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COMPLEX ANALYSIS AND DOCUMENTATION OF HISTORICAL BUILDINGS USING NEW GEOMATICS METHODS

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ABSTRACT

Documentation of a historical building is very important process preceding to every restoration or reconstruction work. It helps to preserve even minor information about objects shape, state, position and is often used for work advancement planning. Documentation is usually done using precise 3D model creation from which demanded cuts like ground plan are created.

This papers shows how new geomatics methods can be used for 3D model creation and its placement in the area, that can be very interesting in terms of north-south position. As a case study two historical churches located in Czech Republic (towns of Holubice and Kralovice) has been used. Photogrammetry and laser scanning methods for 3D model creation are introduced.

KEYWORDS

Historical building analysis, Geomatics, 3D modelling, Photogrammetry, Laser scanning, Reflectance spectroscopy, Church, Kralovice, Holubice

INTRODUCTION

Documentation of cultural heritage objects is very important issue and 3D modelling and other non-invasive methods provide an excellent tool in order to study and preserve historical buildings. Photogrammetry and laser scanning are two methods that are recently very popular for 3D model creation since they provide fine information about the object shape and when supplemented with classical geodetic survey objects global position in desired coordinate system can be determined. Photogrammetric methods use photographs taken from various locations around object of interest with high overlap (min 60%) to derive the point cloud. Special software based on image based modelling methods [1] is applied. Laser scanning is a non contact mass measurement of 3D points, it uses a special active device that transmits high numbers of laser beams that are reflected by the object. Using distances and angles of these reflections a 3D model is created [2]. Comparison and more information regarding mentioned methods in cultural heritage documentation field can be found in following papers [3], [4], [5], [6].

Non-invasive documentation is highly demanded method for analysis of historical objects. It provides specific information without the need to touch and therefore to harm or even damage the object of interest. Besides the two formerly mentioned methods, there are others such as reflectance spectroscopy and GPR. Reflectance spectroscopy is a technology based on spectral analysis of a specific material can provide information of the object chemical composition. Testing of this method on historical plasters can be found in [7]. Sometimes there is a need to analyse objects that are hidden under surface and Ground Penetrating Radar (GPR) is a great tool for that. The GPR uses electromagnetic radiation in the microwave band of the radio spectrum and analyses signals reflected from the subsurface structures. The antenna transmitter emits impulses of sine wave that travels through the material until it beings to reflect back to the antenna receiver by boundaries between the layers or the objects with different dielectric characteristics. The velocity of the radiation depends on the electromagnetic characteristics surveyed material [8].

PHOTOGRAMMETRY

Romanesque Nativity of Mary sexton has been chosen as a test site for photogrammetric 3D model creation. The sexton has been found by Ottokar I. of Bohemia and its origin is dated back to years 1124 – 1125 as it was mentioned in the seal of the Pelhřim bishop, that was found in 1865 when the old altar had been replaced. The sexton's core is a circular rotunda with semicircle apsis made from ashlar. The tower, second apsis and the north sacristy are later annexes; tower's wooden superstructure has been added at the end of 17th century. The sexton is surrounded by high load-bearing walls from three sites and by former cemetery. Well preserved original Romanesque and early gothic frescoes can be found inside the sexton.

Figure 1 – Holubice Nativity of Mary sexton West view

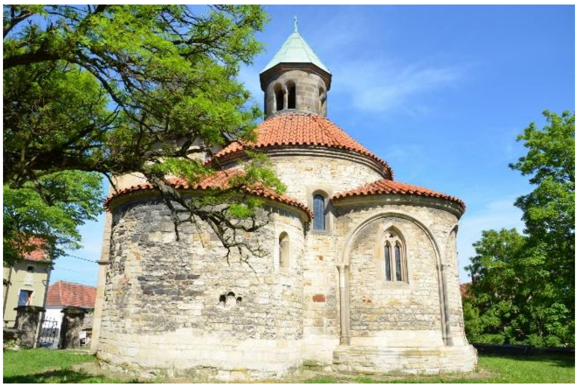

Figure 2 - Holubice Nativity of Mary sexton South view

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Figure 3 – Holubice – Phorogrammetry derived point cloud section, North view

Figure 4 – Holubice – Longitudial vertical section, North view

Figure 5 – Holubice – Ground plan point cloud section, Top view

Interior and exterior structural objects has been documented for the purpose of complex photogrammetric survey [9]. Local surveying network has been created and used as a spatial framework for detailed measurements. The survey has been connected to the national height coordination system (Baltic Vertical Datum – After Adjustment - Bpv). Polar survey has been used as a main mapping method. Together with detailed measurements, a photogrammetric photo documentation has been acquired. Photographs has been used for further processing in the Agisoft Photoscan software. Reference points have been chosen manually from the detail survey database. Processing parameters are listed below.

Processing parameters

General

Cameras	474
Aligned cameras	470
Markers	185
Coordinate system:	Local Coordinates (m)
Camera model:	Nikon D7000

Model

Faces	22,331,560
Vertices	11,186,366
Texture	4,096 x 4,096, uint8

Point Cloud

Points	118,697 of 731,814
RMS reprojection error	0.19196 (0.688 pix)
Max reprojection error	0.740856 (13.747 pix)
Mean key point size	3.476 pix
Effective overlap	4.492

Ground Control Points

Count	181
X error (cm)	2.38
Y error (cm)	2.49
Z error (cm)	2.33
XY error (cm)	3.44
Total (cm)	4.16
Image (pix)	4.85

Dense Point Cloud

Points	105,393,931

When taken into account the jaggedness of the object the created point cloud can be a fine tool for horizontal and vertical section creation. Several “holes” can be found in the pointcloud are due to an unfavourable scanning configuration since only terrestrial photography have been performed. This issue can be solved by using an RPAS or a high crane to obtain photographs from the missing angles. Besides these defects the pointcloud and its outputs are suitable for future building archaeology survey [10] and provides sufficient information for research work.

LASER SCANNING

As a test site for laser scanning a St. Peter and Paul Church in the town of Kralovice was chosen. This Renaissance fortified church was build according plans of Boniface the Wolmut. It belongs to the group of Florian Griesbecks properties, a highly educated Tyrolean aristocrat, private secretary and close adviser to Emperor Ferdinand I. It should be noted that at this place pre-existed gothic church which Florian Griesbeck rebuilt from 1575 to 1581. Parts of the remaining gothic walls were enclosed inside the walls done during Griesbecks reconstruction phase, so their exact structure and geometry cannot be ascertained. Interesting features are the arches on the outer side of the two longitudinal sides of the building and their fairly large thickness.

The main question was to confirm the hypothesis that its orientation seems to follow the cardinal points.

Measurements:

Interior and exterior of the church was documented by terrestrial laser scanning technology (Surphaser 25HSX) with special accent on orientation of walls. Walls were recorded approximately up to 4m high above terrain. Scans were acquired from 16 different scan stations using tripod (12 exterior and 4 interior). The position of each scan station was chosen with respect to conditions on site to ensure sufficient overlay of neighboring scans. The density of scanning was set to 1cm in distance of 5m.

Additional measurements were taken to ensure georeferencing of generated model. Coordinates of four points in immediate surrounding were acquired by RTK method using GNSS receiver. The receiver immediately transform the coordinates from global coordinate system to S-JTSK (Datum of Uniform Trigonometric Cadastral Network - local positioning system) and Bpv (Baltic Vertical Datum – After Adjustment) using global transformation key. These points serve as a base - selected points on surveyed object were determined by the method of intersection from distances (measured by survey tape) from the points determined by GNSS receiver.

Site plan - Kralovice

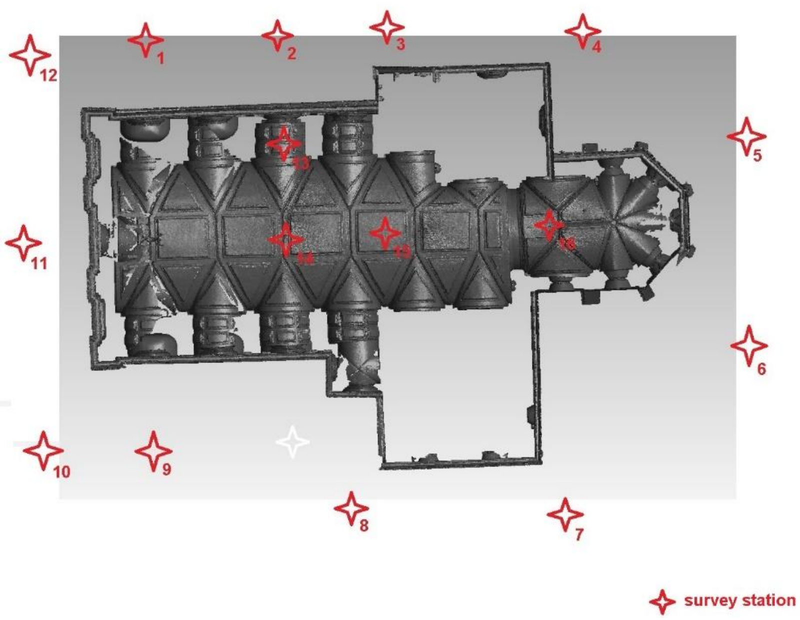

Figure 6 – Kralovice Site Plan

Data processing

The processing of point clouds was done using Geomagic Studio software. Each point cloud was cleaned using manual and semiautomatic selection tools. Point clouds registration (transformation into one common coordinate reference frame) followed. This step is divided into two parts: manual and global registration. The first – manual – is an approximate registration using manually selected identical points and the second – global – is a precise automatic registration using ICP (Iterative Closest Point) algorithm.

Afterwards, the dual coordinates of identical points (one set derived from point cloud and other derived using GNSS receiver) serve for computation of transformation parameters (congruent transformation consisting of translation and rotation was used). The rotation parameter was used to adjust the orientation of the model according S-JTSK axes. However, the axes of S-JTSK are not parallel to axes of geographic coordinate system and that is why the orientation of the model was adjusted again using the value of meridian convergence (angle between cartographical projection of the meridian and parallel to the X-axis). The orientation of resulting model corresponds to the orientation in geographic coordinate system (WGS84).

Finally, the resulting point cloud was used to create polygonal model in the form of TIN (Triangulated Irregular Network). The final outcome serves as a base for cross-section and ground plan production. Cross-sections were exported for further editing using CAD software.

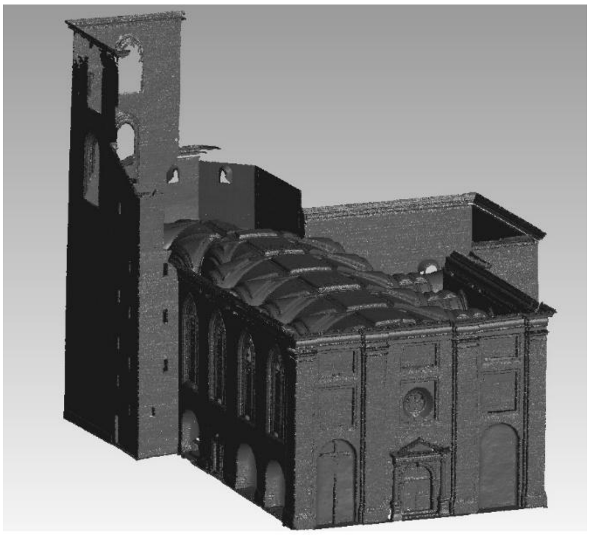

Figure 7 - North-west view

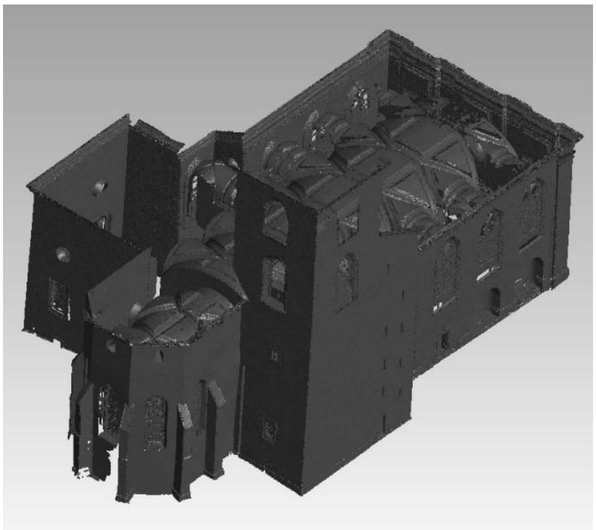

Figure 8 – North-east view

Outputs

Main output of the survey is a detailed model of the church in form of dense point cloud. This model is oriented to geographic coordination system. Other outputs are: wall projections, ground plan and cross-sections. Expected accuracy of model orientation based on used methods is ±0,2gon.

The angle between the longitudinal axis of the church and the true north is 88 degrees 11 minutes that confirms the fact that its orientation follows the cardinal astronomic points – facing east. The aim of the designer was to face the sacristy to the place where sun rises on equinox days. The deviation (1.89deg) was probably created when building the church. It has been found that younger Renaissance structures follows the geometry of former gothic walls since no difference in their thickness or other parameters has been discovered on the model geometry.

Figure 9 – Model East projection

Figure 10 – Model North projection

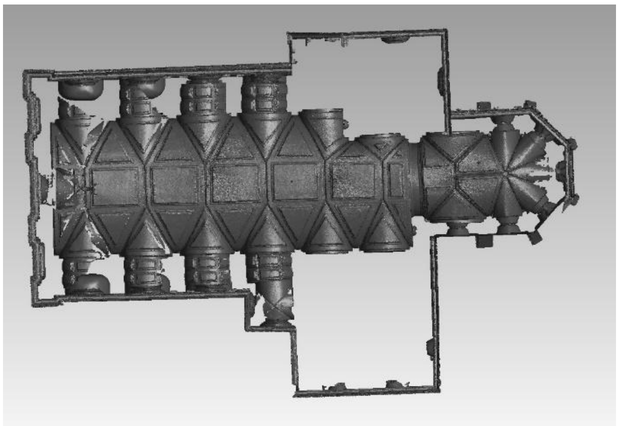

Figure 11 – Model top projection

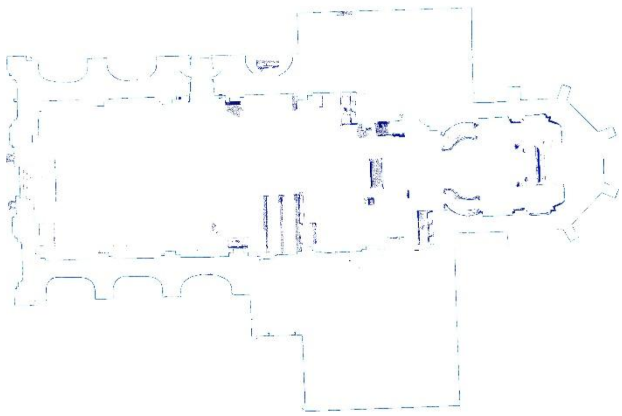

Figure 12 - Gound plan derived from the model

CONCLUSION

A 3D model of a historical building can provide unique information regarding the objects structure, shape and position. Two 3D modelling methods were tested (photogrammetry and laser scanning) on churches in the Czech Republic. Created 3D model affords creating views from various perspective or cross sections with high accuracy suitable for precise analysis. These designs together with the 3D model itself can be exported to CAD software for further investigation.

Presented methods provide results describing the size and shape of documented objects, but they are limited to surface recognition. When there is need of inner structure quality assessment of the building, it is appropriate to complement the survey by other non-invasive methods (e.g. GPR).

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