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Importance of Laser Scanning Resolution in the Process of Recreating the Architectural Details of Historical Buildings

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Abstract. The TLS method (Terrestrial Laser Scanning) may replace the traditional building survey methods, e.g. those requiring the use measuring tapes or range finders. This technology allows for collecting digital data in the form of a point cloud, which can be used to create a 3D model of a building. In addition, it allows for collecting data with an incredible precision, which translates into the possibility to reproduce all architectural features of a building. This data is applied in reverse engineering to create a 3D model of an object existing in a physical space. This study presents the results of a research carried out using a point cloud to recreate the architectural features of a historical building with the application of reverse engineering. The research was conducted on a two-storey residential building with a basement and an attic. Out of the building's façade sticks a veranda featuring a complicated, wooden structure. The measurements were taken at the medium and the highest resolution using a ScanStation C10 laser scanner by Leica. The data obtained was processed using specialist software, which allowed for the application of reverse engineering, especially for reproducing the sculpted details of the veranda. Following digitization, all redundant data was removed from the point cloud and the cloud was subjected to modelling. For testing purposes, a selected part of the veranda was modelled by means of two methods: surface matching and Triangulated Irregular Network. Both modelling methods were applied in the case of data collected at medium and the highest resolution. Creating a model based on data obtained at medium resolution, both by means of the surface matching and the TIN method, does not allow for a precise recreation of architectural details. The study presents certain sculpted elements recreated based on the highest resolution data with superimposed TIN juxtaposed against a digital image. The resulting model is very precise. Creating good models requires highly accurate field data. It is important to properly choose the distance between the measuring station and the measured object in order to ensure that the angles of incidence (horizontal and vertical) of the laser beam are as straight as possible. The model created based on medium resolution offers very poor quality of details, i.e. only the bigger, basic elements of each detail are clearly visible, while the smaller ones are blurred. This is why in order to obtain data sufficient to reproduce architectural details laser scanning should be performed at the highest resolution. In addition, modelling by means of the surface matching method should be avoided - a better idea is to use the TIN method. In addition to providing a realistically-looking visualization, the method has one more important advantage - it is 4 times faster than the surface matching method.

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1. Introduction

Laser scanning is becoming increasingly popular in many areas of life and science, including construction, land surveying, quality control in industry and aviation, archaeology, art and forensic science.

Architecture and construction use laser scanning for building surveying purposes. It is particularly useful in obtaining data on buildings with a complex structure, abundant in ornamentation or in a bad state of repair. An on-site survey conducted using a measuring tape or range finder does not always give the desired result and may be difficult or dangerous. The 3D data provided by a scanner is very precise and allows representing an object with high accuracy and detail. It has recently proven particularly useful in reverse engineering, a method allowing for creating digital images of physical objects. This method consists in digitizing objects located in a physical space by means of 3D scanning and other engineering methods to create their virtual models. Reverse engineering consists in gathering geometrical data about objects, creating their geometrical models and converting the data into a CAD [1,2] compatible format. An important part of the entire process is taking the measurements and processing the collected data, therefore, it should be of a good quality.

2. Field measurements and data processing

The measurements were taken using a C10 ScanStation by Leica. In order to make the most of the scanner, complex elements of a veranda were selected and scanned at a medium and the highest resolution. The quality of measurements has an influence on the density of data presented in the form of a point cloud comprised of points with *XYZ* coordinates (in the local coordinates system of the device) and with a reflection intensity coefficient *I*. Additionally, the device allows for taking pictures which can be superposed over a point cloud and add colours to the measured object. This data was useful in applying reverse engineering, in particular, in creating a model of very complex, sculpted architectural features of the veranda. Creating a model of an object depends not only on the amount and quality of digitized data, but also on the geometrical representation method based on an interpolation of points allowing to create surfaces and structures [3, 4].

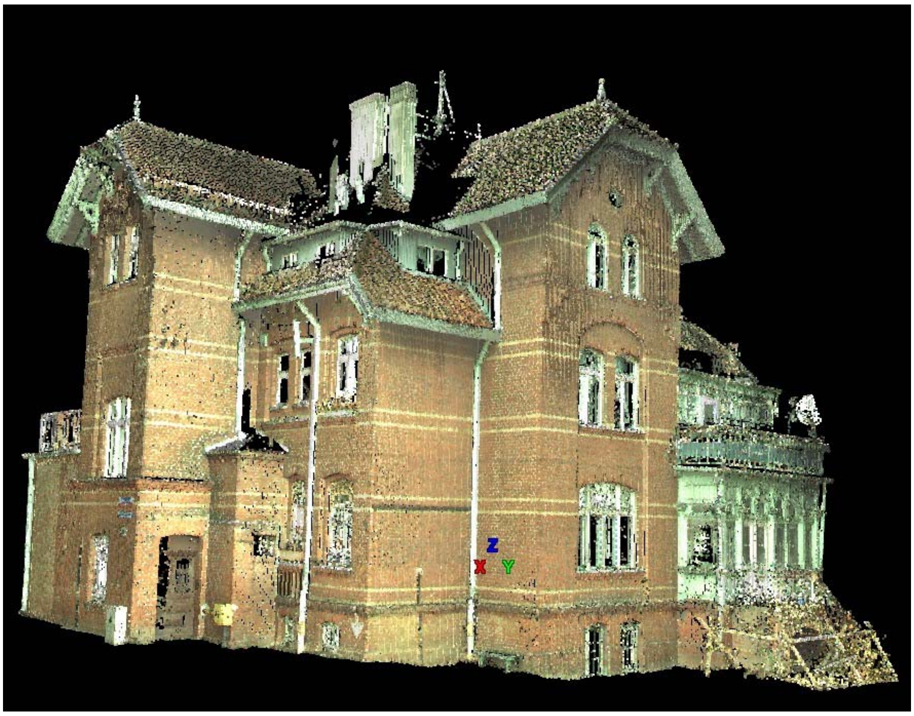

Figure 1. The villa following digitization - a point cloud with photographs superimposed over it

The building chosen for the survey has two floors, a basement and an attic. It is situated in the north-eastern part of the University of Warmia and Mazury campus. A home to a mental hospital before WWII, the campus is currently a conservation area. Originally, the building was a villa inhabited by the head of the hospital. It is made of brick and has a protruding base. Its façade is made of red, ceramic bricks and ornamented with yellow ceramic plates arranged in stripes, and features a solid pointing. It was built on a polygonal plan and has an avant-corps stretching along the longitudinal and the transverse axis. The building consists of three parts and has a staircase and a vestibule in the central avant-corpse. The side parts of the building house apartments. The building is divided by the avant-corpse structures and some of its walls are set back. The building has a veranda located in its eastern corner, featuring a very complex, ornamented wooden structure. It has a richly ornamented mixed-type roof. The roof is covered with pantiles and slants at an angle 45°. The building is generally in a good state of repair, although some of its elements, including the veranda, require repair and renovation. Figure 1 shows the building following digitization with superimposed photographs (Figure 1).

A wooden, richly ornamented fragment of the wooden veranda was chosen for the analysis (Figure 2). Figure 3 shows a fragment of the façade with an area measured at a medium and high resolution. This data was used to create a model of the object in two versions, more and less detailed, respectively. The bright fragment visible in the figure results from taking the measurements at a high resolution, resulting in a greater density of points in a particular spot. The differences between the resolutions are shown in Figure 4, displaying the differences between the digital image (Figure 4a), a point cloud scanned at a medium resolution with photographs superimposed over it (Figure 4b) and a point cloud scanned at the highest resolution with photographs superimposed over it (Figure 4c).

Figure 2. A digital image of the veranda

3. Representing architectural features based on a point cloud

Following digitization, all redundant data was removed from the point cloud and the cloud was subjected to modelling. For testing purposes, a selected part of the veranda was modelled by means of two methods: surface matching and Triangulated Irregular Network (TIN). Both modelling methods were applied in the case of data collected at a medium and the highest resolution.

Reverse engineering based on data obtained at a medium resolution

The model created by means of fitting in surfaces displays poor-quality images of small architectural features (Figure 5). This method allows for representing only bigger elements, which can be shaped by introducing surfaces based on selected points.
Unfortunately, this method does not allow for representing sculpted features, even using the highest measurement parameters, as a surface won't fit in the numerous cavities of these features.

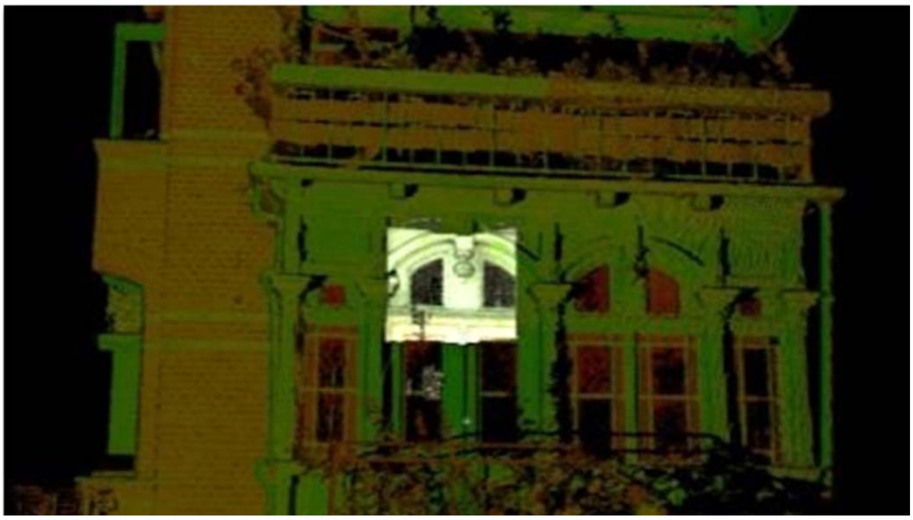

Figure 3. A fragment of a wall and architectural features scanned at two resolutions: the brighter spot is a scan made at the highest resolution

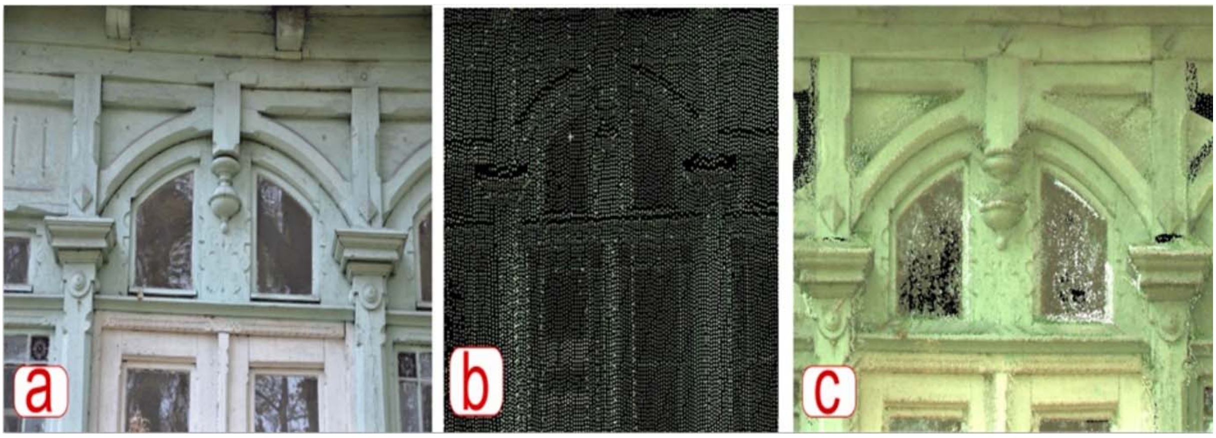

Figure 4. A fragment of the richly ornamented wooden veranda: a) a digital image, b) a point cloud with superimposed medium-resolution images, c) a cloud point with superimposed highest-resolution images

The TIN-based model, in turn, shows that although the measurements were taken at a medium resolution, this fragment of the veranda was represented quite clearly (Figure 6). The interpolation between the points was performed in such a way as to represent the architectural details with as much precision as possible. The sculpted ornaments described above are impossible to represent due to insufficient scanning accuracy (the distance between particular points in the cloud was app. 3 cm).

Reverse engineering based on data obtained at the highest resolution

Obtaining high resolution data, unfortunately, takes six times as long as obtaining data at a medium resolution. However, if detailed models of certain features are required, a good idea is to take one's time and apply the high resolution to obtain as precise data as possible. Creating models based on an accurate point cloud significantly facilitates and accelerates the processing work, and the data obtained this way helps create digital images of even the smallest features which would otherwise be impossible using measurements taken by means of the traditional methods. Resolution, however, is not the only factor that has influence on the scanning accuracy. What also matters is the position of a scanner relative to the scanned object. The best solution is to position the device as close as possible to the object to ensure that the laser beam is perpendicular to it.

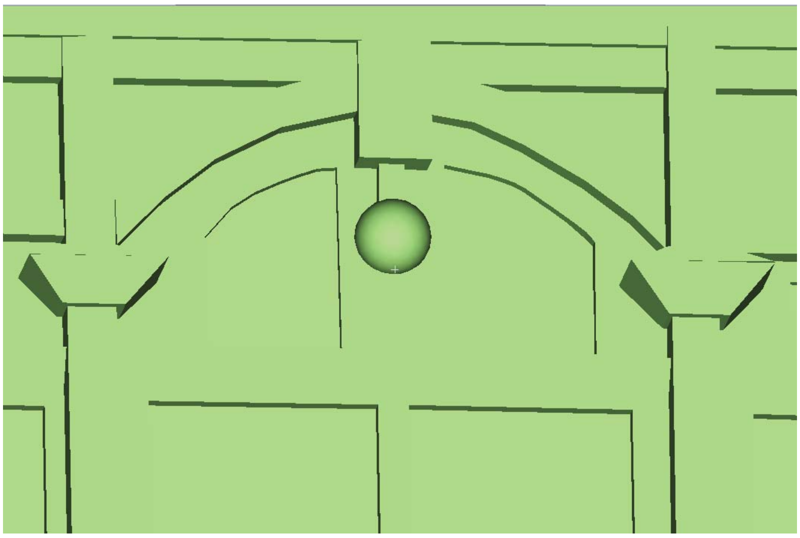

Figure 5. A model of a fragment of the veranda created based on a point cloud measured at a medium resolution

Figure 6. A model of a fragment of the veranda created based on the TIN method - the point cloud measured at a medium resolution

A very accurate point cloud allows for representing particular elements by means of the surface matching method to the extent to which it is possible to create a surface between the selected points. As shown in figure 7, a dense point cloud allows for representing numerous features and ornaments (Figure 7). Detailed features can also be modelled using the TIN method, which is also a good way of showing those ornaments which cannot be represented by means of surface matching.
The TIN method allows for creating very realistic and detailed models of richly ornamented objects (Figure 8). This method can be used to represent even the smallest architectural features (Figure 9).

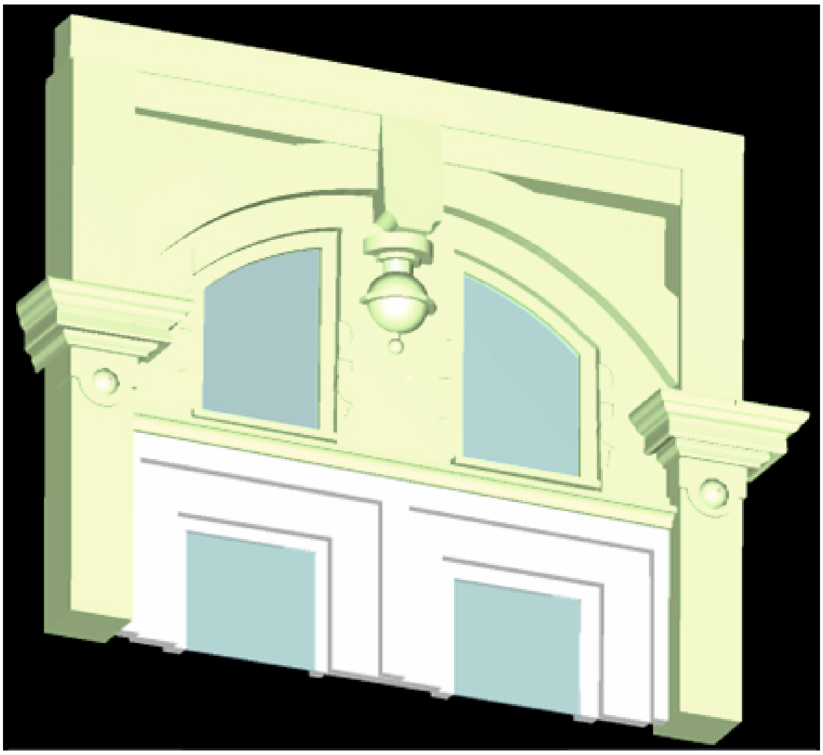

Figure 7. Models of architectural features created using the surface matching method on a point cloud measured at the highest resolution

Figure 8. A model of a feature created using the TIN method on a point cloud measured at the highest resolution

Figure 9 shows a fragment of a sculpted element with a superimposed TIN network (Figure 9) and the actual element shown in a digital photograph for comparison (Figure 9b). The image shows cavities, however, their pattern is not very accurate because of the too big an angle of the laser beam incidence, preventing the laser beam from penetrating the narrow cavities.

4. Summary and conclusions

A point cloud created by means of terrestrial laser scanning allows for creating 3D models of elements of a building and its architectural features. This way one can produce its visualization or reproduce the technical documentation of its particular elements. This way one can also recreate damaged elements, which would be very difficult, time-consuming and complicated using the traditional methods.

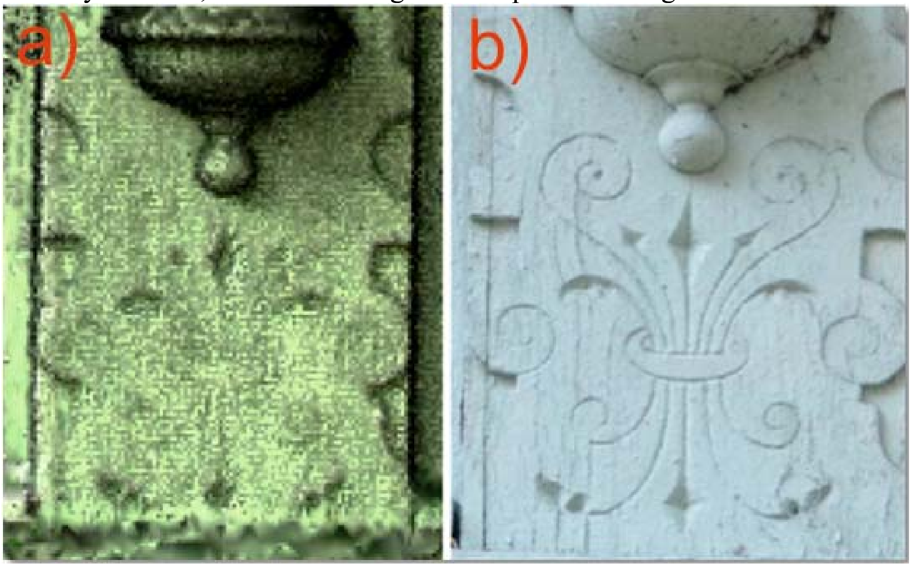

Figure 9. Modelling a point cloud at the highest resolution:
a) on the left - representation of architectural features by means of the TIN method
b) on the right - digital image of architectural features

Creating good models requires highly accurate field data. It is important to properly choose the distance between the measuring station and the measured object in order to ensure that the angles of incidence (horizontal and vertical) of the laser beam are as straight as possible. A 3D laser scanner provides very important data at a high resolution. This technology is very important in representing very complex and delicate architectural details. The highest resolution allows for precise representation of even the smallest architectural features, otherwise impossible using a medium resolution. These differences are visible in figure 6 and 9. The image shown in figure 6 is of a poor quality; only the bigger, basic elements of each detail are clearly visible, while the smaller ones are blurred. This is why in order to obtain data sufficient to represent architectural details laser scanning should be performed at the highest resolution. In addition, modelling by means of the surface matching method should be avoided - a better idea is to use the TIN method. In addition to providing a realistic visualization, the method has one more important advantage - it is 4 times faster than the surface matching method.

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