APPLICATION OF REVERSE ENGINEERING IN MODELLING OF RURAL BUILDINGS OF RELIGIOUS WORSHIP

Joanna A. Pawlowicz, Elzbieta Szafranko
University of Warmia and Mazury in Olsztyn, Poland
jopaw@uwm.edu.pl, elasz@uwm.edu.pl

Abstract. The Polish countryside boasts numerous beautiful and historic buildings of religious worship featuring sophisticated design and rich detail. Unfortunately, time and lack of funds for renovation result in their deterioration and damage. In the Polish countryside there are many churches that need protecting from falling into oblivion and damage. Reverse engineering allows to recreate the shape of a building in the form of a digital 3D model. Application of laser scanning allows to gather digital data, which can later be used to create a 3D model of a rural church. One advantage of laser scanning is that it allows non-invasive gathering of highly accurate data and recreating nearly all details of a building. This way a database and technical documentation related to a building can be created, which is very practical, especially given that in many cases the original technical documentation of historic buildings or rural sites of religious worship is no longer available. This study presents the results of efforts aimed at creating a model of a part of a rural parish church on the basis of a point cloud obtained from a land survey performed by means of the TLS method (Terrestrial Laser Scanning) and reverse engineering. The study presents the way in which data were digitized, resulting in the possibility to build a spatial model of the researched building.

Keywords: Terrestrial Laser Scanning, point cloud, listed sites.

Introduction

The terrestrial scanning technology is used to automatically obtain raw spatial data of real objects in the form of a 3D point cloud constituting a point of reference for subsequent modelling using appropriate software. By measuring polar coordinates of individual points, laser scanners inscribe them in a 3D space. Each point is represented by at least three coordinates *X, Y, Z* referred to the local scanner system. In addition, the scanner also registers the intensity *I* of the reflection of the laser beam marked [1; 2] as the fourth coordinate.

At each measurement point, the laser scanner produces a set of data called a scan. A single scan is usually not enough to gather information about an entire object subjected to research. One should then determine the quantity and location of measurement points allowing to visualize the object. Data from each point are filtrated and oriented. Filtration consists in clearing point clouds off of any surrounding elements, which were not intended to be included in the measurement, such as trees, cars or people [3]. Orientation, in turn, is a process of spatial integration of a few scans into a single point cloud using binding elements in the form of signals arranged prior to measurement. Their application allows for scans from all measurement points to be combined into a coherent whole.

This way a comprehensive set of data is obtained, free of any noise recorded in the local coordinate system of the instrument. Additionally, coordinates may be taken for at least three control points using classic measurement methods, such as the GPS. This allows for spatial transformation and conversion of coordinates of all points measured in the local system in which scans were recorded into the global system [4].

The data in the form of an oriented and cleared point cloud are modelled using appropriate software to arrive at complete information on the actual geometry of a researched object. Obtaining data by means of a 3D laser scanner is often referred to as digitization, whereas the device itself is frequently called a digitizer. The digital image of a researched object is generated as a result of application of the so-called reverse engineering. In order to obtain additional visual effects, the image may be processed to arrive at a modelled object [5].

Reverse engineering allows to create an image of a real object in a virtual space. The name reflects exactly the sequence of activities performed, i.e. first we have a physical, real object, which is digitized and placed in a virtual reality. Reverse engineering covers activities related to collecting geometrical data of objects, recreation of the geometry of a measured object and processing of the data to arrive at an image supported by CAD systems [6; 7].

Characteristics of the researched object

The measurements were taken in the village of Klewki in the Warmińsko-Mazurskie province of Poland. The building subjected to the measurements was the St Valentine's and Roch's church, a listed, countryside church. The original building was erected around 1352, however, it burnt down at the beginning of the 15th century. The church was rebuilt, but burnt down again in 1718. During the rebuilding process its windows were redesigned. In 1829 the building was subjected to another alteration, which included the erection of a wooden tower. The church features buttresses, i.e. vertical supporting structures, which transfer the load of the building to the ground and reinforce its walls. This gothic church is made of bricks and field stones. The wooden tower is adjacent to the eastern side of the building, while the sacristy to its northern side (Fig. 1).

Fig. 1. **Eastern facade of a rural church in the form of a point cloud with superimposed photographs**

Fig. 2. **Eastern wall in the form of a point cloud, including photographs**

The building features rich architectural details, hence, the issue of reverse engineering is discussed herein based on the eastern wall of the building. The building consists of two floors, the separation between which is enhanced by a cornice on the facade. The ground floor is shaped like a rectangle. On the left-hand side, a supporting stone structure extends beyond the wall. The lower part features irregularly arranged field stones. The triangular part of the first floor features a spirelet with a bell, two turrets on the sides, and a main cornice running along the roof line, made of bricks and ceramic blocks. The wall of the ground floor part features two reveals with stained glass. The wall of the first floor features plastered blind windows, different in terms of size and shape (Fig. 2); each of the plastered recesses is bigger than the previous one, starting from the outer side and toward the axis of the facade. The biggest ones feature 4 stained glass windows, two per each recess. At the top of each blind window there are bricked, arched lintels.

Creation of a model based on a point cloud – methods and tools

The data were collected in the summer of 2014 using the Leica Scanstation C10 scanner. The measurements were taken at 8 points arranged around the building, and 14 points inside it. The data were processed using a few programmes available on the market. Cyclone by Leica and ReCap by Autodesk were used to link the measurement points and clear the scans. A selected part of the building was isolated in the form of a point cloud and exported to Revit by Autodesk, where the object was modelled. The cloud was blocked in such a way as to prevent it from changing its original orientation against the model created. The zero level was determined as being equal to the ground level, along with the other required levels and axes. Thanks to the determination of levels, the cloud can be cut, so that they can be treated as reference levels for the purposes of verification of different parameters, e.g., the depth of the window reveals or the thickness of the walls. The wall surface was relatively easy to model, as opposed to the brick cornice between the floors. The so-called shadows were encountered in the cloud during its modelling, which means that it was incomplete, and that points representing the upper surface of the cornice were missing. This resulted from the scanning angle (at a right angle, from bottom to top). The laser beam was unable to reach this spot, hence the shadows in the point cloud (Fig. 3). This problem was fixed by using the processing software capabilities and by using a new shape based on the known cross-section of the cornice. The point cloud was limited in such a way as to bring out the shape of the cross-section of the cornice (Fig. 4), thus allowing to draw an approximate outline of its edge along the line formed by the points, and to model a three-dimensional shape.

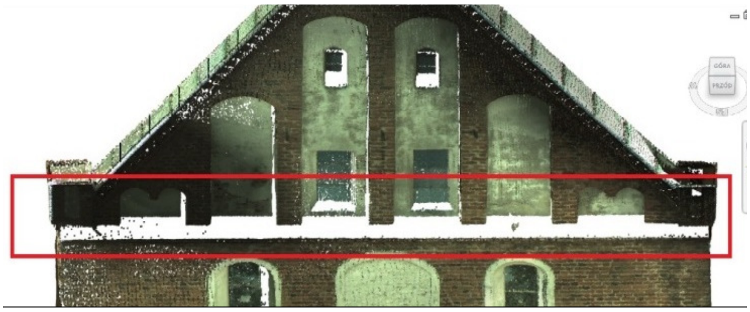

Fig. 3. **Cornice - shadows in the point cloud on its upper surface**

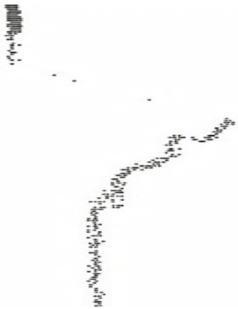

Fig. 4: **Vertical section of the cornice created from the point cloud**

Another difficult element to model was the stone and brick buttress. It required creation of horizontal contours placed 15 cm apart to create a 3D image of it. Fig. 5 shows one of these levels.

Fig. 5. **Horizontal contour running across the cloud at 75 cm**

The horizontal plans of the point cloud created this way represented a system of points at a given level (Fig. 6). Subsequently, at each level the points from the cloud were connected to a line, as a result of which, after superimposing each consecutive level on the previous one, a contour model of the buttress was created (Fig. 7).

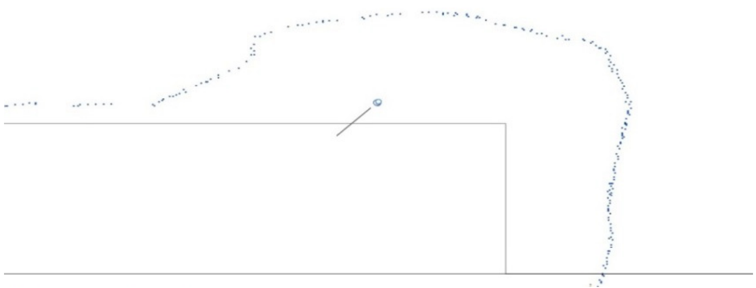

Fig. 6. **View of a 10 mm point cloud slice at the height of 75 cm**

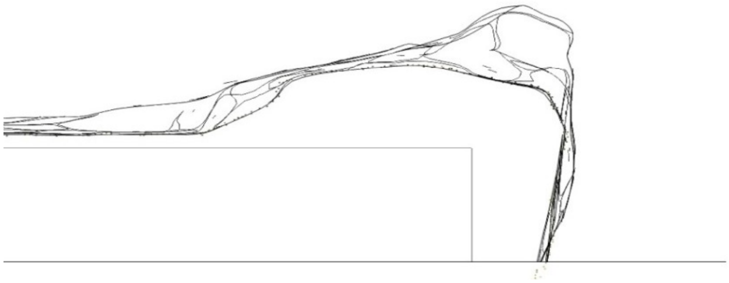

Fig. 7. **Contours representing the stone and brick buttress**

As a result of repeating this activity, several dozen closed envelopes were formed to represent at a given level a system of points at a given height. Subsequently, all envelopes were marked and the shape was modelled (Fig. 8, 9). The envelopes formed a cross-section of the shape at a given level. As shown in the picture, the smaller the distances between the contours, the more precise and closer to reality the final effect.

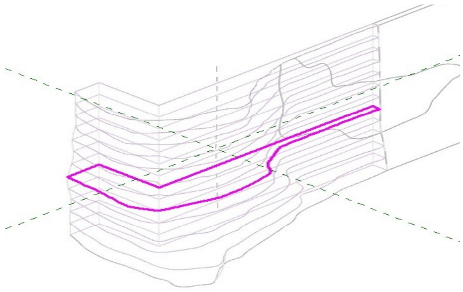

Fig. 8. **One of the envelopes forming the shape of the buttress**

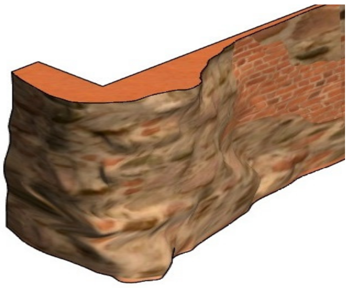

Fig. 9 **Modelled shape of the buttress**

The wall of the first floor with the arched lintels situated over the plastered recesses and the roof cornice crowning the floor wall were processed using the software functions described above. The other architectural elements of the eastern facade, i.e. the two turrets situated on the sides of the wall, the spirelet with the bell and the flashings at the top of the floor wall were modelled the same way.

The model was then subjected to visual processing based on the previously taken pictures of the church. This was done based on the filling palette created out of the pictures, which allowed to obtain an image of the object very close to reality. As a result of rendering, a realistic photographic view of the object was created (Fig. 9).

Fig. 9. **Digitized eastern facade of the church**

Summary and conclusions

Laser scanning gives the possibility to obtain detailed images of even the most complex shapes. Ancient countryside churches often feature complex shapes and a huge number of decorations that would be hard to measure using the classic methods. One of the advantages of the TLS method is that it does not require daylight and may be applied also at night. The device itself is mobile and can be used in almost every spot.

Despite the many advantages of the use of the laser scanner in the data collection about building objects and using them in reverse engineering, you should also mention about the shortcomings of this technology. The accuracy and detail of the measurement depend on the weather conditions. Rain or snows cause splitting of the laser beam, therefore the scanner collects a lot of non-existent data. Modeling scans can be carried out only after cleaning the point cloud of unnecessary data. Furthermore, the efficiency combination of scans from different measurement stations has a large impact on the final result. In the rain, the measurement may be affected by a large measurement error. However, summing up we can say that 3D laser scanning is a technology of the future and with great development potential.

Laser scanning and point cloud digitization is a very good way of creating virtual images of a building. The results obtained in this non-invasive way can be used to recreate the missing technical and design documentation for a listed building. As shown in this study, a highly accurate instrument provides data, which not only allow to recreate the spatial geometry of a building, but also the architectural details of its facade. This technology is worth following. The constantly improving software and the increasing availability of scanners will certainly result in the laser scanning method and reverse engineering being used to a greater extent in different areas of science and life.

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