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DIGITAL SURVEY OF DAMAGES ON THE FAÇADE OF A HISTORICAL BUILDING

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ABSTRACT

This study discusses the application of 3D terrestrial laser scanning (TLS) in the evaluation of the technical condition of a historical building – a brewery located in the town of Szczytno (Poland). The digital database was obtained entirely by means of a Leica ScanStation C10 laser scanner. The works involved obtaining and connecting the scanning data, followed by their application in determination of the extent of damages on a virtual model of the building. The study discusses the efficiency of a laser scanner in surveying damages to a historical building. The measurements were hampered by numerous factors, such as the location of measuring points, street traffic, by standers and adverse weather conditions. However, application of TLS method using an impulse scanner allows quick digitization of an entire object, what is of great importance when it comes to examining large buildings. It should be pointed out that this is one of the few methods which allow points located in poorly accessible places, e.g. on top of a roof or a tower, to be recorded from the ground level. A laser scanner is ideal for digital capturing of details of historical buildings. It is particularly useful in measuring damages or architectural details. Digital data so obtained can then be analysed using a computer in comfortable conditions. A disadvantage of the laser scanning is a large amount of accidental and undesired data, which requires a time-consuming filtration of a point cloud. Digitized data facilitates the research procedure as it allows detailed measuring of complex objects in comfortable conditions.

Key words: terrestrial laser scanning (TLS), point cloud, technical condition of a building, building redecoration, building information model (BIM)

INTRODUCTION

Collecting data related to the technical condition of a building usually requires long and arduous work. Measuring each element requires great perceptiveness and diligence, and practically the entire research is carried out in field conditions. Laser scanning facilitates this process. An instrument capable of collecting digital data allows taking measurements without having to go into details. The rest of the analyses, after downloading the data, can be carried out while sitting in front of the computer. A laser scanner is a starting point when obtaining digital data related to an object. This technology is incredibly useful in situations where it is necessary to create a virtual image of the body and the details of a building for which no technical documentation exists. The measurements are taken by means of touch or touchless scanners which use laser and structural light. To this end, some of them use also magnetic resonance. The result of the research is the so-called point cloud, representing the surface and the geometry of the scanned objects.

Terrestrial laser scanning (TLS) is a contactless method of imaging the surface of a researched object by means of electromagnetic radiation emitted and received by a scanner. It is a static measurement consist-

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ing in measuring the polar coordinates: the distance between a point and the device, and the direction of the laser beam. Based on this data, the X, Y, Z coordinates of the point are determined in a local coordinate system of the measuring instrument. An additional coordinate is I, which determines the intensity of reflection of the laser beam from the object (Wehr & Lohr, 1999; Pawłowicz, 2017). The user decides about the density of the measurements, which are taken by rotating the scanner around its own axis by a pre-defined horizontal and vertical angle. An advantage of the laser scanning over the traditional methods is that one can obtain a large amount of data in a form of a point cloud within a few seconds. In aim to interpret small details more easily, a texture in a form of pictures taken by the scanner camera can be superimposed on the point cloud. The points are assigned colours in the RGB spatial colour model, which correspond with those in the pictures. The quality of the data obtained from the laser beam is influenced by the following factors: absorption of impulses by the atmosphere, reflection and dispersion from the surface of the researched object and the angle of incidence of the laser beam (Kaspar, Pospisil, Stroner, Kremen & Tejkal, 2004; Franceschi et al., 2009). In the case of dark surfaces, laser beam absorption is greater, hence the reflected signal is weaker. In the laser scanning this means that the precision of determining the location of a given point is lower. Bright surfaces, characterised by a greater reflection intensity, disperse more light, as a result of which the precision of measuring the distances is greater. A disadvantage of such materials is that with too high share of reflection, the laser beam will reflect from a surface as if from a mirror and will approach an undesired element or disperse in the space. This may generate noise having a negative influence on the quality of measurements (Zaczek-Peplinska, Góra & Grzyb, 2015; Wujanz et al., 2018).

The technical condition of a historical building is evaluated based on its survey carried out by means of the traditional methods using the common tools: tapes, distance meter, crack meter etc., along with the close-range photogrammetry, where good lighting is required, or building a scaffolding to ensure accurate results in the case of high-rise structures. These solutions were time-consuming and inconvenient. However, the current technology allows the use of terrestrial laser scanners which reduce the time needed to take the measurements, offer a greater accuracy and the possibility of scanning from large distances. Both solutions ensure contactless and non-invasive examination (Bernat et al., 2016).

Digital surveying of buildings allows to evaluate their technical condition and appearance using a computer. In addition, this technology allows to determine the scope of conservation or modernisation works. However, its main advantage is that it enables recreation of individual elements which have been damaged. In conservation of historical buildings, thorough examination of all architectural details is very important for their future recreation (Van Genechten & Schueremans, 2009; Pawłowicz, Bilko, Sawczyński & Szafranko, 2017).

The information obtained this way is also used to analyse the condition of the structure of a building, e.g. the verticality or bend ratio of its individual elements (Ćmielewski, 2011). Based on the recorded intensity of the laser beam reflection, the level of wear of the material from which a building was made is examined. This way, it is also possible to detect e.g. damp spots (Janowski, Nagrodzka-Godycka, Szulwic & Ziolkowski, 2016).

MATERIAL AND METHODS

Researched object – a Castle Brewery

The object subjected to scanning is located in Szczytno near Olsztyn (Poland). Built in 1898, it is called the Castle Brewery (German: *Schlossbrauerei Ortelsburg*). It derives its name from its shape resembling a castle.

The research was carried out in the oldest part of the neo-gothic complex (Fig. 1). In 1996, this part of the building was entered into the register of historical buildings of the Warmińsko-Mazurskie Voivodeship.

Although the building's architecture is strictly industrial, its red brick façades feature cornices, finely crafted arched window lintels and jambs. The building owes its charm also to the corner turrets decorated with spikes. Figure 2 presents the effect of laser scanning of the said building in the form of a point cloud in the upper part thereof, featuring ornaments and turrets (Fig. 2). The building is in a very bad state of repair and requires renovation. Its façades are dirty and have a lot

Fig. 1. Laser scanner seen against the oldest part of the brewery – a view on the southern façade on the court side

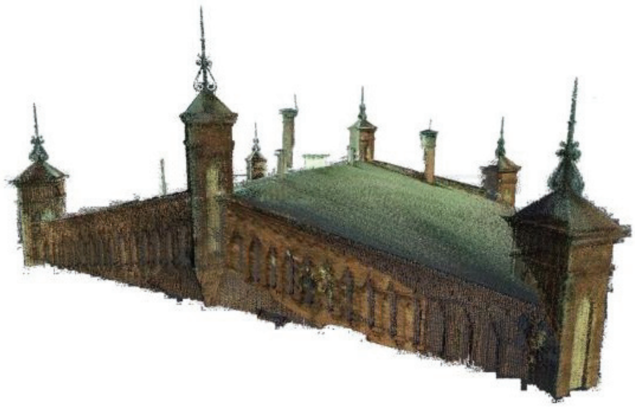

Fig. 2. A point cloud showing the roof featuring decorative turrets. In the foreground there is a cornice in the form of a parapet

of holes and cracks. The same concerns the wooden window and door frames, as well as the metal work.

Measurements

Measuring the façade of the building lasted a few days. First, sketches of the building were prepared, along with its technical documentation. Due to the large size of the building and its rich ornaments, a decision was made to apply the 3D laser scanning technology. Twenty-eight scanning stations were prepared, both inside and outside the brewery compound. The scanning stations were set up with particular attention being given to the architectural details and the visually apparent damages to the façade. The scanner was placed as close to the object as possible, with the laser beam being projected onto it perpendicularly. The measurements were taken by means of a 3D Leica ScanStation C10 laser scanner. The instrument was also used to make a series of pictures by means of a built-in digital camera. After superimposing them on the point cloud in post-processing it was possible to recreate the natural texture and the color of the object. The purpose of the measurement was to collect digital data about the object and damages on it in the form of a point cloud (Fig. 2).

Data processing

The point cloud resulting from scanning contains more than just information about the researched object; it also includes data generally referred to as noise. It results from the reflection of a laser beam from undesired and accidental objects (such as trees or bystanders). Another type of undesired data are points resulting from incorrect or multiple reflection of a light beam (e.g. from glass surfaces). Therefore, a point cloud needed filtrating after being entered into the computer. This way it was cleared of any undesired elements and the damages were identified. Over 60 damages to the façade of the building were discovered, affecting the technical condition of the building.

RESULTS

Analysis of the damages to the façade

Three representative examples of structural and surface defects were selected for the purposes of this study. They include different damages to the external walls of the building, recorded by means of a laser scanner.

Example 1: Cracks in the walls

A crack extending from the ground level upwards was discovered on the eastern wall of the building (Fig. 3a). The crack was recorded during scanning. The scanner was placed 161 cm above the ground, 350 cm from the wall. The laser beam was projected at a 22-degree angle above the scanner lens axis and a 25-degree angle beneath it (Fig. 4). The crack can be clearly seen in the point cloud with a superimposed texture. The image of the crack can be easily measured in the point cloud (Fig. 3b). The crack is 300 cm long. It is 3 cm wide at its widest, and less than 1 cm wide at its narrowest point. The parameters of the crack are presented in the table.

Fig. 3a. Digital image of a portion of the crack

Fig. 3b. A portion of the crack mapped to a point cloud. The measurements are presented in the table

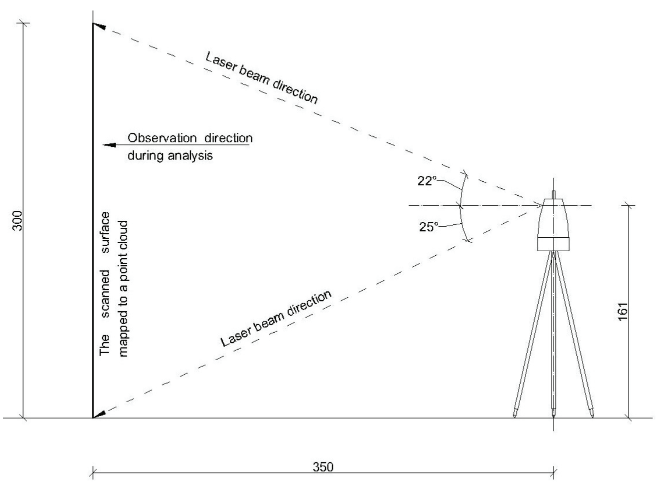

Fig. 4. Example 1: a schematic view of the measurements of a crack on the eastern wall of the brewery (besides angles, measurements in centimeters)

Example 2: Crumbling of the construction material
Numerous gaps were discovered in the upper portion of the western wall of the building. They are irregular in shape and result from crumbling or intentional removal of bricks (Fig. 5).

It was not possible to place the scanner at the level of the gaps during taking the measurements, which would have facilitated measuring their depth.

Therefore, the instrument was placed perpendicular to the wall, with the laser beam being projected at an angle ranging from 39 to 47° above the lens axis. As the angle of the laser beam projection increases, the possibility to measure the depth of gaps decreases. To prevent this, the scanner was placed as far as possible from the scanned object in order to reduce the laser beam angle. Eventually the instrument was placed 630 cm away from the building, whereas the height of the target axis of the scanner was 161 cm. The measurements taken based on the point cloud helped identify the area of the gaps and their location (the table). The damages are located at the height ranging from 664 to 818 cm (Fig. 6).

Fig. 5. The western façade with visible gaps

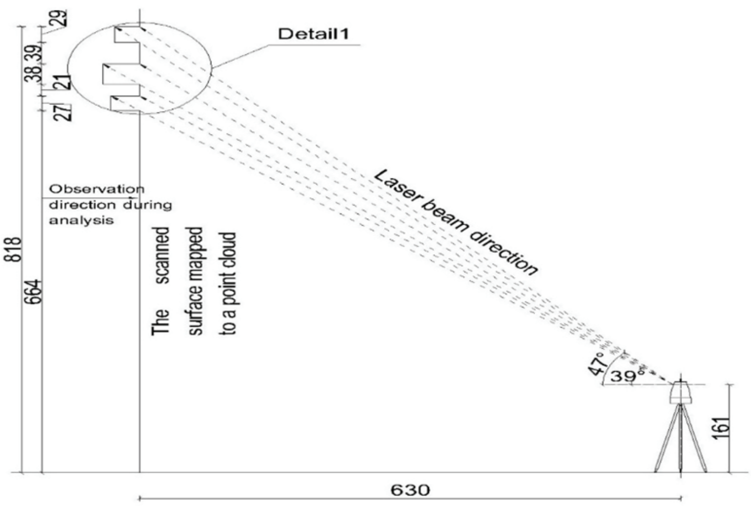

Fig. 6. Example 2: a schematic view of the measurements of the gaps on the western wall of the brewery (besides angles, measurements in centimeters)

As the laser beam is projected onto a gap at sharp angle, it reaches only the upper portions thereof. Consequently, it is not possible to arrive at a reliable measurement of the depth of these damages. It is worth noting that the smaller a gap, the more limited the laser beam range. This way the so-called blind spot is formed in a point cloud. Figure 7 shows that as the section of a gap increases, so does the depth of its penetration by a laser beam.

The other measurements, such as the height and the width of a gap were easily measured in the point cloud (Fig. 8a). To better explain the issue related to measuring the depth of the gaps resulting from the large angle of the laser beam projection, a scan image has been cut out and shown from the side opposite in relation to the measurements taken (from inside the building) (Fig. 8b). The table shows the results of measuring the depth of the gaps based on a point cloud. However, it should be pointed out that these values are false as only the apparent depth was measured. It is due the fact that the laser beam failed to reach the rear edge of the gap (from the inner side of the wall).

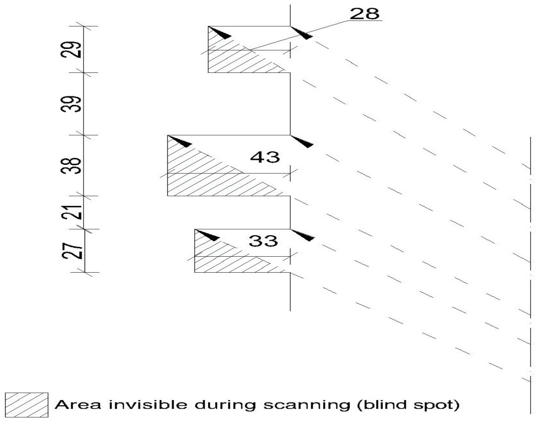

Fig. 7. Example 2: a schematic view of the measurements of the gaps on the western wall of the brewery (all measurements in centimeters)

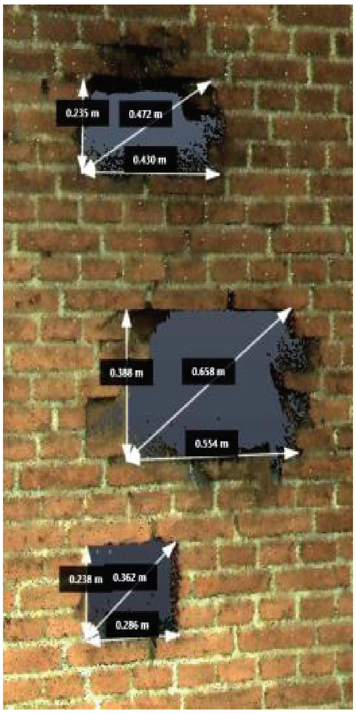

Fig. 8a. A point cloud showing gaps in the façade resulting from the crumbling of the building material. Taking measurements of the gaps (the table)

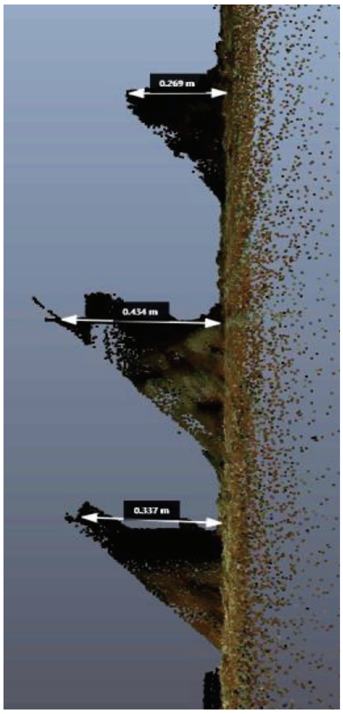

Fig. 8b. A section in the point cloud through the plane of the scanned wall. Indicative depth of a gap in an inverted view (the table)

Example 3: Damages caused by water and wind

The southern façade seen from the court of the brewery compound. Numerous damages were observed here, caused mainly by water and wind. One of the analysed elements was a pillar between windows, featuring water-washed bricks and mortar joints (Fig. 9a). This condition of the pillar results probably from a leaky system for removing rainwater from the roof, causing the rainwater to flow out of the pipes and gutters and to wash out the bricks and the mortar joints. The damaged surface is clearly visible on the point cloud (Fig. 9b). Based on the scan, its area was estimated to cover ca. 90 cm^2. The damage starts at the height of 355 cm and ends at 455 cm (the table). The laser beam opening angle ranges between 18 and 27° (Fig. 10) and was not of great importance for measuring the damaged area in the point cloud.

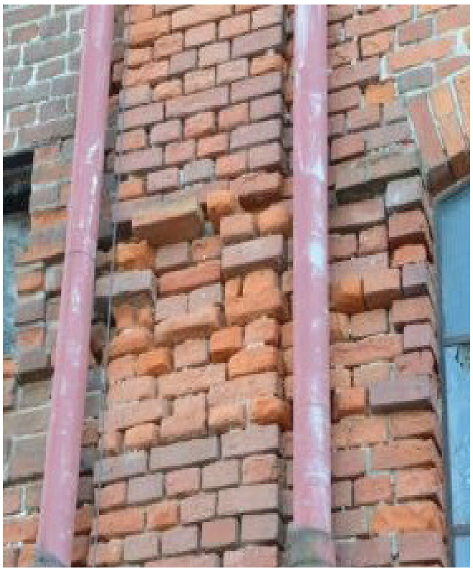

Fig. 9a. Digital image of the washed-out bricks and mortar joints

Fig. 9b. Washed-out bricks and mortar joint in the point cloud. The measurements are presented in the table

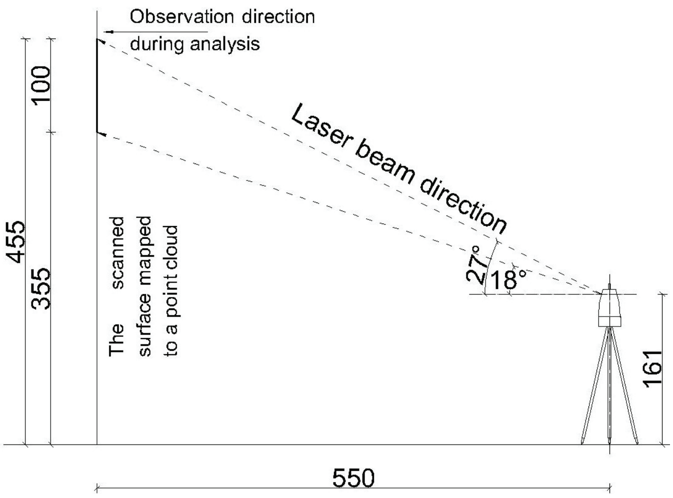

Fig. 10. Example 3: a diagram of measuring the damages on the southern wall of the building (besides angles, measurements in centimeters)

Table. List of all parameters of the damages presented in the study

Parameter	Example 1 Crack	Example 2 Missing bricks	Example 3 Washed-out material
Height [cm]	300	Gap 1: 29 Gap 2: 38 Gap 3: 27	130
Width [cm]	1–3	Gap 1: 43 Gap 2: 56 Gap 3: 29	70
Estimated depth[a] [cm]	–	Gap 1: 28 Gap 2: 43 Gap 3: 33	–
Gap area [cm^2]	23	Gap 1: 1247 Gap 2: 2128 Gap 3: 783	9 100
Distance between the scanner and the analysed damage [cm]	350	631	550
Height at which the damage is located [cm]	0–300	664–818	335–435
Angle between the laser beam and the analysed surface [°]	from –25 to +22	from +39 to +47	from +18 to +27
Instrument height [cm]	161	161	161

[a] Unreliable depth given as an example of actions performed on a point cloud.

Evaluation of the measuring method

Over 60 damages on the façade of the brewery building were identified during the survey, mostly corrosion and cavities resulting from destruction and lack of repairs. In addition, numerous cracks in the walls were discovered, possibly due to the instability of the soil, but most likely due to the intensive vehicle traffic on the nearby regional road.

Moreover, some of the bricks are corroded and the mortar joints are washed out. These damages do not form any regular pattern. Some of them are small and invisible at first glance, but some cover an area of up to a few square meters. The table contains a list of parameters obtained by means of measuring selected elements in the point cloud.

The study presents three examples representing all of the analyses performed on the object. A significant difficulty in identifying and recording damages on an object is inaccessibility of its individual elements. Taking measurements with use of traditional methods, e.g. by means of tapes and gap gauges, would have been difficult in this case, especially with regard to damages situated at a height. It would have also required using ladders or scaffoldings, which would have been connected with a threat of a fall. In addition, using a scaffolding would have required attaching it to the building, which might have caused additional damages on it. This is always a significant issue, especially where a historical building is concerned.

Therefore, the survey was conducted using a 3D laser scanner, which allows collecting the required data in a non-invasive way, without posing any risk to the operator. However, a scanner is not an ideal device. A measuring station should be planned such as to ensure that the laser beam does not hit an object at a too big angle. Elements situated at a height should be measured from a bigger distance. This helps decrease the beam angle and allows deeper penetration of such element. Placing a scanner too close to an object and thus using too big angle of the laser results in the light beam failing to reach the details which are situated high above the ground or are concave. The resulting point cloud is then incomplete (blind spots). It is therefore confirmed that the most efficient scanning occurs when the scanner is positioned as close as possible to the perpendicularity relative to the plane being scanned. During the point cloud analysis, it was also noted that the intensity of the laser beam reflection is weaker when scanning a red brick surface, compared to other elements. However, this was not an obstacle to a thorough examination of the building. The data obtained in the form of a point cloud provides a lot of information about the geometry and structure of the object, as well as about it technical condition. A cloud allows to observe and measure the damages and precisely determine their location and range. Calculation of their size forms a basis for planning and valuation of repair works.

SUMMARY AND CONCLUSIONS

Laser scanning allowed to create a digital database related to the Castle Brewery with respect to its geometry, structure and architectural detail. The resulting point cloud enabled to survey the object and measure the extent of the damages to it. Thanks to scanning, it is possible to apply reverse engineering and modelling later on. A point cloud is often a basis for creating and modifying a digital model of a building. Such a virtual building can be supplemented with information about the structure, systems, materials used or recommendations for maintenance and fire protection. Such information serves as a basis for a preparing a building permit design using the building information model (BIM) technology. A model prepared this way will facilitate planning a renovation of a building, adapting it to the present requirements related to facilities for the disabled, safety or construction standards. It also facilitates adhering to work schedules and cost estimates (Szafranko, 2014) and helps to foresee collisions with respect to discipline-specific or avoid additional costs of alterations. Finally, after the completion of construction work, it enables easy management of a building and its operation. Point clouds are increasingly used to create digital models of existing facilities in the BIM technology.

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CYFROWA INWENTARYZACJA USZKODZEŃ ELEWACJI BUDYNKU ZABYTKOWEGO

STRESZCZENIE

W pracy przedstawiono zastosowanie trójwymiarowego naziemnego skaningu laserowego (TLS) w ocenie stanu technicznego budynku zabytkowego na przykładzie browaru zlokalizowanego w Szczytnie (Polska). Wszystkie prace związane z uzyskaniem cyfrowej bazy danych wykonywano skanerem laserowym Leica ScanStation C10. Zakres prac obejmował pozyskanie i połącznie danych ze skaningu, a następnie określenie na ich podstawie skali uszkodzeń w wirtualnym obrazie budowli. W artykule omówiono skuteczność wykorzystania skanera laserowego przy inwentaryzacji uszkodzeń obiektu zabytkowego. Podczas pomiarów napotkano na liczne ograniczenia, takie jak: trudne usytuowanie stanowisk, ruch na ulicach, ingerencja osób postronnych i niesprzyjające warunki atmosferyczne. Zastosowanie metody TLS wykorzystującej skaner impulsowy pozwala jednak na szybkie zdigitalizowanie całego obiektu, co przy inwentaryzacji dużych budynków jest bardzo ważne. Warto dodać, że metoda ta jest jedną z nielicznych, która umożliwia inwentaryzację punktów trudno dostępnych, na przykład połaci dachowych czy wież, z poziomu terenu. Skaner laserowy doskonale nadaje się do cyfrowej inwentaryzacji obiektów zabytkowych. Szczególnie świetnie sprawdza się przy pomiarach uszkodzeń czy detali architektonicznych. Cyfrowe dane zebrane w terenie mogą być analizowane przed komputerem w komfortowych warunkach. Niewątpliwą wadą skaningu laserowego jest występowanie dużej ilości danych przypadkowych i niepożądanych. Wiąże się to z wykonaniem pracochłonnej filtracji chmury punktów. Zdigitalizowane dane ułatwiają procedurę badawczą, ponieważ umożliwiają pomiary skomplikowanych obiektów przy zachowaniu maksymalnej szczegółowości i w kameralnych warunkach.

Słowa kluczowe: naziemny skaning laserowy (TLS), chmura punktów, stan techniczny budynku, remont budynku, building information model (BIM)