The TLS technique as a way of identification and measurement of damaged elements of a historic sacral building

Joanna A. Pawłowicz[1,*]

[1] Institute of Building Engineering, Faculty of Geodesy, Geospatial and Civil Engineering University of Warmia and Mazury in Olsztyn, 10-724 Olsztyn, Heweliusza str. 4, Poland

Abstract. 3D terrestrial laser scanning (TLS) is a modern measurement technique which enables to obtain a large amount of data in short time. The gathered data is very detailed, thus the scope of its use is vast. Therefore scanners other measurement devices which results in considerable acceleration of stock-taking work. This approach enables to prepare a documentation of a building or to make an assessment of its technical condition using only a 3D cloud of points. Additionally, flexibility of data and advanced computer programmes make it possible to use such data in many sectors, not only in the building trade. The paper shows the issue of using a 3D terrestrial laser scanner ant the TLS (Terrestrial Laser Scanning) technique for identification and measurement of damaged elements on the example of a historical sacral building.

1 Introduction

The region of Warmia and Masuria is abounding in historical sacral buildings. An easy access to deposits of clay and sand was conducive to erection of brick-built objects. Over centuries on the territory of Warmia mainly red brick was produced and used, whereas in Masuria buildings from yellow brick are found more often. They are frequently valuable historic monuments with an interesting shape design and rich architectural ornament. Unfortunately, presently some of them require major repairs. They are in a bad condition which can lead to a building catastrophe. The managers of these buildings should strive for a quick repair. However it requires often huge expenditures, hence they focus mainly on monitoring of buildings condition and current necessary repairs. Sacral buildings fulfil public functions, therefore a good technical condition is to be maintained. A chapel or a church is a place of worship and should arise admiration and positive emotions with their look. Minor repairs conducted currently allow to maintain functionality and guarantee their safe usage.

Buildings are subject to different destructive processes depended upon numerous external factors as well as passing time. Their constant influence makes taking preventive measures necessary. Factors affecting condition of a building can be divided in several groups. The first group is atmospheric factors for example rain- and snowfalls, wind, solar radiation as

* Corresponding author: jopaw@uwm.edu.pl

well as the changes in temperature and air humidity. The next is external factors which result in changes of subgrade, e.g. vibrations and shaking as well as proximal building activities [1].

Another group constitutes factors connected to living organisms. An example of such destructions is that of Serpula Lacrymans or this of insects such as Hylotrupes Bajulus. In the case of this first they infect mainly wall plates, ends of rafters, beams whereas the second do damage to wood elements drilling small holes [2].

A considerable threat for historical monuments is imposed by crisis circumstances [3] such as:

- destructive influence of natural elements: hurricanes, fires, floods,
- technical failures understood as building catastrophes,
- human activities: conducting military operations, acts of terrorism, or vandalism.

Unfortunately, each of the above-mentioned factors may influence on the increase of occurrence of another. For example the increase of humidity may result in development of fungi, mildew or harmful organisms infection. In turn, deterioration of ground conditions influences the increase of cracks, which require repairs the consequences of a bad planning or completion of work will result in additional damage to e.g. foundations of a building.

2 The method of TLS in examination of ancient monuments

In order to undertake repairs to an ancient monument it is necessary to its stock-taking and re-creation of the missing building documentation. This work can be done classically with the aid of a measuring tape or a telemeter. A modern solution is the use of a laser scanner and collecting data in the form of a 3D cloud of points. The method of terestial laser scanning (TLS) allows to make a complex measurement of buildings resulting in an dimensional image of existing physical object. A cloud of points is obtained in the digital form in which each point has coordinates X, Y, Z in the local system of coordinates of a scanner (it can be transferred to any geodetic system) and the fourth coordinate I – describing the intensity of refection of a laser beam from a measured object. This technology was appreciated by many specialists – it enables preparation of multi-discipline works [4,5, 6]:

- stock-taking of monumental objects and of engineering constructions,
- threats of tunnels collapse,
- examination and archving of archeological findings both underground and mural,
- stock-taking of untypical and unique natural findings such as e.g. calcite caves,
- measurements of deviations and deformations of buildings from their original condition.

Other uses of laser scanning in the building trade are e.g. [7]:

- supervising dislocation of an individual part of a construction,
- control of construction safety,
- creating a stock-taking documentation of architectural-building constructions,
- preparation of documentation of buildings real condition [8],
- supervising building activities,
- measurements of ground mass and an analysis of terrain shape [9],
- cubature calculations,
- control of the accuracy of completion,
- supervising deformations.

A cloud of points proves useful in renovation, reconstruction and preparation of an architectural-building documentation, archaeological works or different stock-takings. Numerous advantages of the TLS method is a reason for its growing popularity among different firms.

2.1 Collection and preparation of data

The measurements were made for a neo-gothic chapel in situ, built from full ceramic bricks, fixed with mortar (Fig. 1a, Fig. 1b). The door and window woodwork was made of wood and stained glass. Inside colourful stone floor tiles were used making different patterns, the wall are decorated with many paintings. In the central part of the chapel there are figures depicting the Passion. The building is situated in a swampy ground and in all likelihood it is erected on stone foundations.

Fig 1a. The chapel in a digital photo.

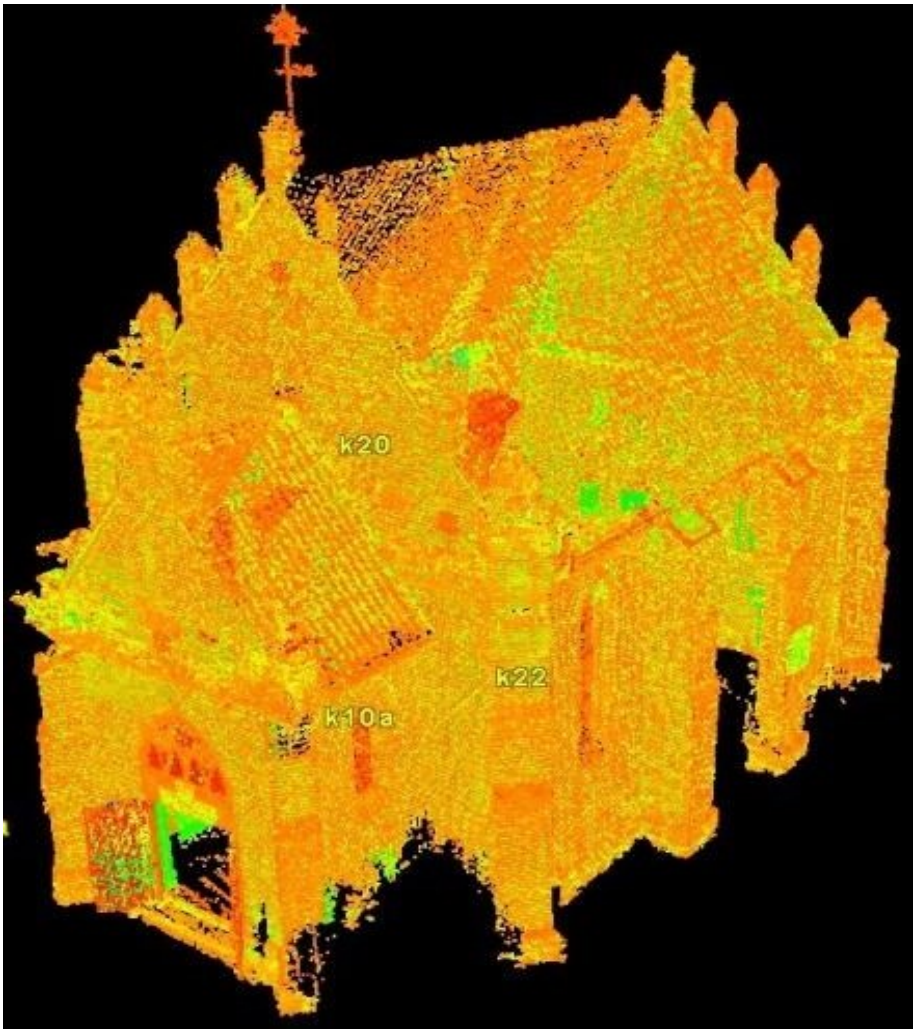

Fig 1b. The chapel in the form of points cloud in the colours of reflection intensity.

2.2 Visual assessment of technical condition

Over centenary-old object subjected to the aggressiveness of the environment require constant maintaining activities. An irregular control of technical condition may lead to the increasing costs of repairs and to the deterioration of visual values. A preliminary visual assessment enabled to evaluate the technical condition of the chapel and to inventory their damages. Several kinds of damages were observed. In this paper only some of them are mentioned. They were to be found in different parts of the building. Their localisation very often ruled out their measurement with the classical method without the use of a scaffolding or a ladder. Therefore the measurements were made additionally with the technique of 3D laser scanning, thanks to which in the post-processing the size of damages could be determined.

Fig. 2. Damaged corner of the building – an example of missing mortar in a wall

The inspection of the walls showed that the most often occurring damages were cracking, crumbling corners and splitting off of a part or an entirety of bricks. In the corners and on the edges of moulds there is no mortar between bricks. Figure 2 shows the result of dislodgment of bond that results in falling off bricks from walls and corners. It is due most probably to the effect of humidity which weakens the bonds between a brick and mortar as well as of a wind blowing the weakened particles away. On the walls attempts made to supplement mortar are visible (Fig. 3), which can be distinguished by different colour and density. In some especially damaged places plants took their roots and the humidity resulted in growing of algae and moss (Fig. 4).

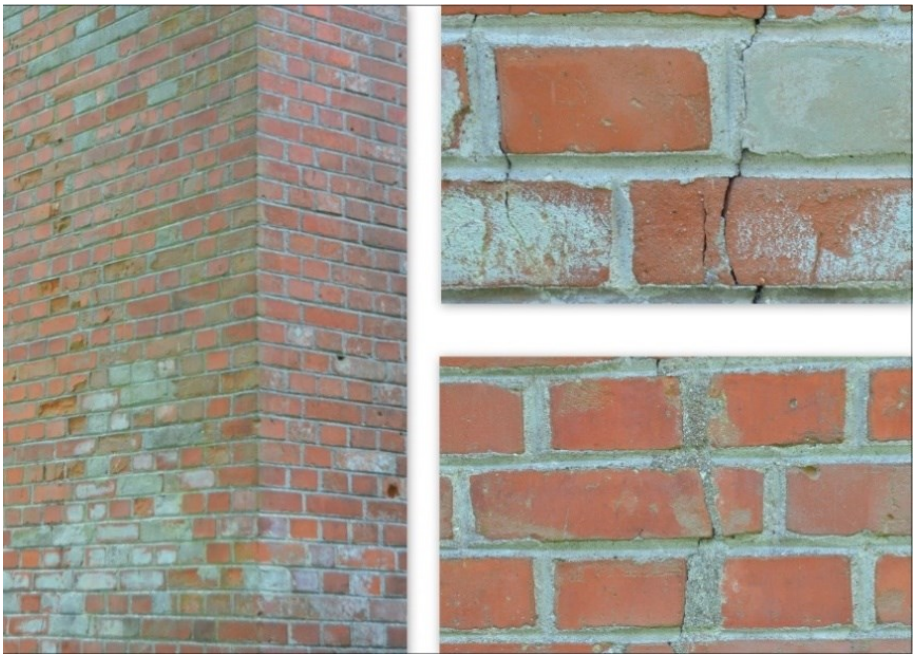

Fig. 3. Examples of damaged bricks and repairs in the form of supplementing mortar.

Fig. 4. Biological damage on the external walls of the chapel.

In the interior there are many cracks of the walls and plaster chipping offs as well as discolour or obliteration of paint (Fig. 5). The character of the damages speaks of high degree of moistness of the interior of the building. Distinct traces show the range of the occurrence of this problem (Fig. 6). The reason may be the damage of the walls, the roof and the window woodwork and the closure of the chapel without ventilation for a long time.

Fig. 5. Damage to internal walls: plaster chipping off and paint obliteration.

The damages and the inapt attempts to repair them destroyed mural paintings, which lost their attractiveness in a high degree.

Fig. 6. The range of moisture damage to the walls.

The most important from the viewpoint of the construction requirements are the cracks and chinks on the vertical and horizontal elements of the building. They are found mainly on the walls of the chapel between bricks and mortar. They are of a lineal character and they begin first of all by window openings which is shown in Fig. 7. It pertain both to the damages in the interior and outside the building. In the chapel the damages head from the windows to the centre of the ceiling. Their localisation on a big height was the reason for using a laser scanner for making measurements.

Fig. 7. Wall cracking: cracking of the internal wall and the external wall by a window opening.

2.3 The use of the TLS method in a chapel examination

The measurements of the TLS method were made with the aid of a 3D ScanStation C10 laser scanner of Leica. The device is characterised with a big range up to 300 meters and the scope of viewing in the horizontal plane up to 360 degree and the vertical plane up to 270 degree. The scanner collects data with the speed up to 50 000 points per second. During a measurement the angle and the distance between the place of scanning and the object is determined. The database obtained is represented in the form of a cloud of points, showing a dimensional image of the measured object. Simultaneously the device takes digital pictures of a high resolution which enables in the post-processing to re-create natural colours of the object. Then the *in situ* data is assessed with regard to their usefulness and purified from noise. With the aid of the computer programmes: Leica Cyclone, AutoCad and ReCap the damaged places were identified and the measurements of the cracks and rifts in the walls were made. To confirm the accuracy of the identification additional digital photograph were taken.

In the building over 30 places of damage occurrence were identified. In this paper a chosen example was a basis for analysis. The digital photograph (Fig. 8a) shows the damage to the middle part of the arch over the entrance to the main room of the chapel. It starts on the vault, then it crosses the arch perpendicularly to the plane of the wall. The measurement of the length of the crack was made in the cloud of points in a big magnification, when each point of the cloud can be identified. Thanks to it, it was calculated that the entire length of the main crack is 1.125 m and the width ranges from 0.003 m to 0.146 m. The surface of the part chipped off the wall was also measured and was equal to 0.028 sq m. Figure 8b, in a schematic way shows the range of measurement of the crack on the cloud of points. Figure 8c reflects the damage in the cloud of points in the normal view. In figure 9 an exemplary way of the depth measurement of a crack was shown in the cloud of points in a big magnification – in this case it was equal to 0.021 m

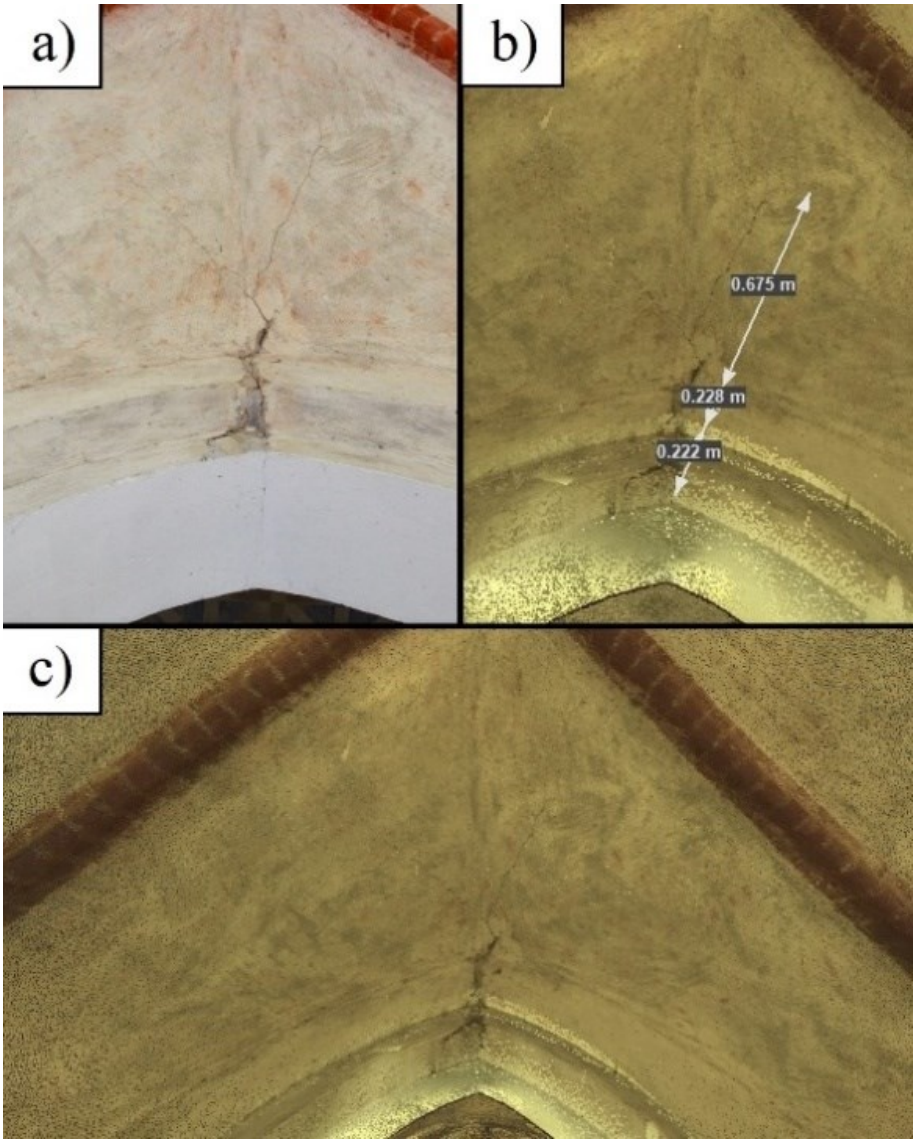

Fig. 8. Damage to the arch over the entrance to the chapel: a) digital picture, b) and c) cloud of points with pictures superimposed.

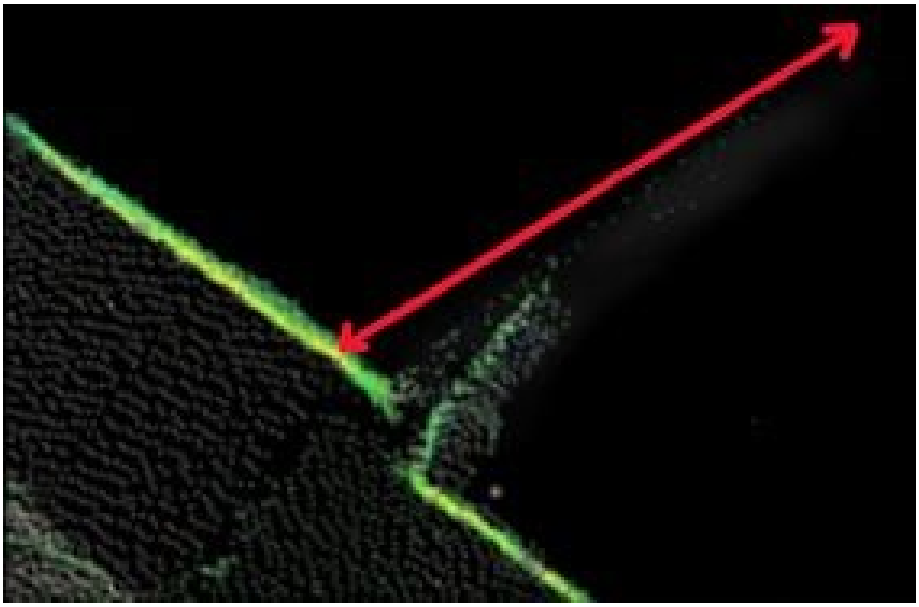

Fig. 9. Measurement of the depth of the wall crack in the cloud of points in a big magnification.

The damages were inventoried on the basis of the cloud of points imply that the building is being torn in two parts. The reason may be both a badly lay foundation on a swampy ground but also road works in the near proximity of the chapel. Research on the reasons behind chapel splitting is ongoing. The conclusions will be published in a next paper.

3 Conclusion

The study done for the purpose of this paper confirms that the TLS method may support identification and enable to measure damages in buildings. Measuring cracks on the ceiling and over the windows of the chapel was difficult and dangerous. The measurement with the use of the classical method (the aid of measuring tape or telemeter) would call for the use of a ladder or a scaffolding. Then it is work on a height which are prone to accident. Moreover the research shows that the measurements made with the use of a scanner give precise results. It is a device which collects numerous data which can prove useful also for other applications in an incomparable shorter time. The result of the use of a 3D scanner and specialist computer programmes is a vaster, more thorough and more legible documentation of the chapel.

This paper is a proof that preparation of documentation of a technical condition of buildings with the help of the technique of the 3D terrestrial laser scanning has many advantages. The development of the building industry is still slowed down by the non-application all modern technologies in their full range such as for example terrestrial laser scanning. Changes in standards and regulations are necessary to make easier, accelerate and even improve all the processes connected to a technical assessment of buildings.

References

1. M. Pająk, *Mining and Geo-Engineering Year 30 Volume 4* (AGH Publishing House. Kraków, pp. 69-78, 2006)
2. P. Rapp, Ancient Monument Protection, **50(1)**, pp. 65-70 (1997)
3. E. Kocowska-Siekiera, *Review of Law and Administration CVI* (Univerisity of Wrocław Publishing House. Wrocław, pp. 145-157, 2016)
4. R. Zapłata R, *Digitalisation in the science about the past and acient monuments protection – digitalisation and non-destructive examination of cultural heritage in situ*. (Publishing House of Kardynał Stefan Wyszyński University in Warsaw, Warsaw, pp. 19-41, 2015)
5. K. Kuzia, Czasopismo Geoinformatica Polonica, **15**, pp. 7-13 (2016)
6. M. Kędzierski, A. Fryśkowska, R. Dąbrowski, M. Wilińska, Conservator's Masseges, **26**, pp. 670-678 (2009)
7. J.A. Pawłowicz, J Int Sci Publ.: Mater., Methods Technol., **8**, pp. 340-345 (2014)
8. J.A. Pawłowicz, IOP Conf. Ser.: Mater. Sci. Eng. **227**, 012093 (2017)
9. J.A. Pawłowicz, E. Szafranko, J. Harasymiuk, IOP Conf. Ser.: Mater. Sci. Eng, **324**, 012005 (2018)