# POSSIBLE APPLICATIONS OF THE 3D LASER SCANNING TECHNOLOGY IN CIVIL ENGINEERING

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**Summary:**
Considering the constant drive to improve and accelerate building processes as well as possible applications of the latest technological achievements in civil engineering practice, the author has proposed to use 3D laser scanning in the construction industry. Field studies have been conducted on two buildings located on the university campus in Olsztyn, with the aim of verifying whether the said technology will find implementations in everyday work of civil engineers. Using a 3 D laser scanner in a building process will provide an opportunity to accelerate certain activities, making the whole process more efficient. For example, data achieved through a 3D laser scanning process will facilitate making inventories of parameters of buildings in a very short time, will enable one to check irregularly shaped masses of earth, heavy and practically impossible to calculate precisely using traditional techniques. The other part of the research, performed in the laboratory, consisted of measurements of a model mound of earth. All the measurements were made with a 3D SkanStation C10 laser scanner manufactured by Leica. The data were analyzed. The results suggest that there are great opportunities for using the laser scanning technology in civil engineering.

**Keywords:** construction works, making inventories, earth masses, historical building, cloud of points, visualization, three-dimensional model.

## Introduction

3D scanning is the state-of-the-art method based on laser technology, which creates endless opportunities for applications. Its main advantage is the rapid acquisition of huge amounts of data in a very short time, which makes it a much superior solution that any earlier measuring techniques. Terrestrial laser scanners easily find implementations in various branches of economy. The range of their capabilities means that they can be used in engineering geodesy, in specification of the parameters of buildings and building objects characterized by very complex shapes (e.g. historical buildings), in the research on deviations and deflections of building structures, but also in archeology or forensic science.

A 3D scanner is a device which analyzes in real time the measured building or surface area and collects data about the shape, texture or consistency of the object it scans and the surroundings. Properly performed scanning provides us with the data which can be processed, leading to the creation of a fully digital, three-dimensional image of the building. The trickiest part of the technology is to make accurate measurements of transparent, reflective, light-emitting or translucent surfaces because a laser beam is reflected from such surfaces in an uncontrollable manner, leading to an erroneous interpretation of the achieved information.

A 3D laser scanner is a teledetection system, which employs electromagnetic radiation emitted by the device itself. It belongs to the appliances called LIDAR (Light Detection and Ranging) equipment, while a ground laser scanner is called a TSL scanner (Terrestrial Laser Scanning). A scanner is an instrument which, once seated on a levelled and stable tripod, collects data while rotating around its own axis. Basically, it works by measuring the distance and angle between the device and the scanned object, using for this aim a laser beam which is reflected by an obstacle and returns to the instrument. The measured distance and angle allow us to visualize the scanned object by creating a point cloud with the set X, Y and Z coordinates, orientated in relation to the local set of coordinates of the laser. A cloud of points together with photographs used for reproduction of the texture of the building walls constitute a realistic visualization of the scanned building.

In this research, analytical data were collected by scanning two buildings, both situated in an area of protected architecture, which stand on the campus of the University of Warmia and Mazury in Olsztyn, called Kortowo. One is the house known as the 'Director's Villa' and the other one is now occupied by a post office. Both are listed buildings and are strictly protected as monuments of architecture. The two buildings were erected in the 1890s, as part of the then existing Asylum of the Mentally Insane.

The Villa (fig. 1) is a two-storey residential house, with a cellar and inhabitable attic. It stands in the north-eastern part of Kortowo. It is a brick building, raised on a polygonal plan, with an *avant-corps* located nearly axially, at the longitudinal and transversal axes of the main block, with a protruding wall base, finished with red kiln brick and decorated with yellow face brick laid in courses, with very carefully finished masonry bonds. The main block of the building is divided by avant-corps and breaks in the walls on each side of the building, and a winter garden, jutting out from the easternmost corner of the house and presenting a very complicated and decorative wooden structure. The building has a tiled roof on a timber rafter framing and a mixed construction.



Fig. 1. The villa, a view from the south (photo J. Pawłowicz 2011)

The other building, today a post office (fig. 2), used to contain flats. It stands in the north-eastern part of Kortowo, and the roof ridge runs parallel to the street. The walls are made of solid kiln brick and faced with brick joined with lime mortar. The building's roof rests on a purlin and rafter roof construction and is covered with Dutch roof tiles. This is a one-storey building with a habitable attic, made higher owing to the knee wall. There is a cellar under some of the building. The house was built on a nearly square plan.



Fig. 2. the post office builidng (photo J. Pawłowicz 2012)

**Field assays**

The preparation and execution of measurements in field must be preceded by surveying a given area. First of all, it is necessary to decide where to position the instrument and how to place the target discs, which during a later stage of data processing will help to combine the scans from all stations into one image. The scanner should be positioned so as to ensure that a laser beam can reach all details of a scanned object.. Wrong positioning or an insufficient number of scanning stations may lead to a situation when there are not enough data and the achieved three-dimensional picture of the analyzed object is incomplete. When the laser beam emitted from the device encounters an obstacle, which stops it from reaching the target, then so-called shadows or dead fields in a digital model of the object appear. Unfortunately, sometimes it is impossible to avoid such barriers as other buildings, stationary cars or plants. In addition to this, empty fields can also be created when the land parcel on which a building stands is too small. This was the case of the villa because it was impossible to move the scanner far enough to ensure that the angle at which the laser beam fell onto the building was not too sharp. As a result, there were some difficulties catching the measurements of the roof of the house. In this case, the objects which obscured the view were not only trees but also elements of the building itself (fig. 3). This is the problem which most often arises when measuring objects with complicated shapes and a complex body of the building.

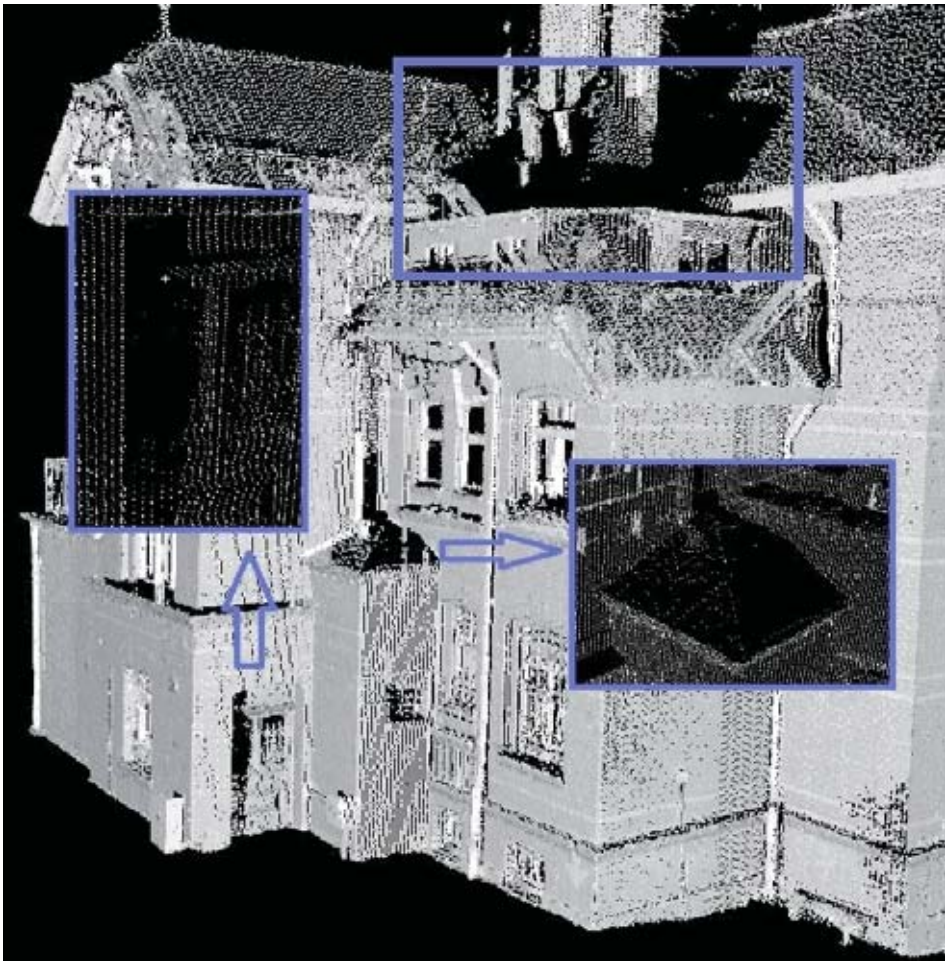


Fig. 3. Shadows on the villa.
*Source: J. Pawłowicz, Z. Olek*

**Processing and analysis of the data**

The data obtained during the measurements compose a point cloud, which is exported from the measuring device via a specialist software programme called Cyclon. When scans from all the stations are aligned and merged into a single model, and all unnecessary information is removed, it is possible to make almost instantly drawings of the building which will show all its component parts. Projections and cross-sections can be produced using the application called "a limit box", which generates a hexagonal box with cutting edges. They can cut models of buildings at any site and create its vertical or horizontal cross-section (fig. 4), where it is possible to determine the dimensions: straight and oblique ones, diameters, arcs and any angles, etc.

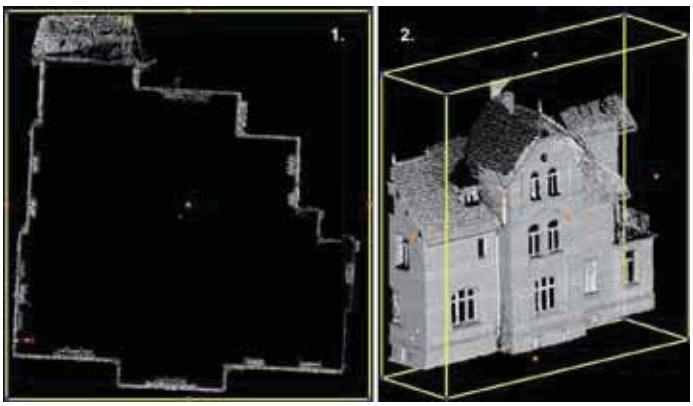



Fig. 4. Horizontal (1) and vertical (2) section through a building using limit box cutting edges (yellow lines).
*Source: J. Pawłowicz, Z. Olek*

Scanned interiors can also be represented as sections based on the contour of a point cloud cut with a reference plane. A point cloud can be cut in a number of ways, employing appropriate software applications. Owing to this solution, you can draw the contours of anything that is inside the building. The type of an option selected from the programme enables us to make a full (fig. 5) or contour (fig. 6) cross-section. The achieved drawings reveal many details, which can be measured and related to each other. This option is extremely useful when we need to make an inventory of a space characterized by a high degre of complexity, e.g. industrial buildings, or where access is difficult and it is impossible to make an inventory with classical methods (fig. 7).

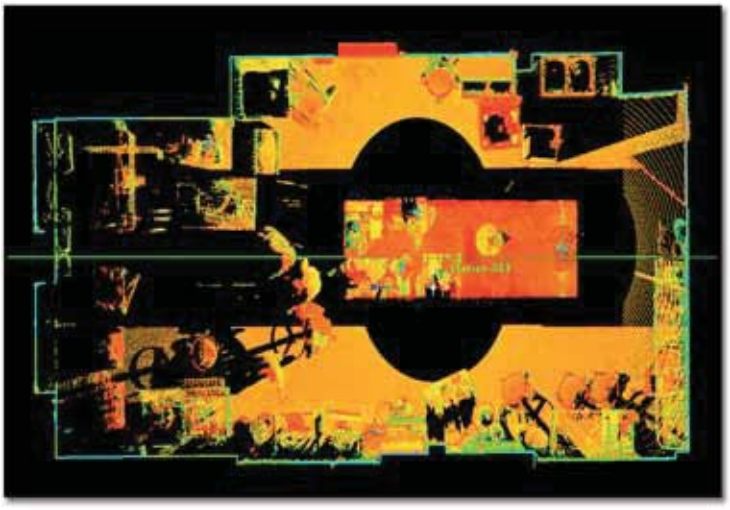


Fig. 5. A projection of a room obtained using the application 'View Half-Space'.
*Source: J. Pawłowicz, P. Ziółkowski*




Fig. 6. A projection of a room obtained with the applications 'Cloud Shaded' and 'Cloud Silhouette'.
*Source: J. Pawłowicz, P. Ziółkowski*

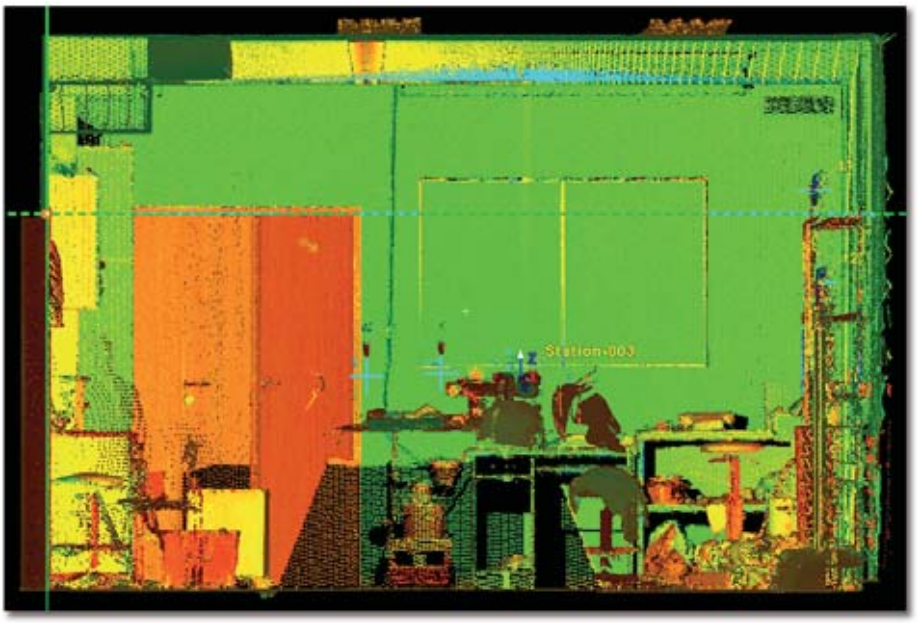



Fig. 7. A vertical cross-section through a room, using the application 'Cloud Shaded'.
*Source: J.Pawłowicz, P.Ziółkowski*

The data from scanning measurements also enable us to elaborate the axionometry of a building (fig. 8) or to visualize its facade walls (fig. 9). To this aim, we can employ a cloud of points obtained during field measurements, which constitutes a model of the objects, directly after the data from the individual stations are merged. The picture can be presented as a 'raw' cloud of points or a cloud with overlaid photographs, which additionally shows that colours and texture of the object.

The above information shows how easy it is to prepare technical documentation of an existing building. In the construction process, it is often necessary to elaborate such documents for a building when the original documentation is either missing or outdated. This is frequently the case when historical edifices and buildings are involved. Such documents are required for refurbishment, renovation, repairs or expansion of existing constructions. Based on the said documentation, architects and designers can work out a new design, while an estimator makes a costs analysis of a given investment. Moreover, such documentation must be made available when construction works will be awarded by a tender bid.

Three-dimensional laser scanning can help to prepare the documentation mentioned above, but it can also be deployed later to record stages of construction works and to monitor their progress when new buildings are erected. Documentation prepared with the aid of scanning technologies can act as proof for a building inspector or a construction site manager in case of any flaws. During the building works, some elements, e.g., reinforcement rods or wires, are hidden in concrete, which makes it a cumbersome venture to try and assess whether the reinforcement made is faithful to the design. Using a scanner for regular checks at consecutive stages of a building undertaking helps to determine later if everything has been done as planned, but also to capture flaws often invisible to the naked eye or found on covered elements. Having a scan of an element, before it is cast in concrete, we are able to see how the reinforcement structure was laid and to determine the parameter of used wires and rods. Furthermore, when we make scans alongside taking photographs which will show the texture of the object, it is also possible to assess the state of reinforcement at the moment it was covered in concrete, for example we can check whether it was not corroded, or if it was smooth or ribbed steel.

Recapitulating, it is obvious that using the 3D laser scanning technique for the purpose measuring and monitoring of a building is extremely helpful in civil engineering, as it can save us time as well as help to achieve better accuracy and safety of constructions works, and complete them in a shorter period of time.



Fig. 8. An axionometric projection of the office building in Kortowo, without an overlaid texture.
*Source: J.Pawłowicz, P.Ziółkowski*



Fig. 9. A wall of the post office building with the texture.
*Source: J.Pawłowicz, P.Ziółkowski*

**Measurements of volume of earth masses – laboratory assays.**

Construction works often inolve earthwork. The 3D laser scanning technology can also be successfully applied to control volumetric volume of earthen mounds and trenches. This part of the research was conducted in a laboratory. The objective was to determine what precison is attainable in measuring the volume of earthen material. The tests were carried out in the Laboratory for Testing Concrete, at the UWM in Olsztyn. A portion of 0.005 $m^3$ of medium grain aggregate was meausred and used to make a mound. The mound was then scanned at high resolution. The higher the resolution, the denser and more accurate the point cloud obtained.

The experiment was conducted in two stages. First, high resolution scanning was performed at three laser measuring stations. Next, during the second, control stage, the measurements were taken at four stations but with medium resolution. Once the observations were completed, the data were exported to a computer. They served as a basis for making a model of the mound in the form of a point cloud (fig. 10).

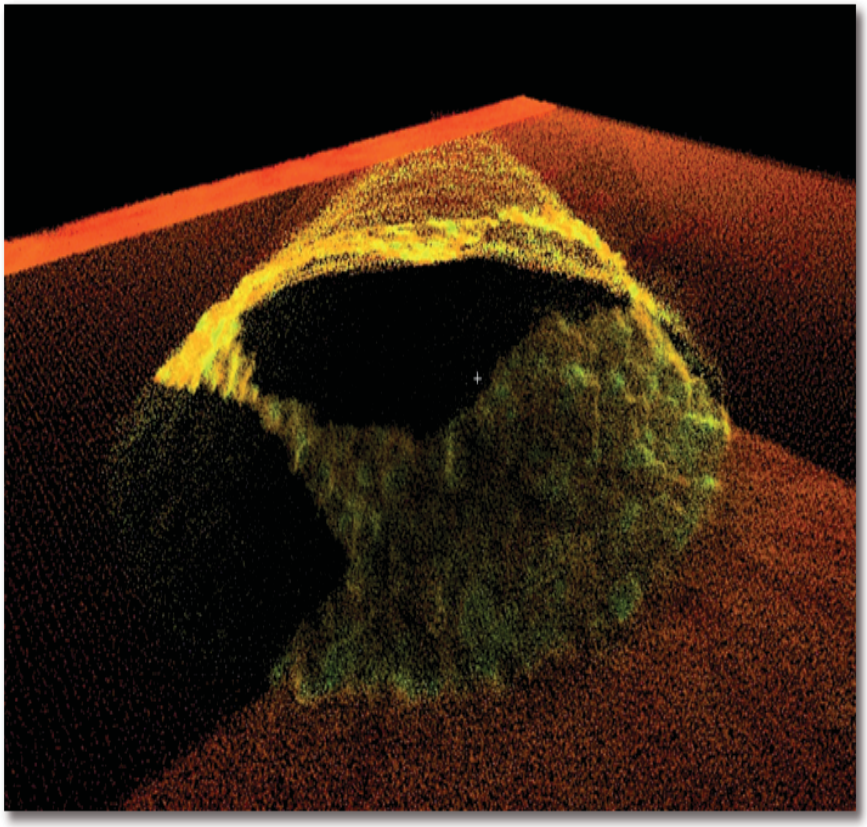


Fig. 10. A model of a mound of aggregate in the form of a point cloud.
*Source: J.Pawłowicz, P.Ziółkowski*

The volumetric volume was measurable once the cloud was transformed into a 'mesh' model, but to achieve this a TIN (Triangulated Irregular Network) mesh had to be overlaid. This is a mesh composed of triangles and each vertex of every triangle connects with points in a cloud, creating a surface. It is possible to modify the number of triangles in a model so as to reduce occlusions caused by matching noises appearing directly above the object to the Tin mesh (fig. 11). The default number of triangles is 105 of the basic model. Once the integration step is set, we can begin the volume of a mound. The result is given in $m^3$ (fig. 12).

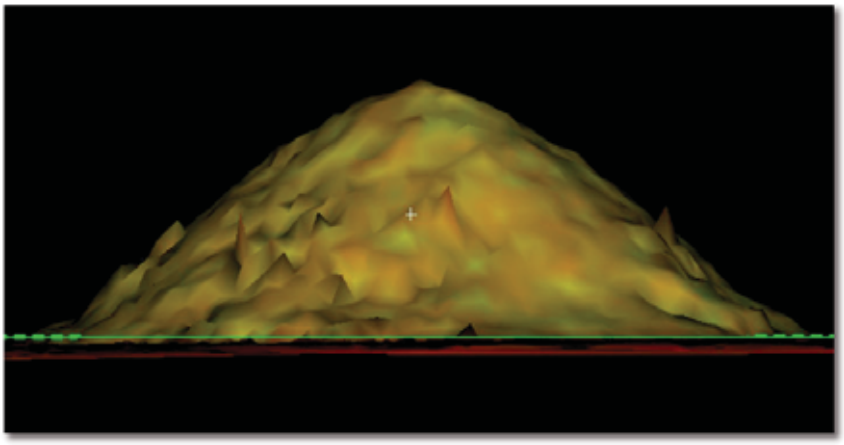


Fig. 11. A lateral view of the mound after overlaying and integrating TIN mesh.
*Source: J.Pawłowicz, P.Ziółkowski*

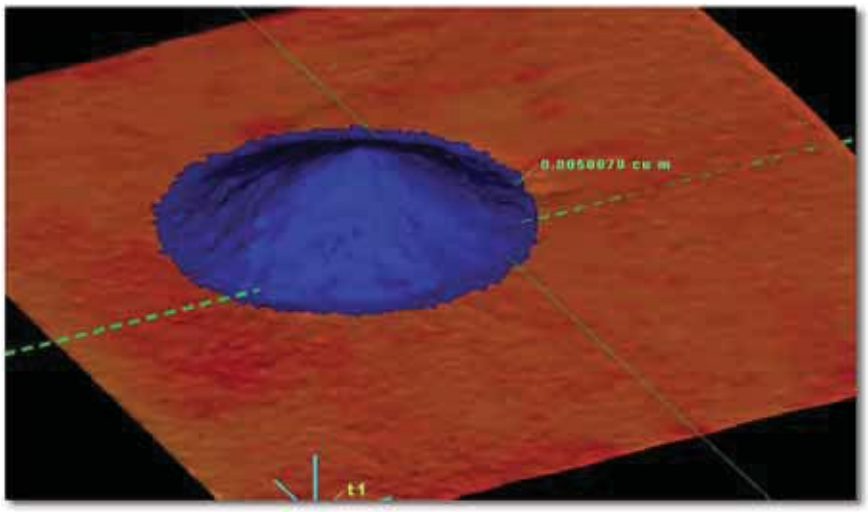


Fig. 12. Measuring the volume of a mound.
*Source: J.Pawłowicz, P.Ziółkowski*

The volumetric volume was measured at three integration steps: 0.1m, 0.05m, 0.01m. The degree of integration attained through decreasing the number of triangles in the mesh was determined consequtively at 100%, 10%, 8%, 6%, 4%, 2%, 1%, 0.5%. The results are contained in the tables below (tab. 1 and tab. 2).

Tab. 1. Results from test 1

| Table of results from test 1 | | | |
|---|---|---|---|
| Degree of diminished density of triangle mesh [%] | Model volume [$m^3$] | Volume of the model | Difference in volume |
| Integration step– 0.10m | | | |
| 100 | 0.005 | 0.0051668 | -0.0001668 |
| 10 | | 0.0050879 | -0.0000879 |
| 8 | | 0.0049888 | 0.0000112 |
| 6 | | 0.0049749 | 0.0000251 |
| 4 | | 0.0049803 | 0.0000197 |
| 2 | | 0.0049701 | 0.0000299 |
| 1 | | 0.0049674 | 0.0000326 |
| 0.5 | | 0.0049576 | 0.0000424 |
| Integration step– 0.05m | | | |
| 100 | 0.005 | 0.0050249 | -0.0000249 |
| 10 | | 0.0050509 | -0.0000509 |
| 8 | | 0.0050499 | -0.0000499 |
| 6 | | 0.005043 | -0.0000430 |
| 4 | | 0.0050411 | -0.0000411 |
| 2 | | 0.005021 | -0.0000210 |
| 1 | | 0.005018 | -0.0000180 |
| 0.5 | | 0.0050099 | -0.0000099 |
| Integration step– 0.01m | | | |
| 100 | 0.005 | 0.0050445 | -0.0000445 |
| 10 | | 0.004874 | 0.0001260 |
| 8 | | 0.0049953 | 0.0000047 |
| 6 | | 0.0050189 | -0.0000189 |
| 4 | | 0.0050182 | -0.0000182 |
| 2 | | 0.0050153 | -0.0000153 |
| 1 | | 0.0050087 | -0.0000087 |
| 0.5 | | 0.0050013 | -0.0000013 |

*Source: J. Pawłowicz, P. Ziółkowski*

Tab. 2. Results from test 2.

| Table of results from test 2 | | | |
|---|---|---|---|
| Degree of diminished density of triangle mesh [%] | Model volume [$m^3$] | Volume of the model | Difference in capacity |
| Integration step – 0.10m | | | |
| 100 | 0.005 | 0.0050020 | -0.0000020 |
| 10 | | 0.0049558 | 0.0000442 |
| 8 | | 0.0049517 | 0.0000483 |
| 6 | | 0.0049456 | 0.0000544 |
| 4 | | 0.0049327 | 0.0000673 |
| 2 | | 0.004921 | 0.0000790 |
| 1 | | 0.0049059 | 0.0000941 |
| 0.5 | | 0.0049015 | 0.0000985 |
| Integration step – 0.05m | | | |
| 100 | 0.005 | 0.0048004 | 0.0001996 |
| 10 | | 0.0047998 | 0.0002002 |
| 8 | | 0.0047986 | 0.0002014 |
| 6 | | 0.0048001 | 0.0001999 |
| 4 | | 0.0048011 | 0.0001989 |
| 2 | | 0.0048201 | 0.0001799 |
| 1 | | 0.0048047 | 0.0001953 |
| 0.5 | | 0.0048021 | 0.0001979 |
| Integration step – 0.01m | | | |
| 100 | 0.005 | 0.0048644 | 0.0001356 |
| 10 | | 0.0048443 | 0.0001557 |
| 8 | | 0.0048447 | 0.0001553 |
| 6 | | 0.0048459 | 0.0001541 |
| 4 | | 0.0048446 | 0.0001554 |
| 2 | | 0.004841 | 0.0001590 |
| 1 | | 0.0048354 | 0.0001646 |
| 0.5 | | 0.0048246 | 0.0001754 |

*Source: J. Pawłowicz, P. Ziółkowski*

Based on the results of tests, the smallest difference in the volume of the mound model was determined, relative to the actual volume of the aggregate, and the result was 0.0000013$m^3$, which corresponds to a deviation in the range of 0.026% of the model value. The mean deviation of all the variants of possible configurations during the processing of data was 0.274% for test 1 and 2.740% for test 2. Obviously, the 3D

laser scanning technology is suitable to measure volumes of earthen masses in civil engineering. Besides, a scan with a higher resolution of measurements yielded results more accurate by an order of values than observations with a laser device set at lower resolutions.

**Summary and conclusions**

While conducting field observations, it became obvious that time of day when scanning is done also matters. An engineer at a construction site, who often works in different weather conditions and different light intensity, must take into account the fact that time of day and weather conditions may affect the accuracy of recorded data.

Some of the measurements of one of the analyzed buildings were carried out in the afternoon and evening (from full sunlight to twilight). While analyzing the data, attention was drawn to the fact that the range of an area a laser can scan is much bigger under full sunlight than just before the sun sets or in the dark. These observations are presented in table 3.

Table.3. Relationship between the furthest point obsereved by a scanner and the sunlight falling on the building.

| No | Hour of observations | Degree of sunlight | Distance to furthest measured point [m] |
|---|---|---|---|
| 1 | 15.00 | Full sunlight | 291.263 |
| 2 | 16.30 | Light clound cover | 245.701 |
| 3 | 18.00 | Sunset | 226.453 |
| 4 | 19.30 | Twilight | 194.911 |
| 5 | 21.00 | Darkness | 192.400 |

*Source: J. Pawłowicz*

Construction works are often carried out under changeable weather conditions, and a construction site is a difficult place for making any kind of measurements. A laser scanner is a device which will enable us to measure more precisely masses of earthen materials or control whether the building works are carried out correctly. However, as the above table shows, the distance to the furthest captured point decreases from full sunlight to twilight, and this can be considered as some kind of nuisance. On the other hand, observations with a laser scanner cannot be made facing the sun and under full exposure of the measured object to the source of light, because then unwanted noises can appear. These limitations mean that sometimes measurements need to be taken from a larger number of vantage points so as to reach all relevant ‘nooks and corners’.

Finally, some light snowfall occurred during our observations. Atmospheric precipitation can also be a cause of serious problems. First of all, a laser scanner is a very sensitive instrument, full of electronic solutions, and should be protected from variable weather. Secondly, falling rain or snow which passes through a laser beam reflects the laser light and causes disturbances and distortions of a point cloud, knows as ‘noises’ (fig. 13).

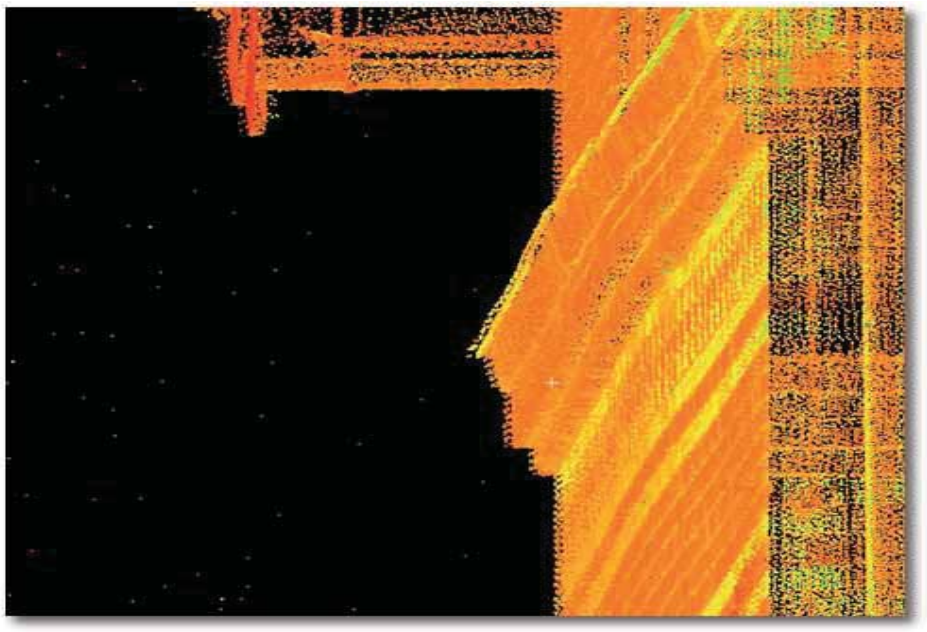


Fig. 13. Noise caused by snowfall during scanning,
*Source: J. Pawłowicz, P. Ziółkowski*

'Noises' are extra points, not connected to a model, which must be removed while processing data. The more noises, the less accurate the generated model. On the other hand, if a sufficiently dense cloud of points is measured, then some light atmospheric precipitation should not affect much the results of observations. Conversely, if the optical parts of a scanner are dirty or splashed with rainwater, then serious distortions of the final image may appear.

Noises are also created when some fragment of a laser beam falls on the edge of a measured object, as a result of which some impulse returns to the emitting device but some is reflected by another object, situated somewhere behind the target. This is known as an echo, which can be responsible for serious problems arising when we start processing data.

Despite the mentioned difficulties, it is doubtless that the 3D laser scanning technology proves useful in each of the analyzed situations. It is an exceptionally promising technology with endless applications in civil engineering, whose number and diversity are only limited by human imagination.

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