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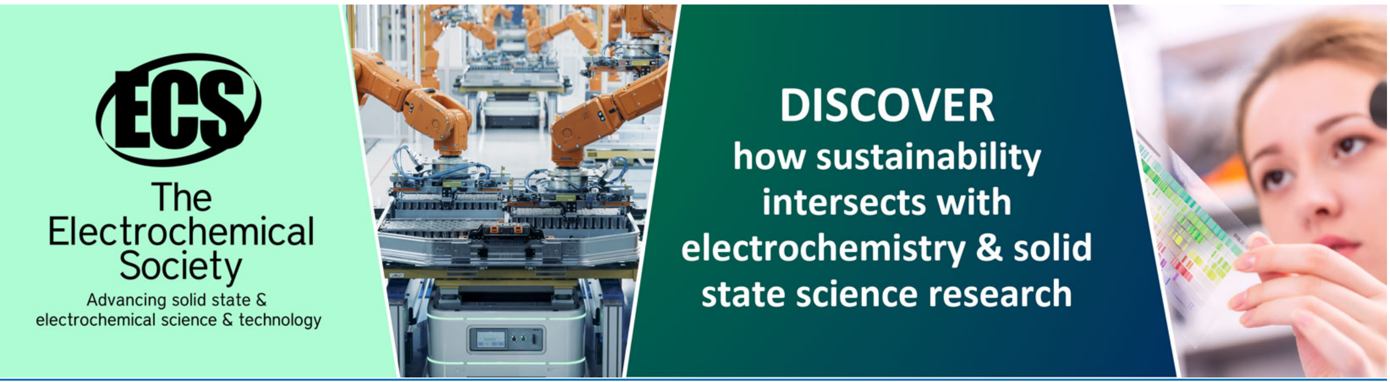

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Modern Methods of Measuring and Modelling Architectural Objects in the Process of their Valorisation

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Abstract. As well as being a cutting-edge technology, laser scanning is still developing rapidly. Laser scanners have an almost unlimited range of use in many disciplines of contemporary engineering, where precision and high quality of tasks performed are of the utmost importance. Among these disciplines, special attention is drawn to architecture and urban space studies that is the fields of science which shape the space and surroundings occupied by people, thus having a direct impact on people's lives. It is more complicated to take measurements with a laser scanner than with traditional methods, where laser target markers or a measuring tape are used. A specific procedure must be followed when measurements are taken with a laser scanner, and the aim is to obtain three-dimensional data about a building situated in a given space. Accuracy, low time consumption, safety and non-invasiveness are the primary advantages of this technology used in the civil engineering practice, when handling both historic and modern architecture. Using a laser scanner is especially important when taking measurements of vast engineering constructions, where an application of traditional techniques would be much more difficult and would require higher time and labour inputs, for example because of some less easily accessible nooks and crannies or due to the geometrical complexity of individual components of a building structure.
In this article, the author undertakes the problem of measuring and modelling architectural objects in the process of their valorisation, i.e. the enhancement of their functional, usable, spatial and aesthetic values. Above all, the laser scanning method, by generating results as a point cloud, enables the user to obtain a very detailed, three-dimensional computer image of measured objects, and to make series of analyses and expert investigations, e.g. of the technical condition (deformation of construction elements) as well as the spatial management of the surrounding environment while the measurements are being taken and processed. An example of the application of this technology provided in the article is a large-size building housing a swimming pool, which belongs to the University of Warmia and Mazury in Olsztyn, north-eastern Poland. With the help of a 3D laser scanner, it was possible to create a spatial model of the building, which is very useful for making inventories, preparing technical documents and evaluating the impact of a building on the surroundings and how its shape matches the urban spatial structure.

1. Introduction
Application of a 3D scanner in many fields of the construction industry, geodesy and other domains means that one of the most advanced measuring techniques is implemented. An output of a 3D scanner-assisted measurement session is a huge number of points, which allows us to model scanned object very

precisely. This technique can very rapidly produce extremely accurate scans, for example a Leica ScanStation C10 used in this study can register up to 500 000 points per second [1]. A point cloud, which is a faithful representation of the scanned space, serves as the basis for creating a three-dimensional model of an object, which can be modified freely. Results of the scanner's work are appealing visually and can be processed easily, hence their various applications in different spheres of life. In civil engineering and architecture alone, scanners are a versatile tool, helpful to make inventories as well as plans and designs of buildings, preserve historic buildings, or analyse deformations of building structures. Three-dimensional scanning can upgrade and accelerate building processes, in which it meets expectations of the modern construction market [2].

This article raises issues of measuring and modelling of architectural objects during their valorisation processes, that is while exposing their functional, usable, spatial and aesthetic values. Most importantly, by generating point clouds, laser scanning leads to the creation of very detailed computer images of a scanned object, and therefore facilitates making analyses and expert assessments, for example connected with the technical condition of a building (deformation of structural elements) or spatial arrangement of its environs. An example discussed in this paper is a large-scale swimming pool building, which belongs to the University of Warmia and Mazury in Olsztyn, northeastern Poland.

2. Characteristics of laser scanning

Laser scanning is a cutting-edge measuring technology, which is still developing rapidly. This technology has an almost unlimited range of applications in many domains of contemporary engineering, where precision and high quality of performed work is of the utmost importance. Architecture and urban space studies are worth being distinguished among these disciplines, as they shape the space and ambient environment occupied by people, thereby having an immediate effect on their lives. Making measurements with a laser scanner is a more complex undertaking than with more traditional measurement implements, like a laser rangefinder or a measuring tape, and must adhere to a specific procedure, the aim of which is to obtain three-dimensional coordinates of buildings in their surrounding space. Accuracy, rapidness, safety and non-invasiveness are the principal advantages of this technology which appeal to attract building engineers, who use 3D laser scanner in practice, for both historic and contemporary architecture. Using laser scanning is particularly fitted for large-scale engineering objects, where application of traditional techniques would be much more cumbersome as well as time- and labour-consuming due to the presence of some hardly accessible areas and the geometric complexity [3].

The technology of terrestrial laser scanning has already become a widespread method of acquiring data for the development of numerical models of buildings, for example to create Architectural Information Systems, which integrate various data, such as inventories of contemporary and historic buildings. TLS-assisted data sets can be used by architects or archeologists, and by teams or office departments engaged in spatial planning [4].

Laser scanners which enable creation of three-dimensional models are divided into several types according to the applied measuring technique 'figure 1'. They include:

- time-of-flight scanners – a laser pulse is sent out a given angle and a scanner measures the time between the emission of the pulse and its return to the scanner. The distance is then calculated from this time. The angle and distance compose polar coordinates, which allow one to determine the x, y, and z coordinates. An advantage of TOF scanners is that they can measure over great distances,
- phase shift scanners – they emit continuous laser light at alternating frequencies and calculate the distance to a measured object from the difference between the emitted and reflected signals,
- triangulation scanners – measure the angle and distance of a laser signal reflected from a measured object and falling on the matrix of one of two digital cameras. They are very short-range scanners (up to 3 meters) but with high accuracy of data collection (0.05 mm) [5].

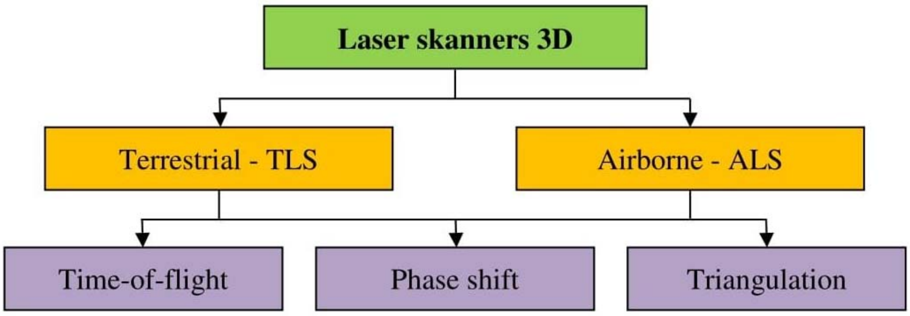

Figure 1. Division of laser scanners

A laser scanner generates point clouds, obtained from each station 'figure 2'. It is possible to integrate individual scans owing to the shared points defined in the scanner's visual field. This way a three-dimensional skeleton is outlined. It serves as the basis for further processing of scans, by modelling the image or reducing noises. This is achieved with specialist software that a scanner is equipped with.

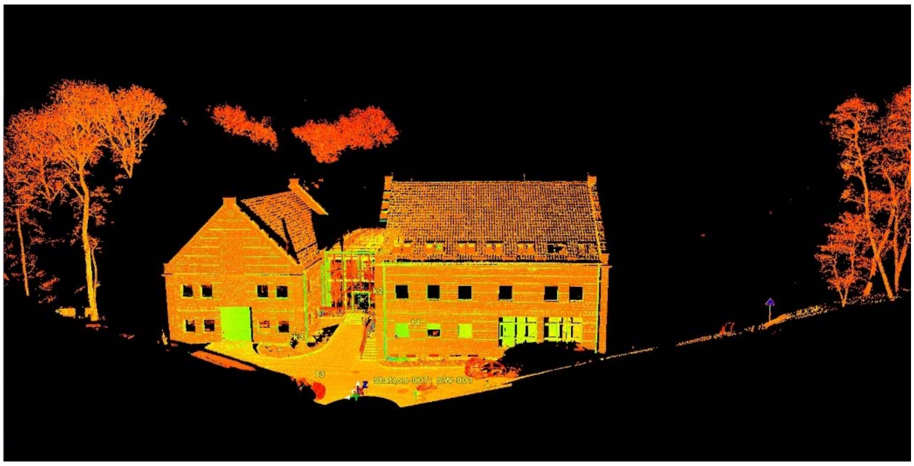

Figure 2. A scan of the teaching and laboratory building of the Civil Engineering School at the UWM in Olsztyn, at 4 Heweliusza Street – a point cloud

Three-dimensional images of buildings produced by laser scanning can be processed with different modelling methods. The most popular ones are:

- skeleton (edge) modelling – it is composed of points and edges, which are straight and curved lines,
- solid/surface modelling – the solid-modelling approach is a geometrical method, based on three dimensions, which faithfully reflect spatial parameters of an object. Surface modelling is a mathematical method, which determines the external properties of an object with infinitely small thinness. The advantages of surface modelling are that it generates objects with intricate shapes and develops more aesthetic models,
- hybrid modelling – a merger of solid and surface modelling. This method allows us to model elements with imperfections of the surface and edges, which makes it useful in the case of objects which are not perfect solids [6].

The choice of a modelling method is primarily dictated by the type of a modelled object and the expected outcome of modelling.

The present study explores the potential of a laser scanner Leica ScanStation C10 ‘figure 3’, which is a new type of a pulsed scanner. The platform of this appliance consists of a scanner, battery, internal data storage, digital camera, laser level indicator, and a controller. The station has an in-built Smart X-Mirror technology, which automatically aligns the camera with the laser light for fast targeting of objects. The technology also enables the user to scan an area above the scanner. The ScanStation C10 has a touchscreen display for control and selection of 3D scans. The ScanStation C10 can be coupled with an external computer, which is certainly another great advantage of this scanner.

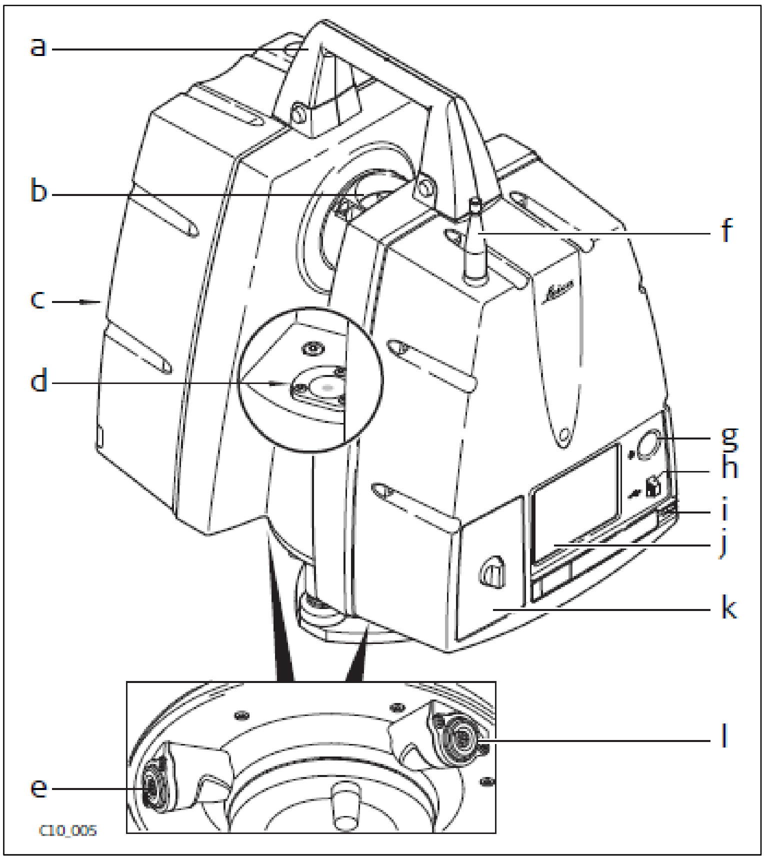

Figure 3. Components of a ScanStation C10 (source: Leica ScanStation C10/C5 – a user manual), where: a – a grip handle, b – rotating mirror (the camera lens), c – battery chamber 2, d – levelling device, e – supply socket, f – antenna, g – on/off button, h – USB port, i – styler, j – touchscreen, k – battery chamber 1, l – Ethernet port

3. Laser measurements of large-scale buildings

The object of the present study, measured with a Leica ScanStation C10, is the building of the University Swimming Pool, located at Tuwima Street in Olsztyn ‘figure 4’. Owing to the properties of the applied scanner, it was possible not only to represent and visualize the building’s actual shape, but also the texture and colour of the walls. The capabilities of this instrument, including the maximum 300 m range, make it very fitted for modelling architectural objects, both their shape and detailed architectural features.

The initial field work, which is the first step in data acquisition, consisted of a field inspection of the building’s surroundings, when it was possible to set up characteristic stations for the scanner, their number and control points. At that moment, it was important to analyse a number of places where the scanner could be positioned, so as to minimize shadows, the so-called ‘dead fields’.

Figure 4. The interior of the University Swimming Pool in Olsztyn

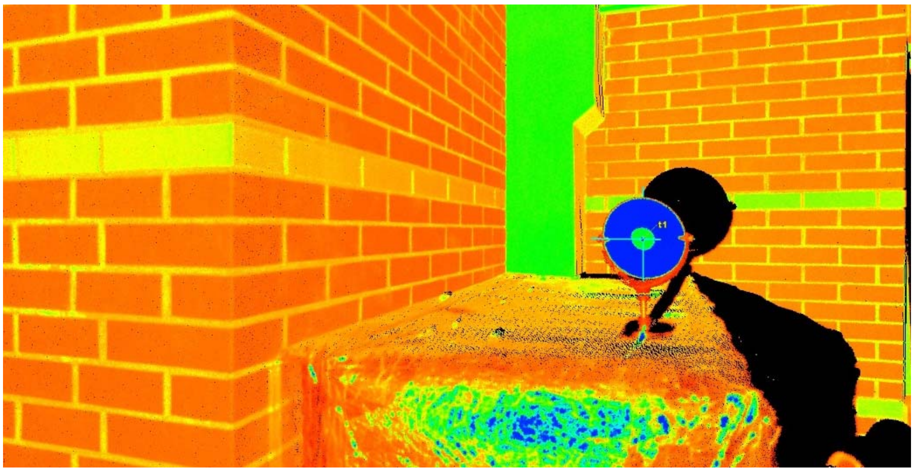

Figure 5. Scan of a target

The second stage in the field work was to set measuring signals, which consisted of HDS 6 targets and styrofoam spheres 10 cm in diameter, which would be received by the scanner as the sphere-type control points 'figure 5', 'figure 6'. They serve as shared points for integration of scans from new scanning sites with the old ones. This set-up was complemented by photographs taken by the scan station and superimposed on the point clouds obtained, which – under the variable weather conditions – was helpful in making a decision about changing the position of a measurement station or repeating a measurement.

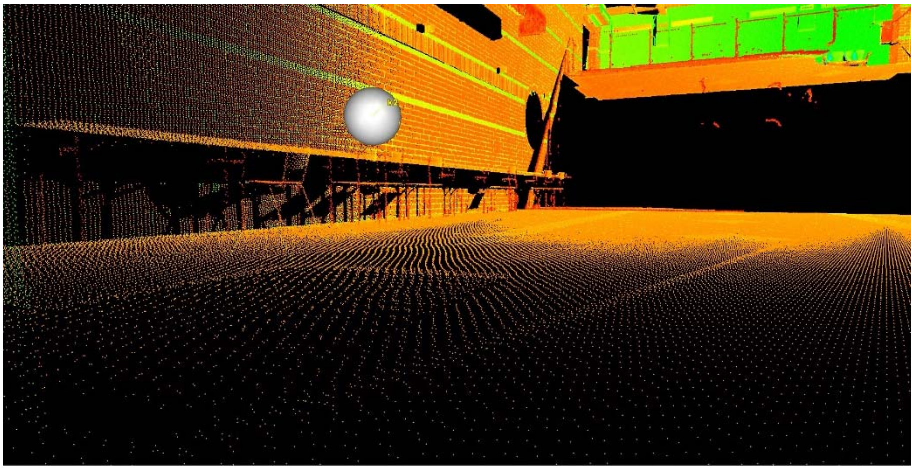

Figure 6. Scan of a sphere

The data acquired with the scan station supported the interpretation of the building's structure – how its form was shaped and what the building materials were used for its construction. With this information, at the first stage of our study, we could estimate the extent of field work and the form of data processing.

The data obtained from all measurements and stored onto the scanner's hard drive were exported to a computer, and Cyclone 7 software was employed to process and incorporate together all point clouds. Integration of individual scans leads to the creation of a unified, three-dimensional model of a building, which requires further processing to erase the so-called unwanted noises from the point cloud 'figure 7', figure 8'. At this stage, two approaches are feasible: by fitting surfaces in the external structure of a building, or developing a TIN mesh, which is a network exclusively composed of triangles. Both methods have advantages and disadvantages. The strength of the former is a shorter time it requires, which unfortunately translates into a worse quality. The latter is excellent for creating images of buildings rich in architectural details because it can account for the smallest deviations of planes. The software contains multiple tools helpful in preparing technical documentation of scanned buildings. Some allow us to select groups of points, thereby creating horizontal or vertical cross-sections in any plane. Others enable us to create visualizations of buildings, using for this purpose series of digital photographs arranged in a panoramic view, which the scanner generates in the final stage of a measurement session.

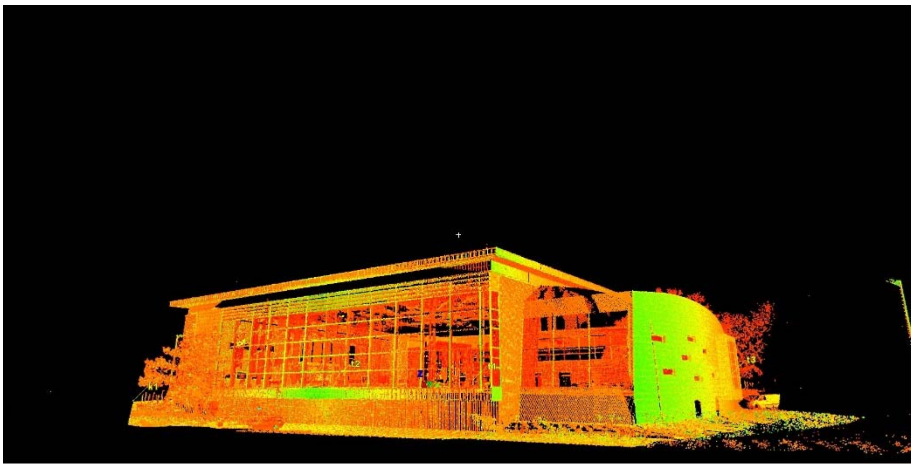

Figure 7. The University Swimming Pool – a scan of the building, a point cloud

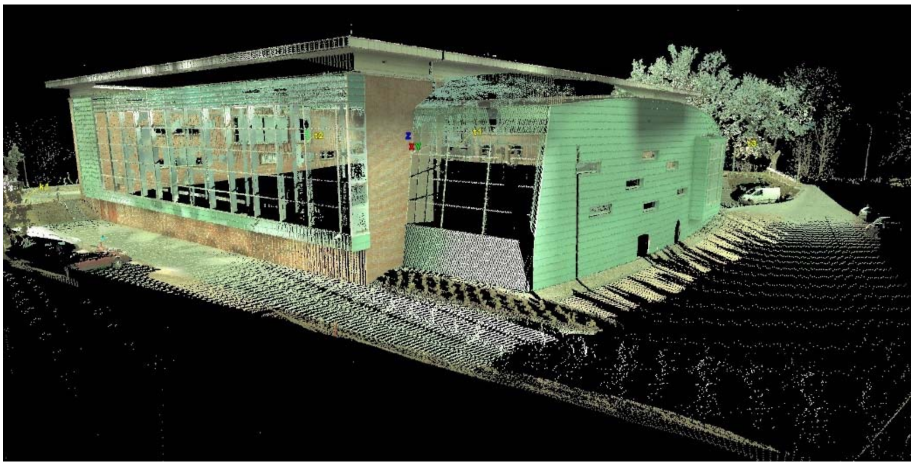

Figure 8. The University Swimming Pool – a scan of the building with superimposed photographs

A great advantage of 3D laser scanning in an assessment of the current state of a building is that it provides a diagnosis of the structural elements exposed to higher loads. The precision of constructing and joining such elements has a bearing on the work of the whole construction. The role of a scanner in evaluating the quality and precision of construction work seems unquestionable in this respect.

In certain types of structures, e.g. metal ones, the precision of assembling elements or connecting them is essential, as it has a powerful impact on the whole construction. Through 3D scanning, we are able to obtain a detailed model, which can be compared with the technical specification and then evaluated in terms of the quality, accuracy and correctness of the work performed to make a given element. Such problems must be dealt with frequently when large buildings, for example swimming pools, are surveyed.

Despite having made an analysis to determine the number and positions of measurement stations and control points, certain undesirable effects of a scanner's work cannot be excluded. A large field of vision (full angle horizontally and 270° vertically) means that objects unrelated to the target one can be captured. They include elements of the spatial development – other buildings, trees – but also passing cars or people. Moving objects cause the appearance of so-called noises during the work of a scanner 'figure 9'.

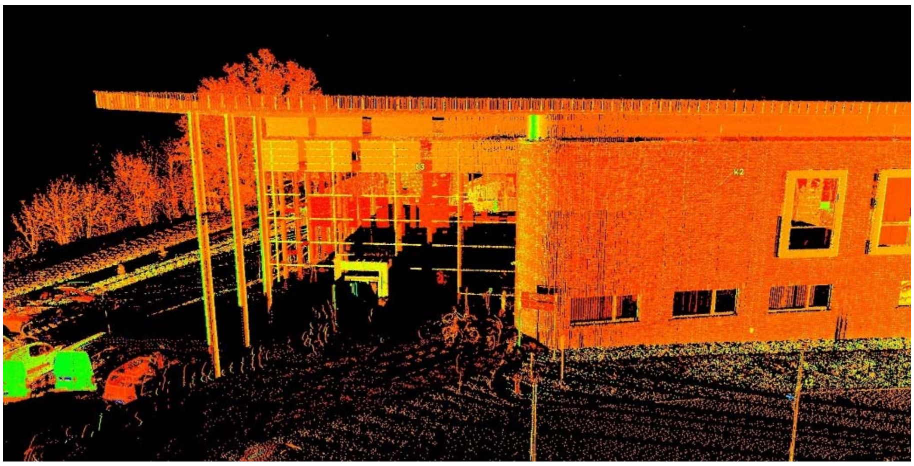

Figure 9. The University Swimming Pool – a scan of the building, so-called noises

The use of a laser scanner for making measurements can be impeded by having to analyse modern architectural objects with large glass panel walls. This is a common attribute of swimming pools built

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nowadays. Translucency of glass walls and the scattering and reflecting of light mean that a scanner interprets such surfaces erroneously 'figure 10'. Another problem appears inside swimming pool buildings, where noises are often created by water in the pool. A reflection of light from a laser scanner by the water surface deforms the image. A possible solution is to select unproblematic measurement stations, but unfortunately this is not always possible.

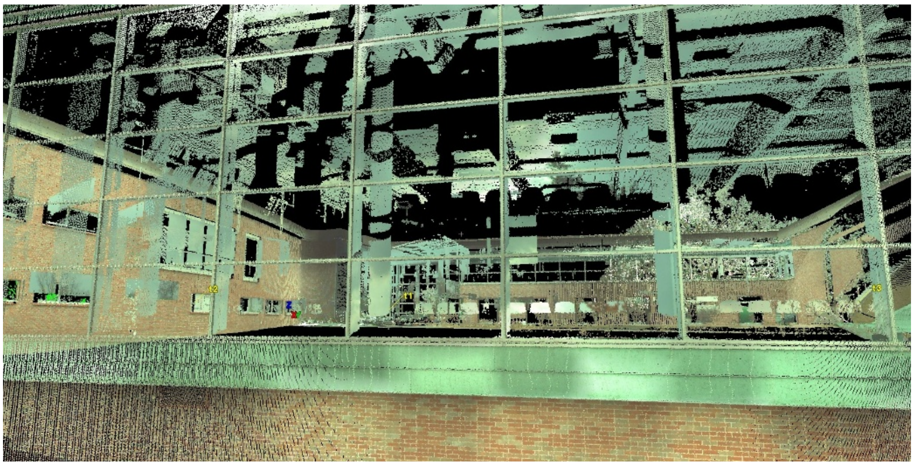

Figure 10. The University Swimming Pool – an effect of the laser light being reflected by a glass wall

Scanning an object is often made more difficult due to other objects, e.g. trees, which obscure the view. As a result, the so-called black holes appear in images of the building's exterior walls 'figure 11'. A possible solution is to make additional scans of the places where points are missing. Other problems are a small size of the land parcel on which the scanned building stands or the lack of suitable places for positioning the scanner. Should this happen, the angle at which a laser light is emitted could be excessively big. Making an auxiliary scan and integrating it with the original point cloud is a solution which can assist us in identifying similar planes and unifying both data sets.

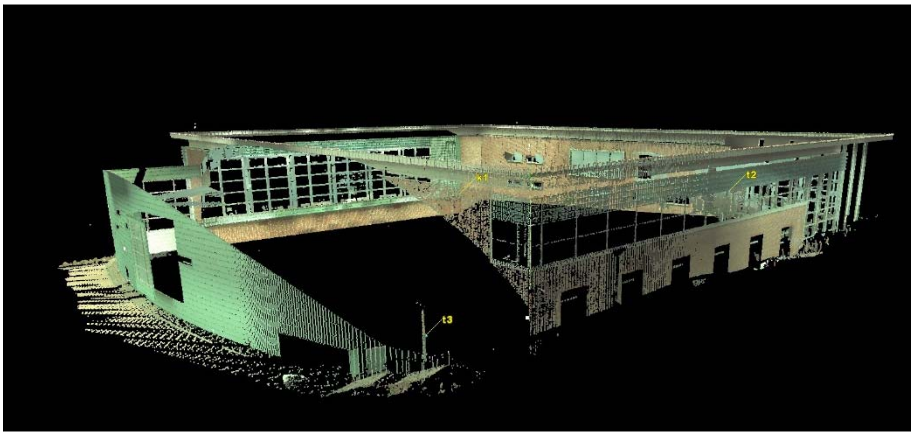

Figure 11. The University Swimming Pool – so-called black holes

4. Conclusions

The laser scanning method applied to making inventories of architectural objects offers a wide range of possibilities. For example, it is possible to obtain a detailed image showing the spatial geometry of a building. Using laser technology to measure buildings, especially large-scale ones, either to produce data sets about a given object or to diagnose its condition, is becoming increasingly popularity. Although it is a time consuming task, making 3D scans enables us to create a three-dimensional model of a building. Laser scanning is a technology which helps to ensure that the maintenance of existing large-scale buildings, e.g. swimming pools, can be monitored.

In structures where the accuracy and precision of construction work are indispensable, the role of a 3D scanner gains in importance. A detailed model of selected elements or connecting components can be compared with the design documents, which may be fundamental to making an evaluation of the quality and precision of construction works performed. This proves that the potential of laser scanning is much wider and can only be limited by the power of human imagination. The capabilities of a laser scanner discussed above indicate that the appliance can aid in creating databases and modelling of buildings distinguished by a complicated spatial structure.

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