Combined geodetic and geophysical modelling of a religious edifice

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Abstract

The implementation of geophysical methods in the monitoring of built heritage offers a valuable, non-destructive insight into the internal structure. We have shown that 2D geophysical images or quantitative interpretations in form of 3D models can be easily incorporated into virtual databases of documented built heritage contributing to the understanding of its historical development also by the public and non-experts. Such multidisciplinary approach to sense the present and past of our historic monuments contributes significantly to their documentation for future generations.

Introduction

Recording of the historic edifice using the state-of-the-art surveying techniques brings easier visualization in form of a 3D model, thus allowing better understanding of its historical construction by the public. We have applied this approach at the Church of St. George, one of the most significant historic monuments in SW Slovakia that dominates a silhouette of the town Svätý Jur (**Fig. 1**). The church was built in the first half of the 13th century and in following centuries underwent many significant alterations [5]. Historical records indicate medieval crypts and single graves inside the church [1].

Geodetic survey

The geodetic survey allowed to record the present-day state of the church. The church exterior was surveyed using a total station (Trimble VX, specified point spatial accuracy of 4 mm). To describe in the best way the geometry and segmentation of the entire exterior of the building about 3000 points on facades and the roof were measured.

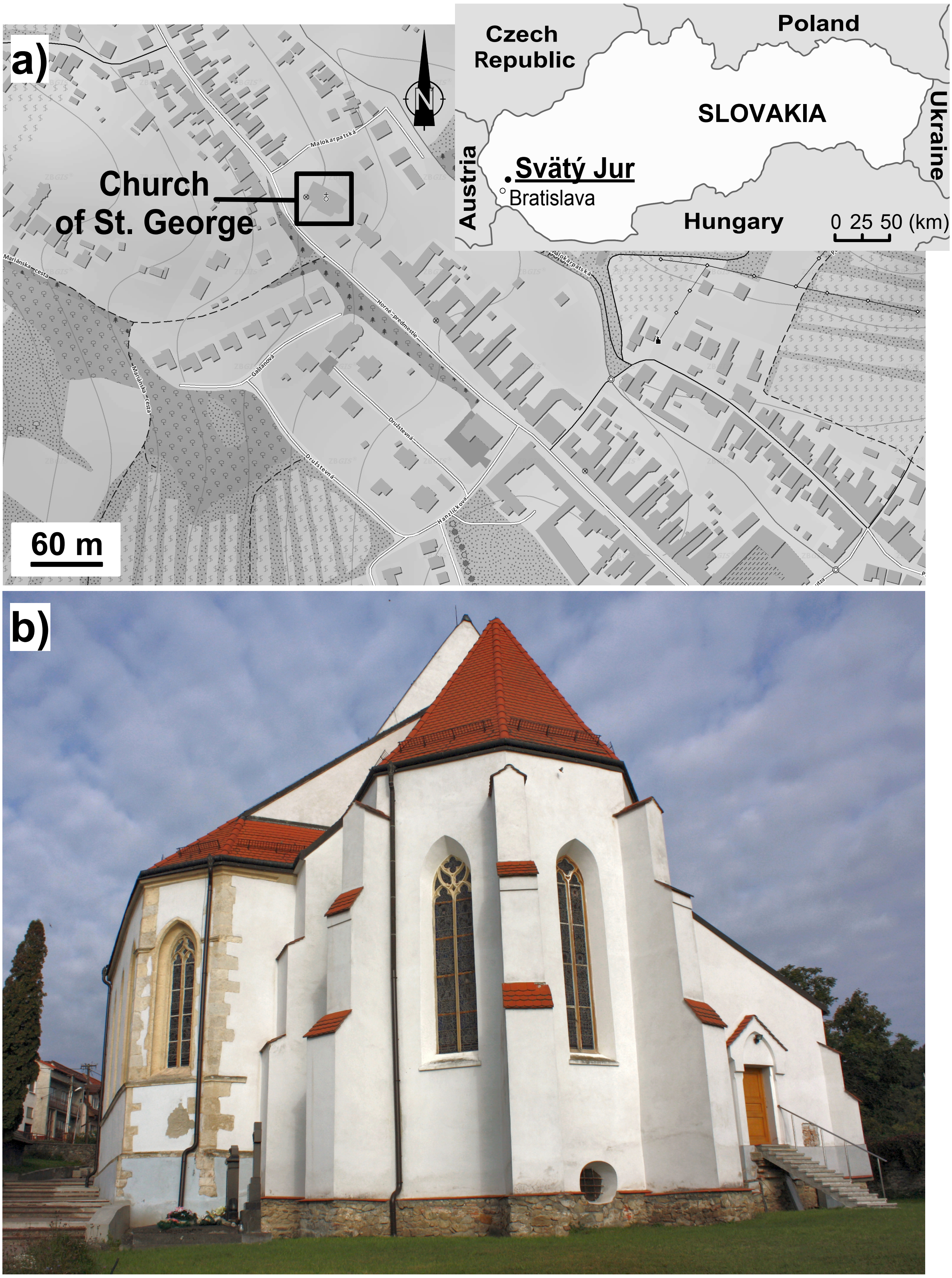

Figure 1: (a) Location map of (b) the Church of St. George in Svätý Jur.

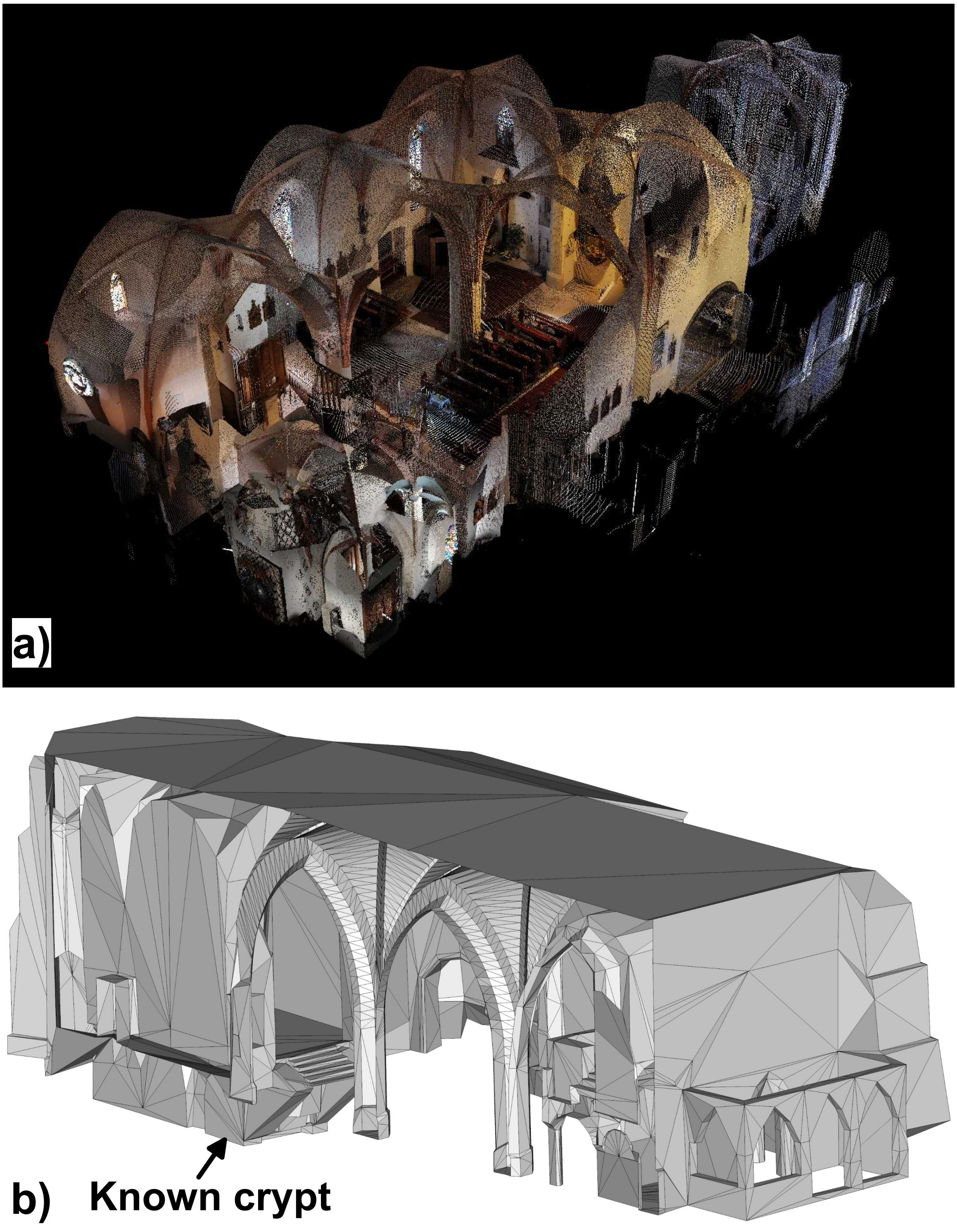

Figure 2: (a) Point cloud of the church interior; (b) Simplified roofless model of the church.

The interior of this historical edifice has a quite complex structural form comprising several rooms, balcony and rib-vaulted ceiling. To virtually reconstruct these interior substructures of the church, a 3D laser scanner survey was carried out using a Riegl VZ-400 laser scanner. Collected detailed point cloud (**Fig. 2a**) was processed, decimated into a 3D vector model and linked with the exterior model through windows and doors. A simplified roofless version of the model, created as one closed polyhedron and described by a triangular irregular network (TIN, more than 10 000 triangles), was utilized also in microgravity data processing ([2]; **Fig. 2b**).

Geophysical survey

Microgravity and GPR methods were selected as the most effective geophysical tools for mapping of shallow subsurface in the interior of buildings. In the complex character of the anomalous gravity field several areas of mass deficiency beneath the ground are indicated (blue, violet to magenta contour colours in (**Fig. 3a**)). The main negative gravity anomalies of interest in the nave (features A-D), which also have been confirmed by GPR measurements, are interpreted as medieval crypts. Another very important outcome of the geophysical survey is the discovery of the west wall foundations of the oldest Romanesque construction (see the linear feature E located around 52 m in the y-direction in (**Figs. 3 and 4**)). Feature C, which seems to be interconnected with empty cavity B and filled cavity D, could be interpreted as a narrow crypt or passageway (**Figs. 3a and 4**). Finally, the feature F might indicate the presence of a filled cavity or grave.

To estimate the depth and geometry of anomalous sources the harmonic inversion method [4], 3D density modelling and 3D Euler deconvolution (ED; [3]) were used. Volume density model obtained by means of harmonic inversion shows empty cavities by black and high-density foundations by light yellow (**Fig. 3b-d**). White lines represent possible boundaries of four medieval crypts from 3D density modelling. Five polygonal prisms (two of them with an arched cross-section and one rectangular prism) with different density contrasts were used to model the crypts. The structural index in 3D Euler deconvolution was set to one assuming a horizontal cylinder shaped bodies to be detected. To find the depth estimate to anomalous source bodies, we used an in-house software Regder developed at the Comenius University in Bratislava. The selected ED solution clusters shown by filled yellow circles are situated in a depth of 0.3-1.9 m below the ground (**Fig. 3b-d**).

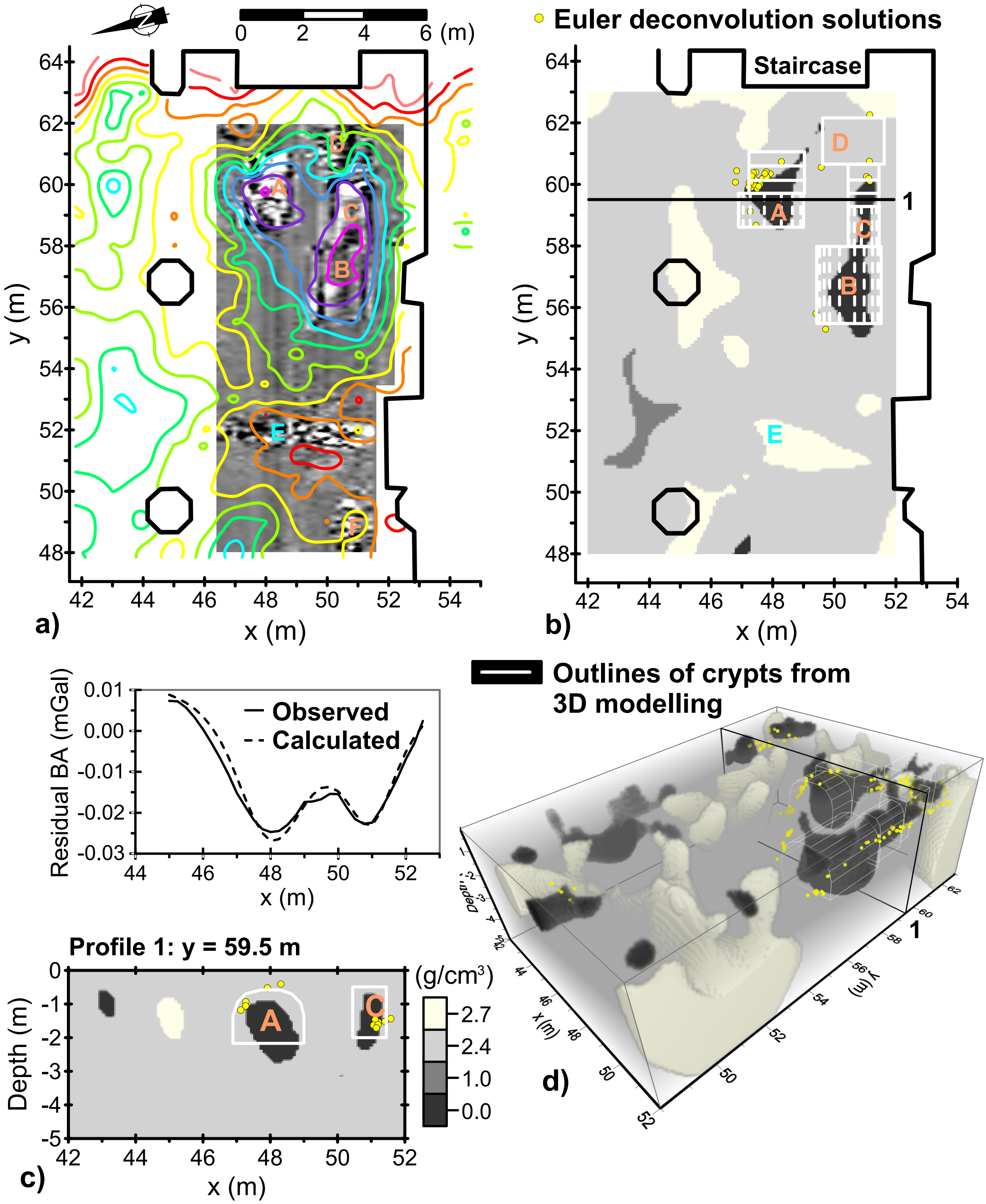

Figure 3: (a) Horizontal GPR time slice for a depth of approx. 0.6 m overlapped with the residual Bouguer anomaly contours; (b-d) Harmonic inversion solution: (b) horizontal density slice (depth of 1.5 m); (c) vertical density section along profile 1 with corresponding 3D modelling output above; (d) volume density model. Mapped subsurface features are labeled as A-F.

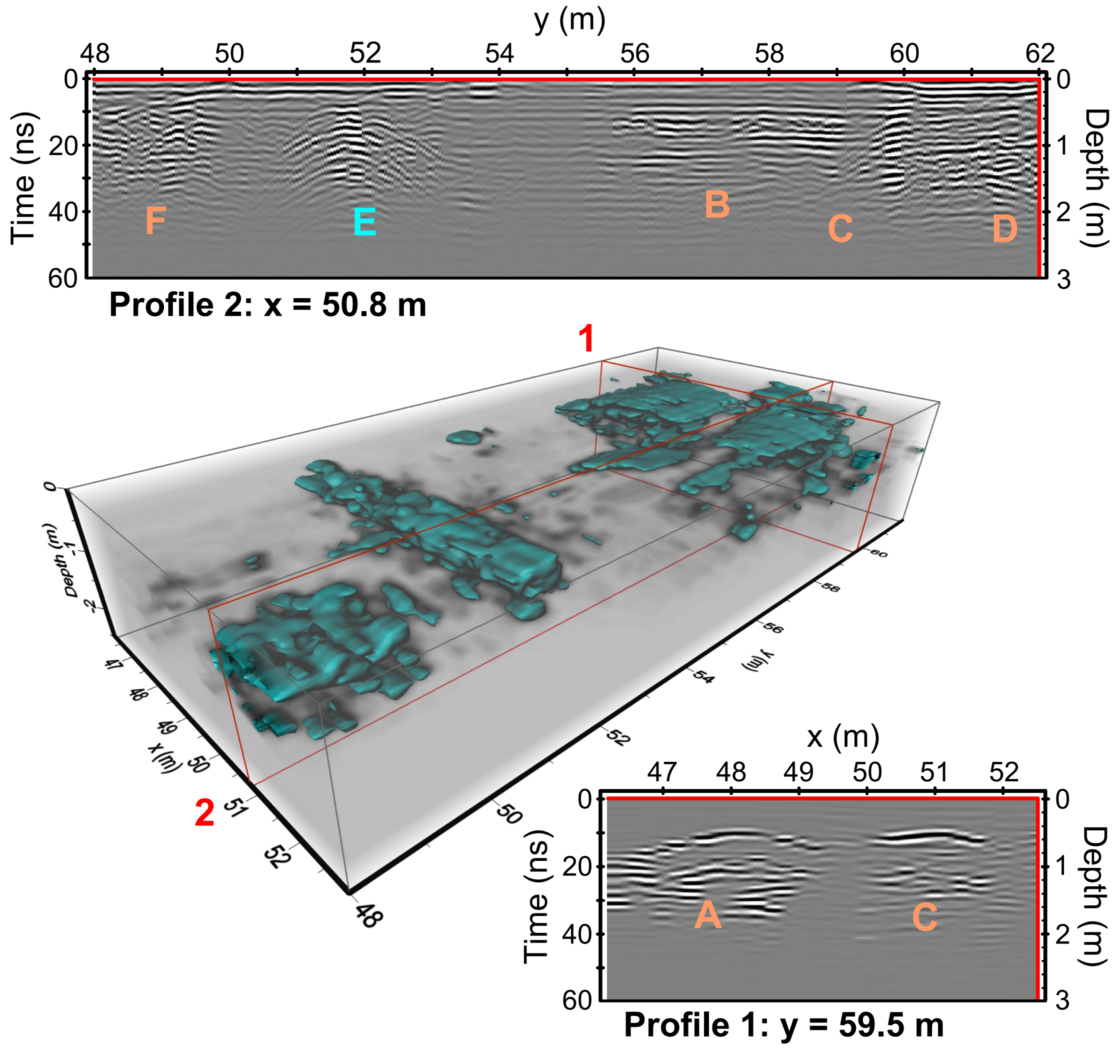

Figure 4: Selected vertical GPR time-depth sections in profiles 2-1 with labeled GPR anomalies together with the iso-surface GPR volume model (in the middle).

Joint interpretation

Figure 3a allows a qualitative comparison of both geophysical methods. There is obviously quite high correlation between two displayed data sets in the case of features A-D related to the predicted medieval crypts. On the other hand, the maximum of the gravity high, which bounds the negative anomalous zone from below, is slightly shifted against the position of the linear GPR anomaly E related to the wall foundations. We cannot now clearly interpret this inconsistency.

The objects A, B, C and E shown in **Fig. 3b** can be correlated with features seen on the GPR horizontal depth slice (**Fig. 3a**). **Figure 3c** shows a reasonable fit between the calculated and observed gravity. The average depths (approx. 0.4-1.7 m) of the ED solution clusters located between 47 and 52 m in the x-direction correspond with the estimated depths of the features A and C obtained by means of the harmonic inversion.

The clustering of the 3D ED solutions rather along the edges of modelled crypts than to their centres could be explained by the proximity of anomalous sources in the upper part of the nave. The calculated shape of bodies from the harmonic inversion does not represent exactly the expected geometry of crypts derived from GPR data. The reason why there is such a big difference between the expected and calculated shape of detected crypts is that the measured gravity data are still too sparse: 0.5 m spacing versus 2 m width of the crypt A, even a 1 m width of the narrow passageway C.

In this case study, the electromagnetic properties of the soil are compared with density changes in a depth of upper few meters beneath the floor in the interior of the Church of St. George in Svätý Jur. Four medieval crypts mentioned in historical archives were successfully delineated in the nave using microgravity (**Fig. 3**) and GPR methods (**Fig. 4**). The discovery of the west wall foundations of the former Romanesque construction approx. in one third of the nave, oriented northwards perpendicularly to the main entry, is the most significant result of the geophysical survey. Verification of these structures by means of archaeological excavation has not been carried out yet.

(3D model of church and subsurface structures)

3D model

From each geophysical data acquired we derived 3D polygonal models, which are compared in the interactive 3D model above, to achieve more realistic picture of the subsurface structures, thus bringing more confidence to the interpretation. A spatial models of detected buried cultural features are now added into the visualization of the visible parts of the church (see the Interactive 3D model). The GPR modelling output, which was interpreted from the iso-surface model and vertical sections, is depicted by cyan colour. The crypts obtained by the 3D density modelling are yellow coloured. A detailed view on the combined models shows quite high correlation of modelled subsurface features, except the upper part of the left crypt A, affirming the reliability of our interpretation. Only the archaeological excavation could validate the relevancy of the hypothetic entrance stairs from 3D density modelling.

References

1. Luz R. 2012. Burials inf the Church of St. George in the town Svätý Jur. Student Scientific Conference, Faculty of Philosophy, Comenius University, Bratislava. (in Slovak)

2. Panisova J. Pašteka R. Papčo J. Frašia M. 2012. The calculation of building corrections in microgravity surveys using close-range photogrammetry. Near Surface Geophysics 10:391-399.

3. Pašteka R., Richter P., Karcol R., Brazda K., Hajach M. 2009. Regularized derivatives of potential fields and their role in semi-automated interpretation methods. Geophysical Prospecting 57:507-516.

4. Pohánka V. 2003. The harmonic inversion method: calculation of the multi-domain density. Contrib. Geophys. Geod. 33:247-266.

5. Sabadošová E. 2012. Church of St George: architectural-historical and art historical research of the walls in the interior of the nave and aisle in the context of overall church history. Yearbook of historical research, report year 2010, The Monuments Board of the Slovak Republic, Bratislava. (in Slovak)