Monitoring the Structural Stability of the Church of St. Michael the Archangel in Veľké Rovné Using Terrestrial Laser Scanning

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Abstract

The Church of St. Michael the Archangel in Veľké Rovné, built between 1753 and 1755, is a historically significant structure requiring continuous monitoring due to its age and structural changes over time. The preservation of such historical monuments necessitates accurate and non-invasive measurement techniques. This study employs terrestrial laser scanning (TLS) to assess the geometry of its load-bearing elements, detect potential deformations, and provide essential data for conservation planning. The methodology involved high-precision TLS using Leica ScanStation C10 and P50 scanners, capturing data from 48 scan positions to ensure complete coverage of both the interior and exterior. The collected point cloud data were processed using Leica Cyclone software, allowing precise registration and analysis. In addition to TLS, other geodetic techniques were employed: precise leveling with a Leica LS15 digital level to detect height displacements and the spatial polar method using a Trimble VX total station to monitor the structural integrity of the church's vaults and supporting elements. The combination of these methods provided a comprehensive dataset for evaluating potential deformations. Results indicated visible cracks in the vaults and roof framework, highlighting the need for continuous structural monitoring. The study also established 11 benchmark points for future height measurements, ensuring long-term observation of settlement patterns. The 3D point cloud model allowed for detailed structural analysis and provided critical insights into the church's condition. Despite the advantages of TLS, limitations were noted in capturing roof structures due to unfavorable lighting conditions, which affected texturing accuracy. The findings confirm that TLS is an effective and precise tool for monitoring historical buildings, offering high-accuracy data for structural assessment, damage detection, and conservation planning. The generated point cloud dataset serves as a valuable reference for future monitoring and comparison, supporting engineers and conservationists in determining optimal stabilization and restoration measures for the church.

Keywords: *Terrestrial laser scanning, historical buildings, stability monitoring, geodetic measurements, 3D modeling, structural analysis*

1. Introduction

The Church of St. Michael the Archangel in Veľké Rovné is a historic structure built between 1753 and 1755. Due to its age and gradual changes in the stability of its construction, it was necessary to conduct detailed geodetic measurements to monitor its structural stability. The main objective was to assess the geometry of the load-bearing elements, identify potential deformations, and provide essential data for the design of remediation measures.

Fig. 1. 3D image of the exterior of the Church of St. Michael the Archangel in Veľké Rovné.

Terrestrial laser scanning (TLS) has become a key technology in recent years for monitoring and analyzing historical buildings. This non-contact method enables high-precision capturing of object geometry, which is invaluable for documenting and assessing the condition of structural elements. The use of TLS for monitoring the stability of structures has been the subject of several studies. For example, Blišťan and Kovanič (2014) presented the application of terrestrial laser scanning systems for monitoring the stability of quarry walls, highlighting the specific features and applicability of this technology in mining operations [1].

Another study focused on monitoring slope movements, where terrestrial methods, including TLS, achieved a spatial point accuracy of up to 1 mm, demonstrating the high precision of this technology [2]. In the field of geodesy and cartography, TLS has proven effective in processing data obtained from building measurements. The methodology for processing this data is detailed in the work of Kopáčik et al. (2014), which emphasizes the importance of TLS in creating accurate 3D models of structural objects [3].

Foreign studies have also examined the use of TLS in construction and the monitoring of historical buildings. For example, the work of Corns and Show (2009) highlights the significance of TLS in capturing deformation changes in historical monuments and its application for long-term stability monitoring [4]. Similarly, Martínez et al. (2012) focused on the accuracy of TLS in determining geometric changes in structural objects [5].

In the case of the Church of St. Michael the Archangel in Veľké Rovné, TLS was chosen as the primary method for monitoring its structural stability. Given the church's age and historical significance, it was essential to use a technique that could provide detailed and precise data on its current condition without interfering with its structure. TLS enabled the creation of an accurate 3D model of the church, the identification of deformation zones, and the provision of essential data for the design of remediation measures.

2. Objectives

The main objectives of the monitoring were:

- Collection and processing of spatial data using terrestrial laser scanning (TLS) to create an accurate 3D model of the church, including both the interior and exterior.
- Determination of vertical displacements of the structure using precise leveling to identify potential settlement of the building over time.
- Monitoring of the spatial position of the church vault using the spatial polar method to detect possible deformations of structural elements.
- Detection and analysis of structural defects, such as cracks in the vaults and roof framework, using high-precision scanning data.
- Creation of a reference measurement database for future monitoring of the building's condition as part of long-term maintenance and heritage preservation.

3. Methods

To ensure a comprehensive assessment of the structural stability of the Church of St. Michael the Archangel, a combination of terrestrial laser scanning (TLS) and geodetic techniques was employed. These methods enabled precise spatial data collection and subsequent analysis of the church's geometry, deformations, and potential structural issues.

3.1 Terrestrial Laser Scanning (TLS)

TLS was conducted using Leica ScanStation C10 and P50 scanners, which provided high-resolution point cloud data for both the exterior and interior of the church. A total of 48 scanning stations were used to ensure full coverage of the structure, minimizing shadowed areas in the dataset. Each scanning station was positioned strategically to capture key architectural elements, including load-bearing walls, vaults, and the roof framework.

In addition to point cloud acquisition, photographic imaging was integrated into the scanning process to enhance visual interpretation. The collected images were used to create **textured 3D visualizations**, improving the accuracy of deformation detection. The data were processed in **Leica Cyclone software**, where individual scans were registered into a **unified coordinate system** using reference targets and cloud-to-cloud registration techniques. A **high-density point cloud model** was generated, allowing for detailed structural analysis.

3.2 Precise Leveling for Vertical Displacement Monitoring

To assess vertical displacements and potential settlement of the church, precise levelling was carried out using a Leica LS15 digital level. This instrument provided millimetre-level accuracy, with a standard deviation of 0.2 mm per kilometre, ensuring highly reliable results.

The levelling network consisted of 11 control points distributed around the perimeter of the church. These points were securely marked and measured against reference benchmarks from the National Levelling Network, specifically ZD12-518, ZD12-519, and ZD12-520. The positions of these benchmarks are illustrated in Figure 2.

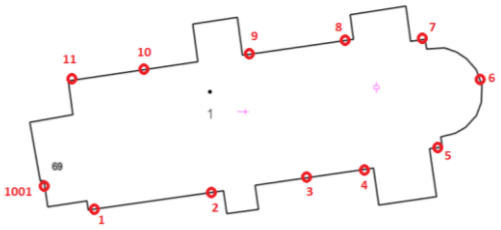


Fig. 2 Numbering of detailed height network points installed on the church

Measurements were conducted in multiple epochs to detect any changes over time. The acquired elevation differences were adjusted in the Balt system, ensuring consistency and eliminating systematic errors.

3.3 Spatial Polar Method for Vault Deformation Monitoring

Due to the architectural complexity of the church, an additional spatial polar method was used to monitor the vault's structural integrity. This method involved measurements taken using a Trimble VX total station, which offers angular accuracy of 0.3 mgon and distance measurement precision of 1+2 ppm.

Special reflective targets were placed at critical points on the vault structure to facilitate repeated measurements in future monitoring campaigns. The data obtained from this method were compared with the TLS point cloud to verify potential deformations.

3.4 Data Integration and Analysis

The combination of TLS, precise levelling, and spatial polar measurements provided a comprehensive dataset for analysing structural deformations. The acquired data were processed and evaluated using:

- Leica Cyclone for point cloud registration and 3D modelling.
- AutoCAD and CloudCompare for geometric analysis and visualization of structural deviations.

By integrating these techniques, a detailed structural assessment of the church was achieved, laying the foundation for long-term monitoring and conservation planning.

4. Results

The results of the measurements were: the creation of an accurate 3D model of the church in the form of a point cloud, which enabled a detailed analysis of the structure.

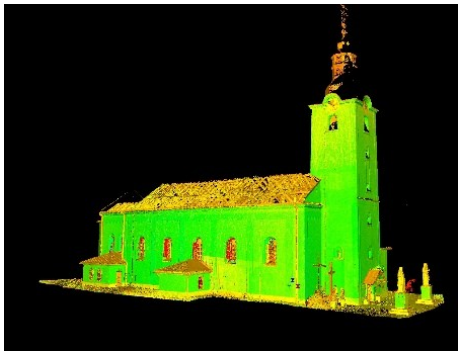
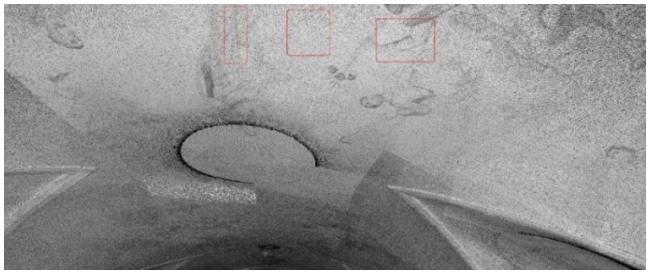


Fig. 3 Visualization of the exterior of the examined object as a coloured point cloud map

Fig. 4 Visualization of the interior of the examined object as a colored point cloud map

Detection of cracks in the vault and roof framework, which are visible in the scanning outputs.



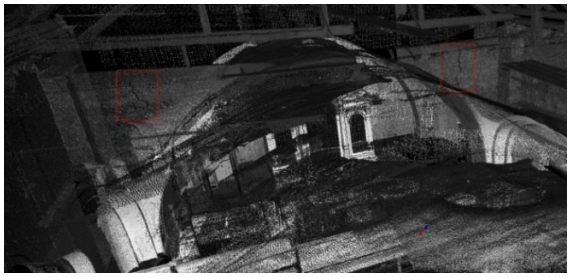


Fig. 5, Fig.6 Visible cracks in the church vault and roof framework, evaluated using a 3D scan.

Determination of the initial heights of 11 leveling points at approximately 0.6 m on the church facade for long-term settlement monitoring and the spatial position of detailed points marked in the church interior on four vaults. The adjusted heights of reference and detailed points are presented in Table 1.

Tab. 1 Heights of reference system points and detailed points on the church.

ZD12-52	**ZD12-519**	**ZD12-518**	**1**	**2**	**3**	**4**
393,9425	391,5054	388,5917	392,068475	392,158075	392,125825	392,132625
5	**6**	**7**	**8**	**9**	**10**	**11**
392,108575	392,171075	392,13185	392,204675	392,201375	392,142525	392,069275

The application of terrestrial laser scanning also revealed certain limitations, including the inability to accurately capture the roof covering of the church nave. This was primarily due to the steep angles and material properties of the roofing, which reduced the scanner's ability to reflect laser beams effectively. Additionally, unfavorable atmospheric conditions during the photographic imaging process further complicated data acquisition. Intense sunlight during scanning caused significant contrasts, dividing the object into highly and poorly illuminated areas. This disparity made it difficult to achieve uniform texturing and color consistency in the final visualization. As a result, some structural elements required additional manual processing and refinement to improve their representation in the 3D model.

5. Conclusion

Monitoring confirmed that the terrestrial laser scanning method is suitable for detailed analysis of historical buildings. The results of the height measurement and spatial polar method provide an important foundation for future comparative measurements. Based on the obtained data, conservationists and structural engineers will be able to determine optimal remediation measures for stabilizing the church.

The aim of the scanning was to capture the geometry of the load-bearing elements of the structures for preparatory work focused on the remediation and stabilization of the object. The scanning result, in the form of a point cloud available in multiple formats, was provided to the structural engineer for further analysis. The result of the height measurement consists of determining the height of 11 detailed points, which will serve for comparison with values obtained in subsequent measurement stages. Similarly, the 3D coordinates of detailed points indicated on the church's vaults will be compared with values determined in future measurement stages.

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