STUDIES ON THE USE OF TERRESTRIAL LASER SCANNING IN THE MAINTENANCE OF BUILDINGS BELONGING TO THE CULTURAL HERITAGE

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ABSTRACT
Within the frames of the use of terrestrial laser scanning we find numerous examples of registration of building facilities, including also historical and valuable in their culture. In the case presented in this paper, at the root of the problem there is a preservation of the historic blacksmith's forge located in Gdansk Orunia. The facility dating from the early nineteenth century was intended to repair involving the complete demolition and rebuilt in the historical form but with the use of new materials. Only selected elements were to be retained, creating a kind of architectural artefacts and handicrafts.

Implementation of the laser scanning was carried out in a conventional manner, though in difficult field conditions. The obtained data have become good material to carry out analyses concerning construction and surveying. The paper presents results of studies on using laser scanning and possible problems which can appear during measurements and data processing. It also indicated solutions for proliferation of the data and models based on point clouds.

Keywords: archiving of cultural heritage, arcaded house, terrestrial laser scanning, database, point cloud

INTRODUCTION
Cultural heritage is an important factor in the life and activity of every human being. It provides material and spiritual achievements of previous generations, as well as achievements of our time. This means the value – tangible and intangible – delivered by ancestors and defining our culture. It includes all environmental effects arising from the interaction between humans and the environment throughout history.

Protection of cultural heritage is UNESCO’s task, under which Member States shall introduce appropriate legislation and technical issues. In Poland, one of the examples of
such actions include: programs conducted by Ministry of Culture and National Heritage (e.g.: "Protection of archaeological sites", "Protection and the digitization of cultural heritage"), activities of local government units in order to revitalize the historical objects of particular importance to local communities. For this type of activity latest innovations and technologies are used. One of them is the terrestrial laser scanning technology. Its main advantage is a short measurement time, high accuracy of obtained data and no necessity of direct contact with the scanned object. In most cases, laser does not affect the condition of the object. Nonetheless, it should be mentioned, that some discolouration may occur if there is a polychromy on scanned object. It is a result of interaction of laser beam and colouring agent used in polychromy.

Result of laser scanning is a relatively large number of data, so-called cloud points. A point cloud is a set of points with XYZ coordinates, measured in 3D space. A point cloud is used to develop many types of products such as 3D models, profiles, cross sections etc. by applying different types of software. It is also possible to perform measurements on the object, preparing technical documentation of scanned objects, carrying out various analyzes of the entire object or its fragments. Undeniable advantages of scanning are the reasons why this technology has been used in many different fields of science and technology such as: the inventory of industrial technical infrastructure, monitoring of works relating to transport infrastructure, monitoring of underground tunnels, analysis of changes in river-bed of meandering river, the study on high-voltage lines and many others [1-5].

In the article, authors focus on the use of laser scanning for inventory task of cultural heritage object - suburban building with forge entered into the Register of Immovable Monuments of the Pomeranian Voivodeship (Poland). Authors identify and diagnose problems encountered that may arise in such works. They also discuss about the publicity of data to a wider audience as a necessity resulting from the interoperability of science, services and business.

**STUDY OBJECT**

The object of the study is a historic suburban house with the forge, located in Gdansk Orunia, 10 Goscinna Street. In 1983 it was entered into the Register of Monuments. Goscinna Street formerly constituted the central square of the village. Around it, the most important monuments of the estate were situated – St. John Bosco from 1823, Villa Widow Peters (now the post office) and the pre-war town hall district. Forge building was built in 1801 and the mid 50's became the blacksmith's workshop. Subsequently, until about 2010, it has exclusively a residential function.

Due to the deteriorating condition of the facility and social activities related to it, program of its redevelopment and change of use began in 2011. It included complete reconstruction and maintenance works in order to create the Activation Centre and Innovation "The Forge". Laser scanning measurements were conducted before renovation.

The forge is a unique facility for both Gdansk and the region. It is in fact the smallest surviving example of local arcaded house. The property was built in post and beam structure - supporting function had wood components – horizontal beams, foundations and top plates, between which vertical beam – columns are stretched. The space
between the timber is filled with bricks – a non-structural material, whose functions is to stabilize and stiffen the whole construction. Before renovation, the wooden skeleton was partially visible. It was covered with a layer of white plaster with visible defects exposing brick. On the tops, the wooden structure was visible. The property is located with the ridge to the road. Its dominant component is a small arcade. It was placed asymmetrically on the right side of the building. It also has a skeleton structure with brick filling. Extended canopy is about 4m from the face of the building. Three wheeled pillars support a small, wide and approximately 3m granary. In the front part there is a window opening. The height of the arcade is equal to the ridge of the building. It is covered, like the rest of the object, with a pitched roof with shingles. The left side of the object is immediately adjacent to a neighbouring building with flat roof, which limited the capacity to perform a full scan.

Today it is The Activation Centre and Social Innovation "Forge" conducted by the Association of Local Initiatives "Orunia" [6]. It is a place dealing with complex overtones of social activities that aim to revitalize the center of Orunia and boost its tourist and education offers (Fig. 1). Other tasks are: to raise the level of protection of the environment and cultural heritage, to counteract negative social phenomena, together with the strengthening of social capital of district and to support of local NGOs and developing more effective forms of cooperation in the implementation of urban revitalization program.

Fig. 1. The Forge – before (scan) and after renovation (photo)

OBJECT REGISTRATION AND DATA PROCESSING

The Department of Geodesy from Gdansk University of Technology and the Municipal Property Management of Gdansk in co-operation with representative of Leica Geosystems and I-NET.PL companies, on December 2011 conducted laser scanning measurements of the Forge for its inventory. The project involved the whole building and its surroundings. Measurements included the inside of the building: the ground floor apartment with preserved relics of the furnace, the forge and the attic with the room above the arcade, and the oldest part in the form of brick-earth basement. The object was prepared for demolition, which caused technical difficulties in locating the positions of the scanner (partial lack of flooring, ceiling with limited capacity, vibration of the object). However, interference in the building caused by the conservators resulted in the unveiling of important structural elements that have been scanned (beams under the floor, the structure of the walls, and structural support elements).
The model was developed by using scans from 21 stations. The layout of scanner stations are presented on inventory plan [6] (Fig. 2).

Fig. 2. The layout of scanner stations (created by means of KeyPlan - option available in Cyclone software); Station-012 and Station-013 are emphasized because of further analyses

Condition of the building – especially the windows, covered with wood panels, very limited space inside and outside of the building, narrow access to the attic – resulted in extra care when targets were placed. Despite the effort, there were stations not connected with others (e.g. the last scan was not associated with more than one scan). Moreover, there have been situations (e.g. Station-013 and Station-014), when it was necessary to eliminate the constraints due to errors in the target identification on individual scans. The analysis of such case is shown in Fig. 3: Fig. 3A shows the top view of the relation between two scanner stations. Fig. 3B shows view of the wall with 4az and 9z targets. Identification errors of these targets are presented in Fig. 3C and Fig. 3D, respectively. The close position to the walls and open spaces behind stations of the scanner resulted in the need to create registration with targets located on walls, where scanning angles were sharp (about 15-20 degrees). Conducted analysis resulted in
elimination of 4az and 9z targets. It has improved the accuracy of combining scans of more than 10cm to 2mm.

For this project free stations has been chosen, thus coordinate system was local. Black-white targets were used during measurement. Because of the planned demolition in a few days, the forced rush resulted in some problems like: difficulties with elimination of duplicate targets ID, unnecessary targets, not optimal relations between targets for two or more scanner stations. Additionally, there was no power supply, so the lighting was supported by power generator. Loss of energy in the generator caused the appearance of dark fields on the part of the picture to one of the scans (Fig. 4). While halogen lighting caused a problem due to the high power: at one scan images are overexposed to the point that the complementary scanning was performed (Fig. 5).
The problem with old and neglected building is their high dirt. There are areas covered with excrescences and natural substances (animal faeces, cobwebs, dust), which not only directly restrict access to the building fabric, but do affect the accuracy of the development and scan registration (Fig. 6). In such cases, particular importance is the use of customized filtration methods, but large part of the work done within the project means manual removing of unnecessary points from scans. Natural and obvious solutions is earlier cleaning up the object, but there are situations that such activities are not possible, because of safety, health, or the limited access time to the object.
In the case of automatic filtration moment of its performance must also be taken into account. Generally, in the case of original ScanWorlds there is no problem with viewing the scans and indicating areas which need cleaning and filtration. However, the 3D model are generated from raw scanning data, and the cleaning and the noise removing are done on the created model. This process is the easiest to implement in uniform environment. However, often various softwares are used. Therefore the technological limitations should be taken into consideration. For example, after using Leica Geosystem Cyclone unification the point cloud can be only export in .pts format. It does not contain the original information about point cloud (e.g. X,Y,Z, intensity). While the file format .ptx can be used for exporting not unified point cloud with more information, like RGB. Format .las or .laz relies on the compression of data contained in .ptx or .pts. The problem of optimization and filtering of data is subject to studies and articles [7,8]. In the project associated with the forge such algorithms were used for improving access to model of the forge via Internet and intranet.

Scans registration was mostly based on method where targets are used. “Cloud to cloud” method was applied only in case of basement area. Vector error of scans registration dx, dy, dz in first method did not exceed 2 mm, In case of "cloud to cloud" method, errors ranged up to 1 cm.

Tab. 1. Juxtaposition of constraints, used in 3D model development (IDs are consistent with the description in the article and digital database, to which URL address is given at the end of this study)

<table>
<thead>
<tr>
<th>Station</th>
<th>Targets (constraints) included in registration</th>
<th>Targets rejected after analyses / without relations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1dp,2dp,3dp,4dp,5dp,6dp,7d,8d</td>
<td>7d / -</td>
</tr>
<tr>
<td>3</td>
<td>3dp,4dp,4gk,7d,10d,11d,15dl</td>
<td>14d / -</td>
</tr>
<tr>
<td>4</td>
<td>1dk,3dl,4dl,5dl,7d,9z,11d,14d,15dl,21ad</td>
<td>8d / 2dl,20dl</td>
</tr>
<tr>
<td>5</td>
<td>3dl,4dl,5dl</td>
<td>- / -</td>
</tr>
<tr>
<td>6</td>
<td>1dk,3dl,14d,16,18,21ad,22ad</td>
<td>- / 19d</td>
</tr>
<tr>
<td>7</td>
<td>2s,3s,4gk,5s,14gk,15s,16,18,Xs</td>
<td>- / -</td>
</tr>
<tr>
<td>9</td>
<td>2s,3s,13gk,14gk</td>
<td>- / 1s,20s</td>
</tr>
<tr>
<td>10</td>
<td>5s,13gk,15s,18,Xs</td>
<td>14dk / -</td>
</tr>
<tr>
<td>11</td>
<td>5s,15s,16s,17s,18s</td>
<td>- / -</td>
</tr>
<tr>
<td>Station-001</td>
<td>1dp,2dp,5dp,6dp</td>
<td>- / -</td>
</tr>
<tr>
<td>Station-004</td>
<td>3dp,4dp,7d,8d,10d,11d,12d,13d</td>
<td>19ad / 2d,3d,5d</td>
</tr>
<tr>
<td>Station-005</td>
<td>11d,18, Xdf</td>
<td>22a / -</td>
</tr>
<tr>
<td>Station-006</td>
<td>4az,11df,14d,16,18,21ad,22ad,23az,2az,Xdf</td>
<td>- / 10df</td>
</tr>
<tr>
<td>Station-008</td>
<td>3az,5az</td>
<td>24az,7az / -</td>
</tr>
<tr>
<td>Station-009</td>
<td>3az,4az,5az,6az,7az,24az</td>
<td>- / -</td>
</tr>
<tr>
<td>Station-011</td>
<td>3az,5az,7az</td>
<td>12az / -</td>
</tr>
<tr>
<td>Station-012</td>
<td>4az,6az,9z,12az,23az,24az</td>
<td>- / -</td>
</tr>
<tr>
<td>Station-013</td>
<td>1az,2az,8az,9az,10az,12az</td>
<td>4az,23az,24az / 8az</td>
</tr>
<tr>
<td>Station-014</td>
<td>1az,2az,7az,8az,10az,12d,13d,Xp</td>
<td>- / -</td>
</tr>
<tr>
<td>Station-017</td>
<td>10d,Xp</td>
<td>- / -</td>
</tr>
<tr>
<td>Station-018</td>
<td>3dp,5dp,6dp</td>
<td>- / -</td>
</tr>
</tbody>
</table>
Tab. 2. Project characteristics – features that represents the quality and range of source material.

<table>
<thead>
<tr>
<th>Project name orunia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object name                             Forge Orunia, Kuznia Orunia</td>
</tr>
<tr>
<td>Address of the object                   St. Goscinna 10, Gdansk, Poland</td>
</tr>
<tr>
<td>Location of the object                  54°19'22&quot;N 18°37'57&quot;E</td>
</tr>
<tr>
<td>Type / model of scanner                 Leica ScanStation / C-10</td>
</tr>
<tr>
<td>Certificate                              yes, certified by the manufacturer</td>
</tr>
<tr>
<td>Medium resolution in 100m [m]           0,01</td>
</tr>
<tr>
<td>Medium resolution on object (from-till) [m]          0,007</td>
</tr>
<tr>
<td>Scan coverage of object                  95%</td>
</tr>
<tr>
<td>Did photos were taken?                   yes, 99%</td>
</tr>
<tr>
<td>Coordinate system                        local</td>
</tr>
<tr>
<td>Number of stations (appropriate for further processing) 21</td>
</tr>
<tr>
<td>Number of levelled stations              21</td>
</tr>
<tr>
<td>Levelled model                           yes</td>
</tr>
<tr>
<td>Vector error (dX, dY, dZ) for 3D model medium/worst [m] (0.002, 0.002, 0.001) / (0.005, 0.006, 0.005)</td>
</tr>
<tr>
<td>Raw dataset                              .bin</td>
</tr>
<tr>
<td>Datasets in form of combined scans       .imp &amp; SiteMap</td>
</tr>
<tr>
<td>File formats available in dataset       .imp, .bin,</td>
</tr>
</tbody>
</table>

The above analyses are based on results of recording. However, due to its wide range, details were not presented here. They are available in digital database, to which the link is provided at the end of the article. It enables other types of analyses within the Project (e.g. analysis of historical methods of bricks assembling and their size, connecting wooden structures, recording accuracy analysis, verification of reconstruction correctness, remote elaboration on the revitalization methods, construction of the object copy at the point distant from the location). Table 1 and Table 2 include some part of this information, significant for creating the model of the forge.

After detailed analyses of each point cloud, results of registration based on selected constraints were saved and subsequently 3D model of the forge was developed. This model was then the subject of analysis in the context of other engineering study, for example: analysis on vertical deviation of front wall with the arcade, deformities and defects of the walls (Fig. 7). Authors also indicated the possibility of the creation of technical documentation on the basis of data from scanning (Fig. 8).
The levelled scanner stations were used. Hence, despite the measurement in the local coordinate system, the resulting 3D model of the forge was also levelled. This allowed to undertake additional analyses referring to tilting from vertical and structure instability.

Fig. 7. Fragment of a deformation map (the brighter color, the deeper points are located)

Fig. 8. The front wall of the building: point cloud and design of construction – the geometry analysis was presented along with the verticality and the possibility to prepare technical documentation on the basis of scan was indicated
Other issue is the publication of the 3D model. Leica Geosystems enables it by the TruView option (Fig. 9). It not only gives the opportunity to view the model but also allows to analyze its geometry. For objects of cultural heritage, like the forge, virtual tour in the facility before the renovation brings additional effect of the project on the local environment.

![Fig. 9. Measurements on model in Leica Geosystems TruView](image)

Scanning of objects is more and more frequent. It is conducted not only for facilities very important for the world cultural heritage, but also for ones valid only for local communities, such as the Forge in Gdansk Orunia. The reason for this is the proliferation of scanning technology, and the result is the emergence of numerous data sets and gradually extended access to it. Such data sets are not publicly available mainly due to its volume. However, there were few attempts to build scans database. The authors, whose have made efforts to develop an online database for studies on close-range photogrammetry [9,10] in 2004-2006. Now they start work on creating and making available for users laser scanning database. The material presented here is the first (2011), which supply the database and gave basis to the development of standards for the maintenance of the scans repository. Information presented in Table 2 (The Forge project – characteristics) are minimum required for a project to be put in the repository. Repository of digital data from scanning can be used by architects, conservators and other persons interested in such subjects. It can be a good source of information about methods and solution used in construction and architecture not only in the history.

**CONCLUSIONS**

Laser scanning is the one of the most dynamically developing method that each day involves more and more users. The main aspect that draw attention to the supports of this method is to determine the spatial coordinates and the execution of a faithful visualization of even the most complex objects in a very short time and with high precision. Due to its advantages, laser scanning can compete with the classic and photogrammetric methods, and often it is more and more widely used in many fields of science and engineering. In case of inventory of historic buildings, obtained data can be used to develop their digital, highly detailed and reliable 3D models. Such model can be made available to worldwide users via the Internet. Option Leica Geosystems TruView available in Cyclone allows to look more closely at the object even though there is no physical access to it. In case of sharing such data, the issue of the big data should also be mentioned. The presented analysis are only a small part of studies that can be created on the basis of terrestrial laser scanning.
A real highlight of this laser scanning project is that in a short time after scanning the forge was demolished. Currently, in the same place there is a new building, faithful to historic look. Developed 3D model is the only trace of valuable historic building.

Data obtained during laser scanning of the Forge in Orunia was the basis for two thesis in field of Geodesy and Cartography on Gdansk University of Technology [11,12].

Data saved in the project (file .imp; software Leica Geosystems, Cyclone v. 7.3.2) is available at http://www.i-net.pl/pub/skaner/kuznia-orunia/.

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[12] Rzepa, S.: Implementation of a real 3D model of historic forge in Gdansk Orunia, based on the received data (Polish: Wykonanie rzeczywistego modelu 3D zabytkowej kuźni w Gdańsku Oruni, na podstawie otrzymanych danych), engineering thesis, Technical University of Gdansk, Faculty of Civil and Environmental Engineering, Department of Geodesy, Gdansk, Poland (2012)