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Strengthening and long-term monitoring of the structure of an historical church presbytery

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ABSTRACT

The paper presents results of long-term monitoring of structural displacements in the historical presbytery in St. Ann's Church in Ząbkowice Śląskie (Poland), which was carried out from 2009 to 2013. The monitoring involved periodic HDS 3D (High-Definition Surveying 3D) laser scanning coupled with analysis of the status and scope of conservation work completed.

The church was built at the turn of the 14th century. Following a long period of neglect, conservation work was initiated to restore this valuable historical monument. Recognition of the historical value of the building meant that conservation work was preceded with a HDS 3D laser scan of the whole interior of the church. Data from scanning provided geometry information, which formed basis for a numerical analysis (FEM) conducted prior to repair work. It was decided that the oldest and most damaged part of the church – its presbytery – would be monitored in the years following repair work in order to observe conservation effects.

Methods used for strengthening and consolidation of cracked brick walls and vaults of the presbytery involved application of steel tie rods, as well as C-FRP (Carbon Fibre Reinforced Polymer) and C-FRCM (Carbon Fibre Reinforced Cementitious Matrix) technologies.

1. Introduction

St. Ann's Church in Ząbkowice Śląskie (Poland) (Fig. 2) is located in the south-west part of the town (Fig. 1). It was built as an oriented church. The building is a hall church with three naves and four bays (Figs. 3 and 4). Chapels located at eastern bays on the north and south sides of the building form a type of transversal nave, which imitates a transept. The church's closed pentagonal three-bay presbytery is wider than the central nave. A two floor sacristy with an annex and a porch is located on the north side next to the presbytery. A baptismal chapel is located between buttresses on the southern side at the eastern bay and opens into the interior with a moulded arcade. Moulded arcade are made of lime stone. Arches are made of lime stone or ceramic units.

A low quadrilateral stairway tower is located in a corner of this chapel. The rood arch arcade is bevelled. The naves are separated from one another by offset pillars. An octagonal tower is located in the north-west corner of the upper floor of the sacristy. The portal leading from the presbytery to the sacristy is made of stone and its entrance is in the form of a shouldered flat arch, moulded in its upper part.

The church building dates back to the second half of the 14th century. The parish church was first mentioned in the chronicles of 1292. Construction work on the building was also mentioned in information dating back to 1302, 1354 and 1356. The presbytery was most probably built in that year and covered with a timber roof structure. In 1413 a quadrilateral tower was built adjacent to the south wall of the presbytery. The church was burnt down by the Hussites in 1428. The construction of the nave walls was completed in 1453 and the nave vaults date back to 1547. The presbytery vault was completed almost 19 years later in 1566. The ribs and keystones of the vaults are made of ceramic units. Only vault abutments and a few keystones are made of stone blocks. Lime mortar was used to bind the bricks in the Polish (Gothic) or cross bond, which provided for a visually aesthetic cladding surface. The church was restored in the neo-Gothic style in the years 1893–95. Machine-made bricks of a much smaller size than the original Gothic ones were used in restoration work. The

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next round of restoration work was carried out in the years 1976–1978. In 2009, the 400 year old vault of the presbytery was strengthened using modern composite C-FRP and C-FRCM materials. The roof structure of the church was repaired and the damaged roof covering was replaced [8]. Studies on the use of composite materials to strengthen brick vaults and arches are presented in [1–5], on the use of laser scanning to monitoring engineering structures are presented in [6,7].

Construction of the building spanned a long period of time (Fig. 5). As a result, a variety of vault types were used (i.e. groin – rib vaulting of the aisles and porches, net vaulting of the central nave with a stellar vault over the organs and rib vaulting with lunettes of the presbytery). A variety of materials was used for the original construction of the church and subsequently for its restoration. It is possible to observe the different ways in which time has influenced bricks dating from different historical periods and manufactured with different techniques and methods. However, when looking at the axes and curvatures of vault arches, there is no suggestion that the vault structures lack symmetry or order.

2. A laser scan of the presbytery structure

A HDS 3D laser scanner was used to monitor structure of the church. This method of measurement and documentation of monuments also used in [9,10]. In our case three scans of the interior of the presbytery were generated, as well as three spherical photographs in greyscale (Figs. 6 and 7).

Scans were made in different years (2009, 2011, 2013) but, at the same times of the year and similar air temperature and humidity conditions. The measurement conditions are shown in Table 1.

The point clouds saved as individual files were merged into one. Registration error at the merge point clouds was taken as negligibly small (max. dimension – 5% resolution of the scanner). The reference spheres were used to position the scans accurately in relation to one another. Spherical objects of a known diameter were placed in locations shared by each subsequent scan. A reduction of cloud density was necessary due to the computational limitations of the programmes used for data processing.

Several programmes (Faro SCENE, AutoCAD, VRMesh) were used at the model development stage. The first one served to connect scan points essential to estimating rib curvatures, resulting in a spatial, broken polyline. Outlines were also traced of the most significant structural profiles, especially cross-sections of ribs and walls. A second programme was used to draw a horizontal projection of the building at a height of approximately 9.00 m from floor level, which referenced also the pattern of vault ribs. The rib curvatures obtained in the first programme were then imported to

Fig. 2. The front elevation of the church (2013).

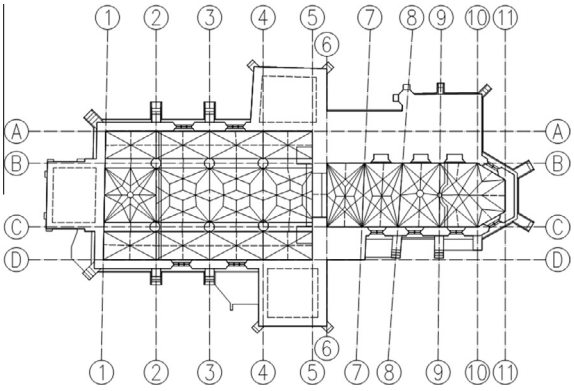

Fig. 3. Horizontal layout of the church with arrangement of axes used for describing its structural elements.

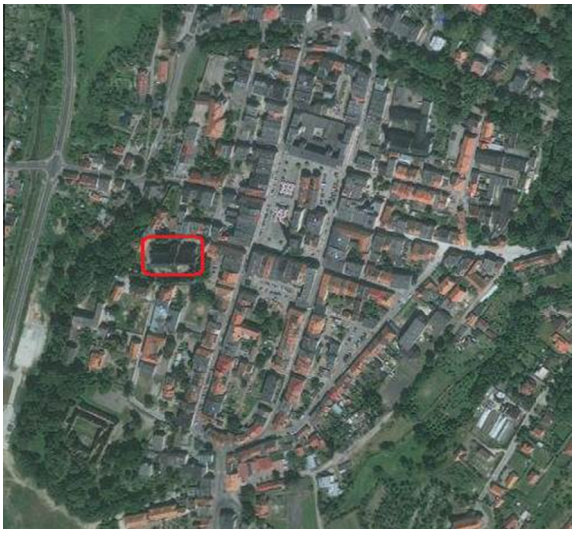

Fig. 1. The location of the church in the south-west part of the old town.

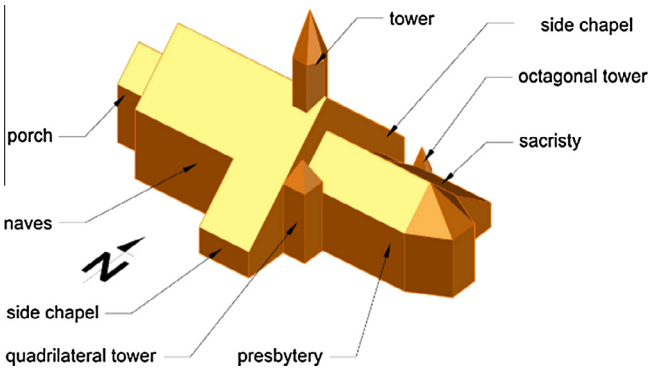

Fig. 4. The architectural form of the church.