RECORDING AND ANALYSIS OF ANOMALIES APPEARING IN STRUCTURES OF WOODEN CONSTRUCTION OBJECTS USING THE 3D LASER SCANNER

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Abstract

Every construction object is built according to a project which should be developed with particular diligence by the designer, in such a way that the effect of their work is safe in use and serves people properly. The contractor and the implementer of the project also have to perform their work in an accurate and meticulous way. It is generally known that every construction object commissioned for use moves. This is why it is often possible to observe various phenomena confirming the movement of structural elements. They include deflections, deformations, scratches and cracks. The article shows an example of possibilities of the use of laser scanning technology in observation and analysis of damages and deformations of structural parts. It is a technology which serves for capturing of three-dimensional data of the measurable elements of space; it can help finding defects and monitoring structures. Such actions may contribute to quicker detection of dangerous "behaviours" of buildings – which often show signs of imminent disaster – and to the implementation of preventive and precautionary measures.

Key words: *3D measurement, laser scanning, wooden construction diagnostics*

1. INTRODUCTION

Modern construction aims at creating more and more interesting advanced design solutions. There is a noticeable tendency to use elements of lightweight constructions and glass surfaces. The structures of new generation external glass partition are erected as post and beam walls, post and beam walls with structural glazing and mechanical (point) mounting of glass panes. Various roofing systems have developed to complement glass shell walls. Equally modern structural solutions, using spatial movement of individual elements, have been elaborated. Structural elements can be made of different materials, with frequent use of light metals (e.g. aluminium) and lightweight timber structures (Witakowski et al. 2009). Wooden components deserve particular attention due to non-uniform material structure. The elements tested and described in this article are fragments of the roofing of the patio in the UWM building in Olsztyn. The roofing structure is based on girders and purlins made from glued wood. The measurements made using a laser scanner allowed determination of displacements and deformations of fragments of the structure.

2. METHODS OF MEASUREMENT

In present times, among the many measuring and monitoring systems which have been known in construction by date, the ones which allow controlling displacements and deformations already at the construction stage, as well as during their further operation, are gaining special importance. The structure's stability is assessed on the basis of many different criteria, always expressed in the form of a certain condition. According to it, the measured feature (geometrical or physical) should be contained within the limits considered as safe. Since the building collapse is an unintended, violent change of a structure’s geometry (collapse, breakage, etc.), its occurrence is always preceded by deformations of supporting elements (Bornaz , Rinaudo 2004). These deformations may, in turn, be translated into displacement of selected points and monitored for structure safety (the so-called displacement criterion). Along with the increase of external load, the displacement of characteristic points slightly changes, corresponding to the elastic movement of the structure, then a little faster through the plasticising of supporting elements, to a violent construction disaster. Therefore, knowing

the course of destruction of the structure, the designer can specify the displacement equivalent to the limit load (Briese Pfeifer 2007). It is thus enough to monitor displacement of control points and, by comparison with permissible values, assess whether the building's safety-related parameters are met.

The above comments refer both to the phase of erection of structures and to their further operation; in this connection, the displacement monitoring systems should allow their free use in both phases of the building's life cycle. An important feature of measuring instruments should be their universality (use in different conditions and for measuring diverse objects) as well as non-invasiveness (Witakowski et al. 2009). These conditions are fully met by the laser scanner Leica Scanstation C10, performing its measurements in terrestrial laser scanning technology (TLS), used in the tests described in this work.

3. LASER SCANNING – 3D DATA COLLECTION PROCESS

Laser scanning also known under the name LIDAR (from English: Light Detection and Ranging) is the system performing the measurements using a laser placed on a tripod (TLS – terrestrial laser scanning), in a mobile vehicle (MLS – mobile laser scanning) or in a plane (ALS – air laser scanning). It allows automatic obtaining of raw spatial data of real objects in the form of a three-dimensional "dot cloud", which constitutes the starting material for further modelling in appropriate software. Laser scanners, by measuring polar coordinates of single points, allow their description in three-dimensional space. Each of the points is represented by at least three coordinates X, Y, Z, related to the local system of the scanner. What is also frequently recorded is the intensity (I) of reflection of the laser beam which is marked as the fourth coordinate (Zogg 2008), Scanning results accuracy depends on the density of measurement set in the device (e.g. each 1 mm, 5 mm, etc.). By choosing the density of measurement, the appropriate software sets the correct interval of incrementation of angles (horizontal and vertical) which, along with the distance measured, gives the appropriate density of the "dot cloud" (Bojarowski et al. 2008)

The result of laser scanner measurement at a given measurement post is a set of points with their assigned coordinates XYZ in the scanner's system, called a scan. A single scan is usually not enough to collect information about the whole studied object. What should therefore be defined is the number and distribution of workstations which will allow good imaging of the object of our interest (Pawłowicz 2014). The scans from each workstation are oriented and filtered. Orientation is a process of spatial integration of several scans into one "dot cloud" using linking points which are special signals. The markers are distributed in the scanning area as close as possible to the scanner, in order to obtain a possibility of connecting individual scans into one coherent whole. Filtration is the process of cleaning of the "dot clouds" of all unnecessary elements (plants, passers-by, cars) as a result of which we obtain a comprehensive set of data without unnecessary "noise", stored in the instrument's local coordinates system. The data, in the form of an oriented and cleaned "dot cloud" in the system generated in this way are subject to modelling by appropriate software, its final product being the information about actual geometry and shape of the studied object (Pawłowicz, Szafranko 2014)

In the case of the study presented, the measurement was done using Scanstation10 laser scanner from Leica. The instrument was set to measuring with the highest scanning resolution (0.02 x 0.02 m), the 360° horizontal and 270° vertical scanning scope (full-range scan) and the medium resolution of photographs. Once the scan parameters are defined, the terrain and its linking points are scanned from each workstation planned beforehand, arranged so as to accurately image selected structural elements in two public utility buildings. These data, after being transferred to internal memory of a computer with Cyclone 7 software were finally subject to modelling whose final product is complete information about the shape, geometry and structure of the objects of our interest (Szafranko, Pawłowicz 2014)

4. MEASURING OF DISPLACEMENTS OF SELECTED STRUCTURAL ELEMENTS OF A PATIO WITH WOODEN STRUCTURE

The analysed structure is a cuboid-shaped patio in Olsztyn, covered with an arched roof with wooden structure (glued wood girders based on reinforced concrete pillars, wooden purlins connected with the girders). The self-supporting front wall has an aluminium structure. The whole structure is equipped with multiple glazed panels in half-structural system (Fig. 1).



Fig. 1. Patio with glued wood structure in Olsztyn – view of girders and purlins

In order to investigate the possibilities of use of the Leica Scanstation C10 laser scanner to measure the space, deflection was analysed for a glued wood girder constituting the structure supporting the patio roof (the central girder was selected due to being the most loaded one).

The analysis was based on determination of the deflection value for the selected element in the Cyclone Model software. The first step in the procedure was drawing the reference line connecting the structural channel support with the roof girder. In the programme, points of support were indicated and the reference line was created in order to determine the deflection of analysed elements (Figure 2).

Eurocode 5 PN-EN 1995: "Design of timber structures" recommends that the deflection of girders should not exceed the value: L/500. The deflection value for the girder under consideration was 2.3 cm while the limit value for this element is 3.7 cm, hence the serviceability limit state remains within the norm.

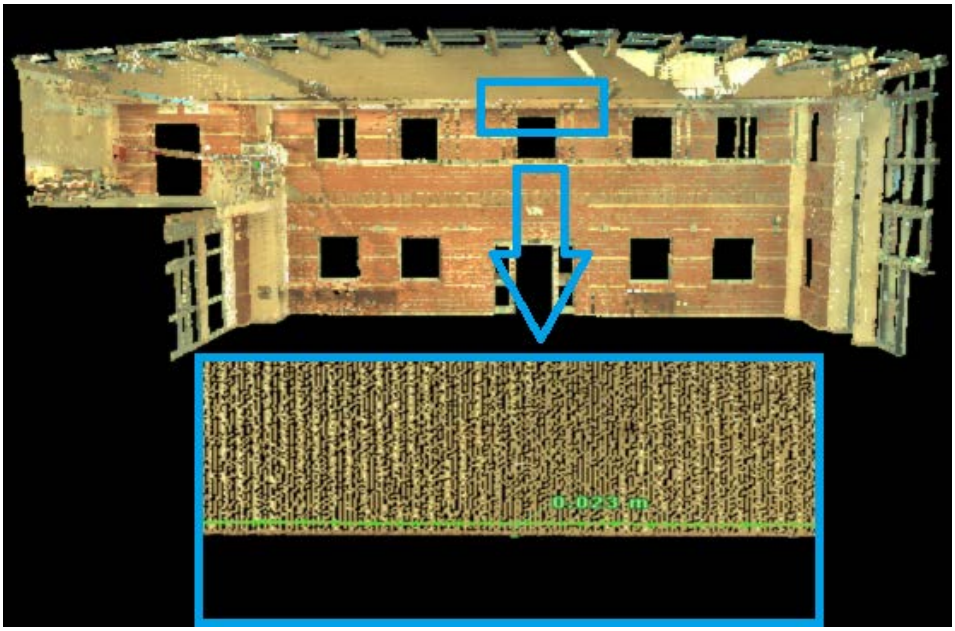

Fig. 2. Deflection (0.023 m) of the central girder in a wooden structure, measured in a 3D image of the building body, generated from laser measurement

5. ANALYSIS OF ACCURACY OF OBTAINED RESULTS

What should be analysed at first is the accuracy of the model created. Let us consider the errors affecting the accuracy of obtained results, including:

- imprecision of scanner measurement;
- scan integration errors;
- errors resulting from modelling (affected by the specificity of surface detail, surface identification ambiguity for model elements, etc.).

At the first stage of the analysis, imprecision of the "dot clouds" obtained was determined. In the case of the measurement preformed, the scan accuracy will be determined on the basis of the actual dimensions (taken from a direct ladar measurement) and the dimensions obtained on the 3D model, measured in the opening of the internal walls of the patio. The differences between the dimensions are shown in table 1.

Tab. 1. Summary of dimensions of the plan of the patio in Olsztyn

Dimension		
Actual	**Obtained**	**Difference**
10.07 m	10.068 m	0.002 m
10.07 m	10.064 m	0.006 m
10.07 m	10.059 m	0.011 m
10.07 m	10.063 m	0.007 m
14.58 m	14.575 m	0.005 m

On the basis of the above summary, it can be found that the maximum deviation of the dimension obtained in respect to the actual one varies within the range of 1 cm. The irregularity of the "dot cloud" representing the patio in Olsztyn is therefore significant and results mainly from the incorrectness of the control signal scanning performed, since the averaged error in case of one of the connected links was as large as 9 mm.

In the second stage of the analysis of accuracy of obtained results, precision in modelling of elements was defined. For this purpose, two ground floor plans were compared with the dimensions plotted in the same place, measured in the opening of the internal walls of the patio. The differences between them are shown in Table 2.

Tab. 2. Summary of dimensions of the plan of the patio in Olsztyn

Dimension		
From the "cloud"	From the model	Difference
10.068 m	10.071 m	0.003 m
10.064 m	10.067 m	0.003 m
10.059 m	10.058 m	0.001 m
10.063 m	10.057 m	0.006 m
14.575 m	14.574 m	0.001 m

As it results from the above summary, the average deviation was about 3 mm. This value in connected with inaccuracy of the spatial model obtained from the scanning. The offset of single scans in respect to one another makes their surfaces overlap; in consequence, the software, fitting an element to the "dot cloud" finds irregularities in its structure and selects the best fit by itself. According to the technical specifications of the scanner, the average error of the modelled surface is about 2 mm. In our case, this value is close to it, although it can be minimised through measurements of better quality.

Inaccuracy of modelling is not only due to a scanning error. It is also strongly influenced by the curvilinearity of the structural elements, shown in Figure 3, representing a purlin constituting a part of the structure of the wooden roof of a patio in Olsztyn; the purlin is modelled out from a "dot cloud". The actual appearance of this element is shown in Figure 4. Comparing both illustrations, we can notice deviations of the obtained model from reality. The purlin does not match the girder perfectly, its offset in respect to the original being 2.4 cm. The inaccuracy of fitting is connected, is in this case, with the loss of rectilinearity of the element under consideration, resulting from the deflection of wooden girder of the structure supporting the patio roof. As a result of the displacement of the structure, the purlins bent, making it impossible to fit correctly the modelled element into the "dot cloud".

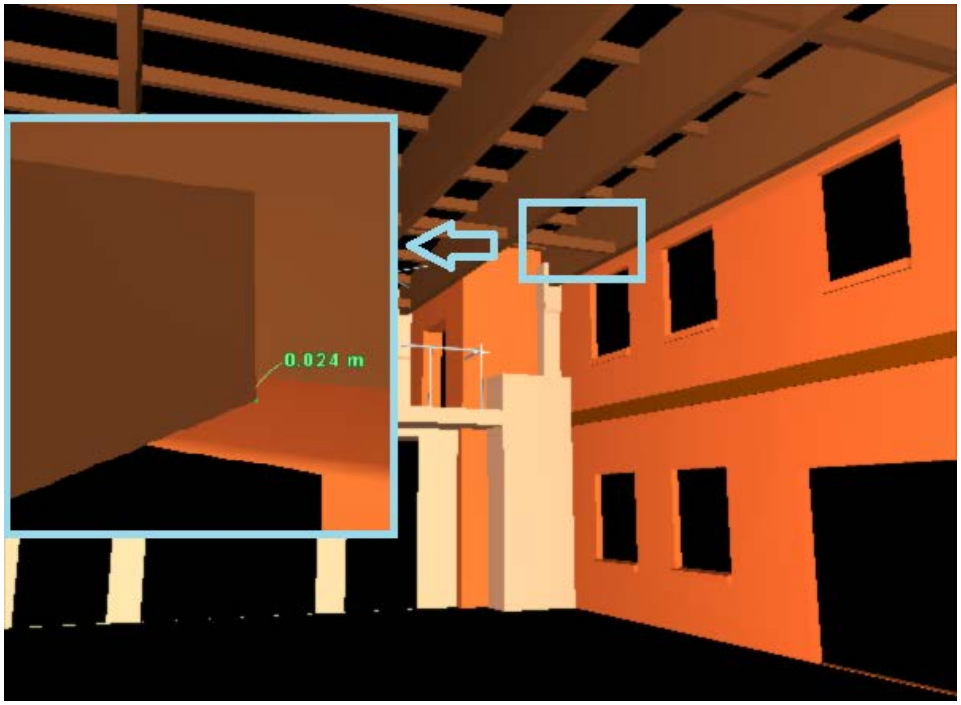

Fig. 3. Error in modelling of the purlin constituting a part of the structure supporting the wooden roof of a patio in Olsztyn



Fig. 4. Actual appearance of the connection between the purlin and the girder

6. SUMMARY AND CONCLUSIONS

Laser scanning, just like any other, even the most advanced technology has features that determine or disqualify its use in a particular study. The key benefits of terrestrial laser scanning in construction include: quick and easy measuring, non-invasiveness, scanning scope (up to 300 m) and the possibility to obtain many final items from one "dot cloud" obtained, thanks to the software compatible with the scanner and offering a broad range of data processing functions which make it possible to study phenomena like displacements and deformations referred to in the article.

Terrestrial laser scanning has, however, a serious disadvantage, namely the accuracy of the measurement itself. Unfortunately, technical limitations do not allow representing reality in a perfect

way. The error of connecting individual scans and the laser spot problem (along with increasing distance, its diameter grows larger, resulting in inaccuracy of distribution of the measured point in space) are unavoidable. In the case of certain types of research, e.g. in displacement monitoring, where millimetric accuracy is fundamental, its importance may disqualify the possibility of the use of the method in a particular study. Another drawback of laser scanning in also the redundancy of measurement data and incorrectness of the information supplied by the laser beam, resulting from e.g. additional rebounds causing errors of the "dot cloud", such as discontinuity, unclear edges, points sticking out, excessive thickness of the "cloud" etc.

Undoubtedly, laser scanning is not a perfect technology. It has both advantages and disadvantages. Therefore, for some studies, it will be the best method to work on a particular issue, while it will remain an option in other cases. The choice of scanning as an optimal measurement technique in construction depends essentially on the accuracy expected by the user. In case of a property condition survey, a 5-mm error is an acceptable value, and the use of a scanner in this situation makes our work faster when it comes to developing full documentation; particularly architectural-construction including three-dimensional models. However, with regard to studies more sensitive to scanning errors, e.g. displacement and deformation monitoring, where we expect sometimes even micrometric accuracy, this technology can be used only optionally.

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