

## PHOTOGRAMMETRIC DOCUMENTATION OF THE VAULTS OF HISTORICAL MONUMENTS

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### ABSTRACT:

Photogrammetric documentation of historical monuments plays an important role in the reconstruction and protection of our cultural heritage. Due to a huge number of historical sites, it has been used widely in the Czech Republic. This paper describes photogrammetric measurements and visualization of five selected vaults of the Cathedral of the Assumption of Our Lady in Sedlec, in the central Bohemia. The Cathedral appeared on the World Heritage list of UNESCO in 1995. It was originally built up in a gothic style and rebuilt at the beginning of the 18<sup>th</sup> century in the baroque style. The purpose of a detailed documentation of the vaults was their complete reconstruction. The vaults were taken down, all bricks were cleaned and the vaults were built up again by the same technology as 200 years ago. In order to guarantee a visibility of each point of interest at least at three images, about twenty photos of each vault were taken by the analogue camera Rolleiflex 6006 metric. After scanning, the images were processed in the software package Photomodeler. Separated models for each vault were created first. Points at the bricks' corners were measured in all models. Outlines of the bricks or textures were added for visualization purposes at some parts. All models were imported to AutoCAD and connected to one final 3D model. Moreover, sixteen profiles of the vaults were measured with a reflectorless total station and processed in AutoCAD as 2D plots.

## 1. INTRODUCTION

### 1.1 Goals of the investigation

The paper reports on photogrammetric and geodetic survey of the vaults in the southern part of the Cathedral of the Assumption of Our Lady in Sedlec, the Czech Republic. The main goal was to create a detailed 3D model of five selected vaults for the purpose of a static investigation (e.g. wall crashes or fall down of vaults) and a complete reconstruction.

### 1.2 The Cathedral in Sedlec

The Cathedral was built in the gothic style approximately between the years 1280 – 1320 in the neighborhood of an existing Cistercian monastery. Damaged during the Hussite wars in 1421, it was rebuilt in the baroque-gothic style between 1700 and 1709 by J.B. Santini. From architectonic point of view, it is one of the largest and the most complicated building in the Czech lands originated in the gothic period. It has a plot of the Latin cross. It consists of a central nave and four aisles (Figure 1). The decorations inside the Cathedral originate in the first half of the 18<sup>th</sup> century. The Cathedral has been on the World Heritage list of UNESCO since 1995 (<http://www.sedlec.info>).

### 1.3 Reconstruction in the years 2002-2006

A new reconstruction of the Cathedral has started in 2002. The tilt of the southern wall of the aisle could cause collapsing some of the vaults. Therefore it was decided to take the vaults down and to build them in bricks again using the same materials and procedures as during the baroque reconstruction. This reconstruction required a detailed documentation of the existing vaults including 3D position and size of all bricks. 3D

models of the vaults to be reconstructed were created by means of photogrammetry.

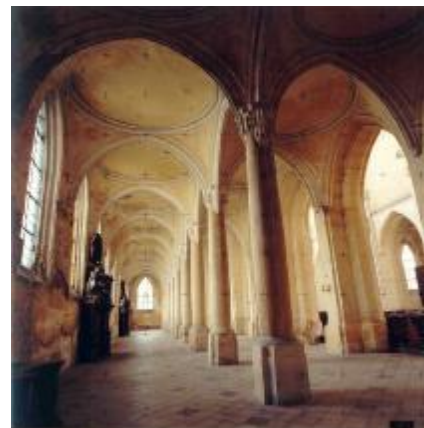


Figure 1. Southern aisles of the Cathedral

## 2. PHOTOGRAMMETRIC RESTITUION OF THE VAULTS

### 2.1 Image acquisition

Convergent photographs were taken with the analogue camera Rolleiflex 6006 metric. The camera constant equaled 40 mm. A colored film with the sensitivity of 400 ASA was used. The photos were scanned with a film scanner Super Coolscan 8000 ED. The images with the resolution of 2000 dpi and size 4480 x 4480 pixels<sup>2</sup> were saved in the tif format. In contrary to many other projects, the images were taken from above the vaults (under the roof) and not from the aisle of the Cathedral.

The vaults were first cleaned from malt so that all brick and joints were visible (Figure 2). A set of about twenty photos per a vault were collected. The positions of the camera were chosen with respect to the further processing in the software package PhotoModeler.



Figure 2. A vault from above

The number of photos is rather high due to worse a visibility of some parts covered by wooden roof beams. With respect to the further processing, the images were taken in such a way that all points of interest (bricks) were visible at least in three images. Figure 3 demonstrates an example of camera positions with respect to a vault. Moreover, three to five photos of vault ends (close to connections of the vaults with the walls and pillars) were taken from a shorter distance due to a lack of space. 15 signalized control points were determined for each of five vaults.

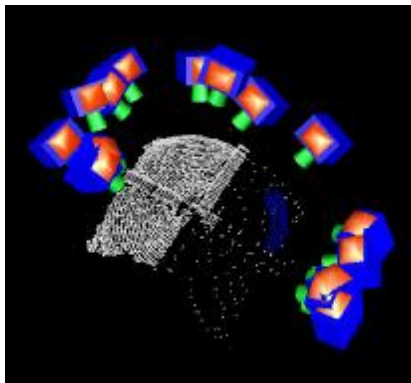


Figure 3. Typical camera positions with respect to a vault

## 2.2 Geodetic measurement

Except of photogrammetric measurements, sixteen profiles both from bellow and above the vaults were collected. The profiles were measured in three directions (N-S, NW-SE, NE-SW). The profile measurements were imported to AutoCAD, processed and exported as 2D plots. An example of one of the profiles is shown in Figure 4.

Control points and profiles were measured with the reflectorless total station Leica TCR 307. The heights of points used as stations for collecting control points and profiles were determined by means of technical leveling using the level Zeiss NI025. The floor level behind the entrance to the central nave was set as the origin of the local height system. All coordinates

were calculated in a local coordinate system using the software package Groma 5.0. An accuracy of the control points is better than 2 cm in position (XY) and 1 cm in height.

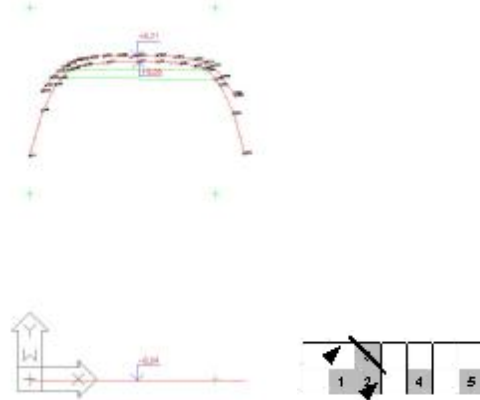


Figure 4. An example of a profile measured with reflectorless total station Leica TCR 307

## 2.3 Image processing

Processing of images as well as creating single models of each of five vaults was done by means of the program PhotoModeler. It was chosen due to its ability to process convergent images. In order to obtain a model of any object, eight steps have to be done (PhotoModeler Pro 4.0, 2002):

1. Create a calibrated or approximate camera description
2. Plan the Measurement Project
3. Take photographs of the object or scene
4. Import the photographs into PhotoModeler
5. Mark features on the photographs
6. Identify which points are the same
7. Process the data
8. Export the resulting 3D data to a CAD or graphics program.

In the described case, processing consisted of three stages: bundle adjustment of the set of images (comprises a solution in a general position followed by a transformation to the local coordinate system using control points), detailed vector restitution of each brick, and visualization. Each vault was processed as a separate project. A restitution of bricks was carried out sequentially by means of the measurement and referencing all points using functions Object Points, Surface Draw, Lines and Surface. The precise and realistic position and the shape of all bricks could be recorded in this way. The final wire model contained outlines of all bricks. The textures from original images were added in the visualization stage.

## 2.4 Outputs

A single spatial model was created for each vault in PhotoModeler. Examples of outputs in different stages of processing and visualization are presented in Figures 5 - 7. All models were exported as dxf files and connected in AutoCAD at the end as shown in Figure 8.

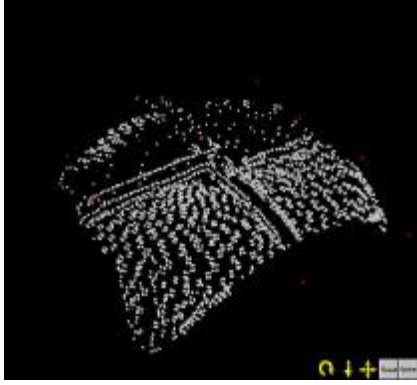


Figure 5. An example of a point representation of a vault. The white points represent the bricks, the red points show positions of control points used for a transformation to the local coordinate system.

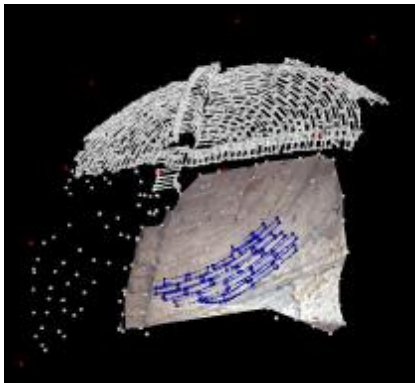


Figure 6. The vault could be divided into single planar segments representing the bricks. The function Surface Draw could then be used for a detailed measurement (blue lines).

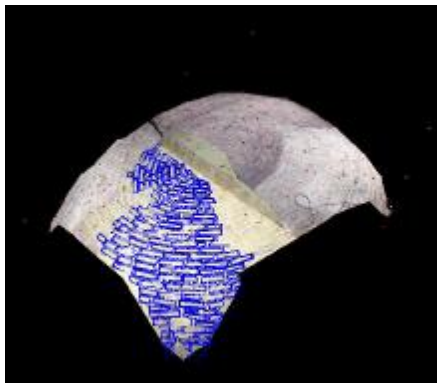


Figure 7. Textures can be placed on single planar segments. Subsets of several images had to be used in order to visualize a 3D model. It can be seen from colour differences in the model shown in the image.



Figure 8. The final result: a 3D model of all vaults in one reference coordinate system after importing to AutoCAD. The measured points are displayed in blue colour, outlines of the bricks are in green colour and red points show control points used for the final 3D model.

### 3. CONCLUSION

The presented shows how the combination of photogrammetry, surveying and digital image processing can be used for a documentation of cultural heritage and its conservation. The final documentation of the project contains 3D models of five vaults, 16 profiles, and reports of calculations of 3D points in Groma and PhotoModeler. Regarding accuracy of the final models produced in PhotoModeler, the maximal error did not exceed 5 cm in coordinates  $x$ ,  $y$ ,  $z$ . The results showed that the five measured vaults did not fit the shape of circular arcs as had been expected. The provided documentation has been used for the reconstruction work that followed i.e. re-bricking the selected vaults of the southern aisle “by hand” according to the original technology.

#### References:

PhotoModeler Pro 4.0, 2002. User Manual.

<http://www.sedlec.info> (accessed 28 May 2007)