Vol. 12, 2023, 63-69

DOI: 10.17512/bozpe.2023.12.07

Construction of optimized energy potential
Budownictwo o zoptymalizowanym potencjale energetycznym

ISSN 2299-8535 e-ISSN 2544-963X

Determining the degree of deformation in rain drainage installations through point cloud modelling

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Abstract: Buildings are often complex and hindered by identifying and measuring deformation in both the building itself and its elements. However, we have the assistance of 3D laser scanning technology which allows us to collect geometric data. Scanners are particularly effective for measuring high and hard-to-reach locations. This paper focuses on the measuring and modeling of roof drainage installations, which are usually placed at elevated heights, making it impossible to measure using traditional methods. Rain gutters need constant monitoring in order to fulfill their function and ensure proper drainage of rainwater. Laser scanning produces a point cloud which can be converted in a 3D model using software such as Leica Cyclone, AutoCad and ReCap. This study demonstrates the successful utilization of laser scanning in identifying geometric features and deformations in building installations.

Keywords: 3D laser scanning, point clouds, inventory, 3D modeling, roof drainage

Please, quote this article as follows:

Pawłowicz J.A., Skotnicka-Siepsiak A., Serrat C., Determining the degree of deformation in rain drain-age installations through point cloud modelling, Construction of Optimized Energy Potential (CoOEP), Vol. 12, 2023, 63-69, DOI: 10.17512/bozpe.2023.12.07

Introduction

A point cloud is a set of data points represented in a 3D form created from scanning an object. The point cloud contains information on the location of the scanned points in physical space. Each point is represented by three coordinates X, Y, Z, which allows it to be located in the environment (Jurczak, 2021). This set

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of points is called a scan and is the foundation of 3D modelling in appropriate computer programs. Digitization, in turn, facilitates the creation of a digital replica of the real object, which is known as a digital twin and enables a BIM model to be created (Löhmus et al., 2018). Consequently, this provides us with the material for a geometric analyses of deformations of the entire building or its individual components without the necessity of further on-site work.

Laser scanning as a modern remote-measurement method is a convenient and constantly developing technology. According to the 2011 Decree (Journal of Laws no 263, item 1572) laser scanning is defined as ”a method of imaging the surface of terrain, involving the measurement of distances between the measured object and a scanner installed on an airship, car or a stationary post. It emits and receives laser impulses reflected from the object, simultaneously determining the spatial coordinates (X, Y, Z) of the object, the location of the scanning device and the direction of laser beam at the moment of emission” (Maksymowicz et al., 2010). Laser scanners are applied in construction processes, supervision (Mitka, 2007), reversed engineering, preservation of ancient monuments (Pawłowicz, 2018) and the documentation of crime scenes (Pawłowicz, 2020). They enable the rapid creation of 3D documentation for the scanned objects and their surroundings. Point clouds also provide a good source of data for analyses of overall building constructions and their components (Respondek, 2016; Rozporządzenie, 2011; Srokosz et al., 2017).

In the building industry, scanner measurements may be used not only for the recreation of a building’s geometry but also to detect imperfections, control damage and conduct architectural inventories. Scanners provide data which would otherwise be difficult to obtain due to the inaccessibility of the measured elements such as a high ceiling or roof. Manual measurements would need the use of ladders or scaffolding, which could be hazardous. Additionally, at such heights, taking precise and detailed measurements could be a challenge. Point clouds enables the assessment of pillar and column perpendicularity (Wardach et al., 2022), as well as the analysis of geometric changes (room deformations, deflections) (Zagroba & Gawryluk, 2017; Zhou et al., 2014) in horizontal elements, such as lintels, beams or technical infrastructure components of a building. Furthermore, this modern technology offers the opportunity to examine water flows or hydrotechnical installations (Zima, 2017).

1. Collecting and analysis point clouds

A point cloud is a collection of geometric data points obtained from onsite measurements with a laser scanner. Once saved to a hard drive, this data can be analyzed in various ways. Digitization and data processing software, such as Cyclone, ReCap and AutoCAD, can compare the point cloud to any point of reference, for example, points, lines or surfaces. To effectively use point clouds, it is important to purchase suitable software in addition to a scanning device.

In this article, we present an example of a point cloud being used to identify and model deformation in a roof drainage installation. The data was collected through onsite measurements using a Leica 3D ScanStation C10 laser scanner. The accuracy of the horizontal and vertical point was 0.01 cm. The measurements were taken in good weather conditions and no other factors were deemed to affect the results. The aim was to obtain geometric data on the building under conservator-restorer protection and re-create its elevation in digital form. The data was saved on a hard disk and processed in Cyclone and ReCap. After exporting the data to AutoCAD, several interesting ”defects” were observed which were not noticed during the onsite inspection or scanning process. These defects would have been difficult to observe and measure using traditional measurement methods, such as with a measuring tape.

One irregularity identified in the point cloud of the building was a twisting of the horizontal elements in the elevation of the examined object. Deformation of the roof gutters was also noticed, as seen on the gutter on the south-eastern elevation of the building (Fig. 1). The deviation from the horizontal and vertical alignment, as well as the longitudinal twisting, became apparent only on the point cloud and was not visible to the naked eye (Fig. 2). In Figure 2a, a reference line connecting the two ends of the upper gutter is marked in white. Figure 2b provides a magnified view of one end of the gutter. By comparing the white line with the actual position of the gutter, the displacement can be visualized and measured, allowing for further modelling.

Fig. 1. A point cloud of the south-eastern elevation of a building overlayed with digital photos (*own photo*)

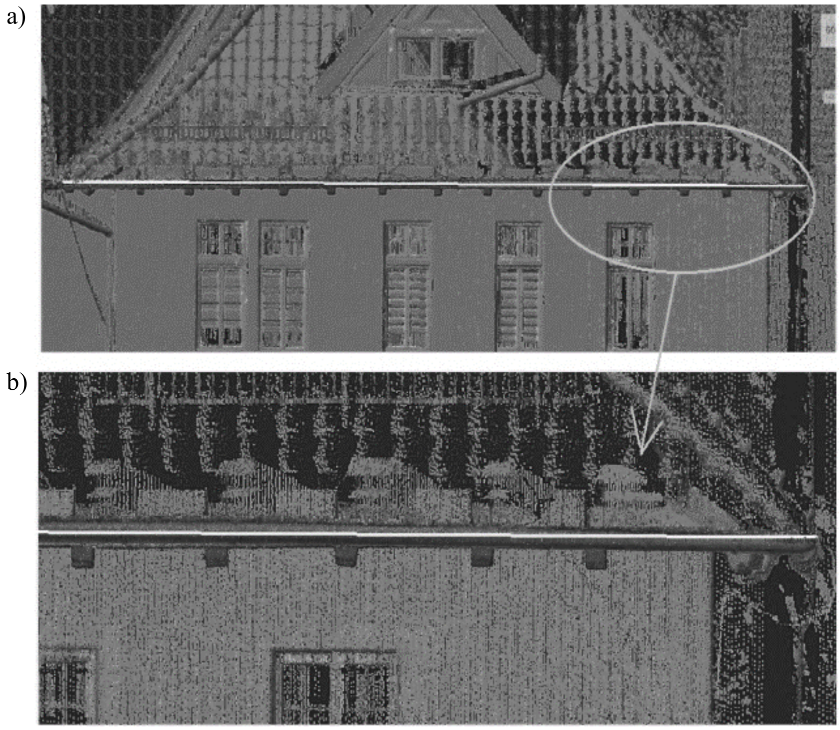

Fig. 2. Deformation of the gutter: a) the gutter with an added white reference line, b) fragment of the gutter magnified with a visible deformation (*own photo*)

2. Modelling of the roof drainage system

Modeling of the rainwater drainage installation started with the creation of a point cloud model of the selected gutter. As shown in Figure 3, a coordinates system was established at the centre of the cross-section on the left end. The X axis (red color) indicated the width of the traversal cross-section of the gutter, the Z axis (in blue color) represented the height of this cross-section, while the Y axis (green color) determined the longitudinal cross-section of the gutter. Subsequently, two virtual models of the analyzed object were generated.

Initially, a visualization of the actual condition of the gutter was created based on the point cloud data (the yellow colour in Fig. 3a). To represent properly its geometry, cross-sections placed every 200 mm were made. Using these cross-sections as a reference, an outer layer was constructed to form a 3D model representing the present condition. In Figure 3b, the model is visible as a black plane. Additionally, a reference model of the gutter (shown in red) was also included in Figure 3. By comparing these two models, the degree of deformation in the drainage system can be determined (Fig. 4). This analysis helps ascertain whether the gutters can still fulfil their intended function or if repair or replacement is necessary.

Fig. 3. Deformation of the gutter – reference and real models: a) on the point cloud background, b) without the point cloud (*own research*)

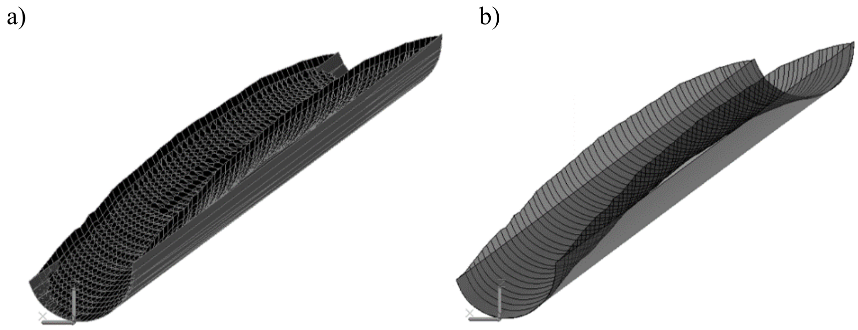

Fig. 4. Result of placing the modeled gutter on the reference model: a) view of the triangles network (TIN), b) plane model (*own research*)

A comparison of the two models (Fig. 4) showed how they over-lapped, which allows for an assessment of the real element's geometry. It is clearly visible that the element is twisted mainly along the Y axis and bends upwards along the Z axis. In the middle part of the gutter, the real model rises visibly and is shifted to the left as well as it is twisted in the longitudinal axis. Measurements taken on the model showed that the middle part of the gutter rises by 95 mm along the Z-axis. The twisting along the Y amounts to 15 degrees.

Summary

The present case demonstrates the value of 3D laser scanning technology in examining deformations of various building components. In the analyzed case, the captured point cloud data proved to be an excellent source of information on the geometry of the roof drainage installation. With this data, measuring the scanned object became straightforward. The scans enable the identification and examination of deformations and damages, including those that may not be readily apparent during an on-site visit. Additionally, the scan allows an inventory of the entire object to be prepared. The point cloud facilitates reading measurements and calculating the surface area of individual elements.

In conclusion, the laser scanner serves as an effective tool for data collection and the generation of inventory documentation for both individual elements and entire historic buildings. The point cloud accurately represents the object's geometry, facilitating measurements in hard-to-reach areas. The disadvantage of this method is the requirement to buy specialist computer software for analyses and modeling. However, its key advantage lies in the ability to reuse the collected data for multiple analyses and studies without the need to repeat the measurement process. Additionally, the data can serve as a foundation for the restoration of an object in the event of its destruction.

Information

The publication was written as a result of the author's internship in Universitat Politècnica de Catalunya-BarcelonaTECH (UPC), Departament de Matemàtiques at the Barcelona School of Building Construction (EPSEB), co-financed by the European Union under the European Social Fund (Operational Program Knowledge Education Development), carried out in the project Development Program at the University of Warmia and Mazury in Olsztyn (POWR.03.05. 00-00-Z310/17). Authors appreciate the fruitful discussions with colleagues at the Building Laboratory (LABEDI) and the Institute of Statistics and Mathematics Applied to the Building Construction (IEMAE) at EPSEB.

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