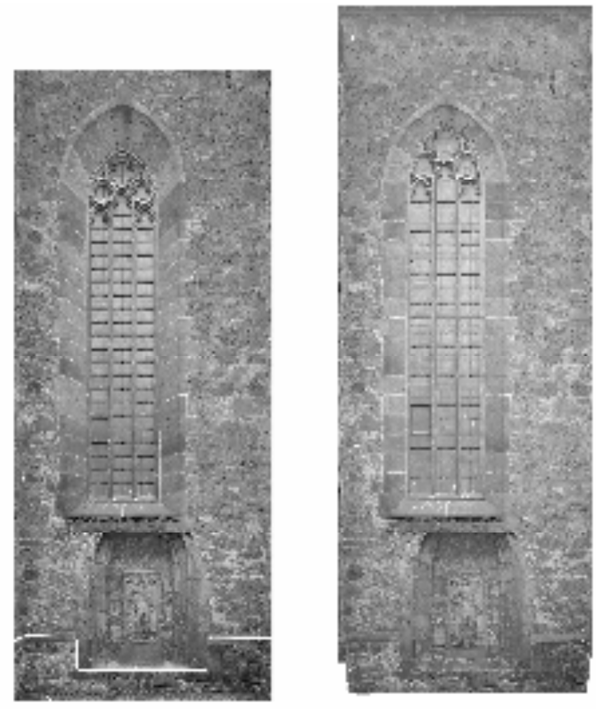

Figure 5. Projective transformation (left) and orthoprojection (right) of the same facade

2.4 Creation of Facade Drawings

The finished image maps in scale 1:50 exposed on photo paper constituted the basis of the course “Facade Drawing” at BTU Cottbus in summer 2004. Every compartment of the cathedrals facade including the tracery window, the side faces of the flanking pillars and the front face of the right pillar was worked on by one student (Figure 6). The drawings were made using hard pencils (4H-6H) on distortion-free drafting film on top of an exposure. These stone-correct plans should contain distinguishable stone surfaces, plaster areas, visible lines between between older and newer sections, splits, damage symptoms like spalling and sanding as well as details like stonemasons' marks and inscriptions.

Figure 6. Students at work

To understand the construction of the tracery all visible joints were drawn. Furthermore in an additional drawing the students noted findings to stone types, different plasters, damages and surface defects. A detailed documentation of findings and damages was not created, because of specialists’ knowledge on different materials and their typical damage patterns as well as direct physical contact to the surface was lacking. Thus, photomaps and drawings in combination are the basis for a later in-depth analysis by conservation specialists.
After completing this field work the pencil drawings were redrawn in ink for an uniform representation of all plans (Figure 7) by just a few student assistants in winter 2004/2005.

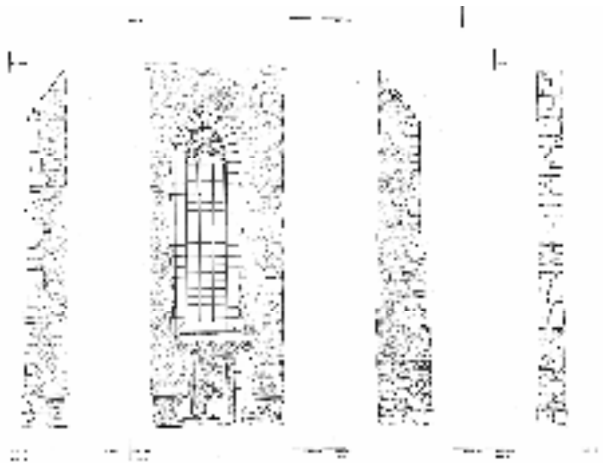

Figure 7. Final ink drawing of compartment EN

3. TERRESTRIAL LASERSCANNING

Under the high saddle roof of the St. Petri cathedral a truss is located which consists of five floors. On the bottom floor, sized 60 m x 31 m x 5 m, terrestrial laserscanning was used to record the geometry of this floor. The aim was to compare terrestrial laser scanner data with data received by a total station concerning their usability for an effective generation of a general map.
The scanning equipment, provided by the Institute of Photogrammetry and Remote Sensing of TU Dresden, contains the 3D-Scanner LMS-Z420i by Riegl and the digital camera Nikon D100 (Figure 8). The scanning process is controlled by a notebook and the software *RiSCAN PRO* from Riegl. With a field of view up to 80° x 360°, this laser scanner belongs to the class of panorama-view-scanners (Kern, 2003). The range finder, based on the principle of pulsed time-of-flight, is able to record distances in a range of 2 m to 800 m with an average accuracy of ± 7.5 mm.

Figure 8. Laserscanner Riegl LMS-Z420i [Riegl, 2004]

3.1 Measurement

Because of numerous rooftrees located inside the truss, many occlusions exist. These scan shadows can be reduced by increasing the number of scanning positions. The used configuration consists of 12 reticulate distributed scan positions. For a panorama scan (Figure 9) recorded at each of the 12 positions, an angular resolution of 0.1 degree was chosen and the entire field of view of the laser scanner was used. Thus, about 3 million points were measured at each laser scanner position.

Figure 9. 360° intensity image (panorama scan)

Due to the fact that the goal was to acquire the buildings geometry instead of a textured 3D model, the digital camera had not to be used. The geometry of the first floor is finally represented by approximately 35 million points. In addition to the coordinates (X, Y, Z), an intensity value was recorded for each point.

3.2 Point cloud registration

The 3D point clouds are given in the right-hand co-ordinate system of each laser scanner position, which have to be transferred into a uniform project co-ordinate system. Usually an available co-ordinate system of a central scanner position is defined as PRCS. Flat circular retro targets and cylindrical retro reflectors (Figure 10) with a height of 50 mm and a diameter of 50 mm, were distributed in the observation area, to serve as tie points for the 12 scans. Because of the retro reflective material, the intensity value of laser signals, reflected at the surface of tie points, i very high in comparison to their surrounding, which makes it suitable for the automatic detection. Finally, the automatic transformation of the individual co-ordinate systems into the project co-ordinate system using detected tie points produced standard deviations of 3 mm up to 5.2 mm.

Figure 10. Cylindrical retro reflectors [Riegl, 2004]

3.3 Transformation into the building co-ordinate system

In order to reference the laser scanner points to the co-ordinate system of the building (Figure 11), the right-hand PRCS was transformed into the left-hand building co-ordinate system. The transformation is based on 26 flat, circular retro-targets with co-ordinates derived from tacheometric measurements. These points, distributed in three of five floors of the truss, are part of the planimetric net of St. Petri cathedral.

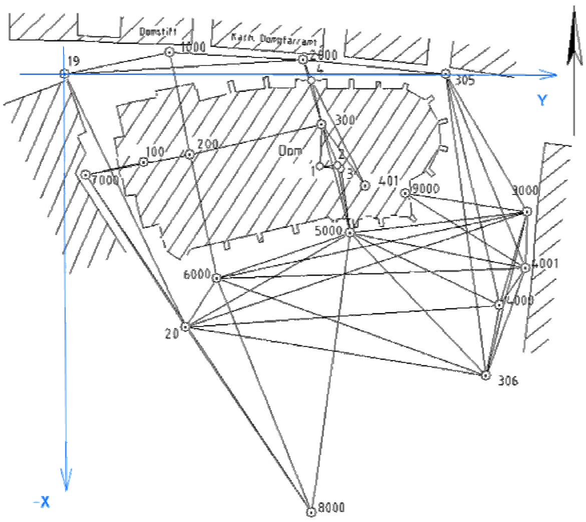

Figure 11. Planimetric net of cathedral St. Petri

3.4 Map generation from laserscanner data

The goal of the measurements is the recording of the geometry for reconstruction and possibly the analysis of the static of the truss. Even if the 3D laser scanner point cloud contains a huge amount of geometrical information, 2D maps allow users better interpretation of the geometry. Therefore intersections are generated, that represent the geometric object information in terms of two-dimensional maps. Within the laser scanner points of the scanned roof floor a horizontal intersection plane was defined at a certain height level (Figure 12a). All points with a height distance up to 5 mm from this plane were orthogonal projected onto the plane. In this manner a 2D map of the rooftrees with a scale of 1:50 were produced. Precondition for this procedure is a perpendicular position of the point cloud realized by referencing the point cloud with respect to the co-ordinate system of the building.

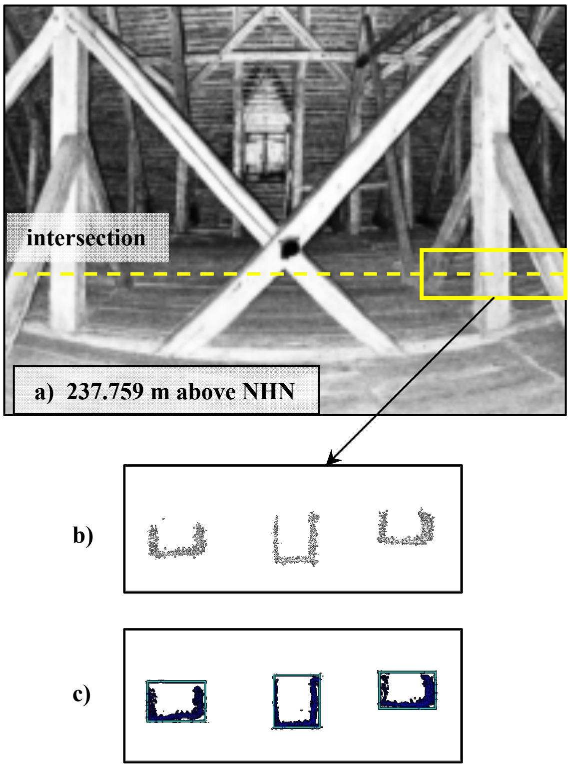

Figure 12a. Rooftrees with the horizontal intersection plane
Figure 12b. Laser scanner point cloud
Figure 12c. Result of interactive object extraction (example)

Since the generated map still contains a 2D point cloud without any information about their topology (Figure 12b) a CAD-program was used to replace groups of points by geometrical shapes. Using a CAD program, straight lines were fitted into the points. These lines were afterwards intersected to polygons which represent the shape of the rooftrees (Figure 12c). The generation of the map was very time-consuming because about 205 000 points had to be handled in order to extract geometric shapes. Figure 13 shows the time proportion between the recording of the point cloud and their following interactive analysis. An automation of this process would decrease the processing time of the map generation from laser scanner data conspicuously. Currently algorithms for the automation are developed at the Institute of Photogrammetry and Remote Sensing of TU Dresden based on automatic segmentation and automatic shape modelling of 2D point clouds.

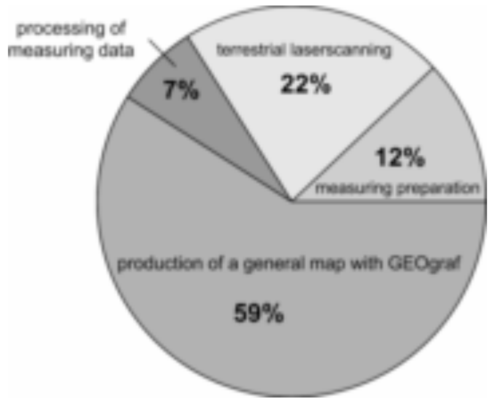

Figure 13. Proportion of the working process

3.5 Advantages for the structural recording

There are many advantages of the use of laser scanner data for structural recording in comparison to conventional methods such as tacheometric measurements. For example, there is only one measurement necessary to define an arbitrary number of different height levels. On the basis of the data a 2D map of any height-level can be generated.
The measured point clouds, as well as the corresponding photos, offer a high potential for documentation purposes. The data can be archived and used for extracting the desired geometrical information at a later time.
Older buildings have usually instable floors, which may cause vibrations and may therefore limit the quality of the measurement results. For example, the truss of the St. Petri Cathedral Bautzen consists of timber floorboards. Working with the total station was not practicable because of the operator moving around the tripod. Using the laser scanner with wireless data transfer solved this problem.

3.6 Recording of the reticulated vaulting

The Gothic reticulated vaulting of the three northern naves was recorded from four laserscanner positions. After the generation of a surface model (Figure 14) by the triangulation of the point cloud, textures, which were captured with the Nikon D100 digital camera mounted on top of the laser scanner, were mapped onto the surface. The model looks photo realistic, due to the use of original texture. There are different ways to visualize the final model, such as a video or a virtual tour based on VRML. An orthophoto of a vault segment can also be produced applying the recorded geometry and the appropriate photos. This orthophotos can finally be used to generate a map of the geometry of the reticulated vaulting.

Figure 14. Model of the vault without texture

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