Application of Integrated Photogrammetric and Terrestrial Laser Scanning Data to Cultural Heritage Surveying

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Abstract. The terrestrial laser scanning technology has a wide spectrum of applications, from land surveying, civil engineering and architecture to archaeology. The technology is capable of obtaining, in a short time, accurate coordinates of points which represent the surface of objects. Scanning of buildings is therefore a process which ensures obtaining information on all structural elements of a building. The result is a point cloud consisting of millions of elements which are a perfect source of information on the object and its surrounding. The photogrammetric techniques allow documenting an object in high resolution in the form of orthophoto plans, or are a basis to develop 2D documentation or obtain point clouds for objects and 3D modelling. Integration of photogrammetric data and TLS brings a new quality in surveying historic monuments. Historic monuments play an important cultural and historical role. Centuries-old buildings require constant renovation and preservation of their structural and visual invariability while maintaining safety of people who use them. The full process of surveying allows evaluating the actual condition of monuments and planning repairs and renovations. Huge sizes and specific types of historic monuments cause problems in obtaining reliable and full information on them. The TLS technology allows obtaining such information in a short time and is non-invasive. A point cloud is not only a basis for developing architectural and construction documentation or evaluation of actual condition of a building. It also is a real visualization of monuments and their entire environment. The saved image of object surface can be presented at any time and place. A cyclical TLS survey of historic monuments allows detecting structural changes and evaluating damage and changes that cause deformation of monument’s components. The paper presents application of integrated photogrammetric data and TLS illustrated on an example of historic monuments from southern Poland. The cartographic materials are a basis for determining the actual condition of monuments and performing repair works. The materials also supplement the archive of monuments by means of recording the actual image of a monument in a virtual space.

1. Introduction
Cultural heritage surveying is a set of field and indoor works which involve the acquisition of comprehensive data on an examined object and, subsequently, its presentation in the form of 3D visualisations, cartographic studies or technical descriptions. Surveying works should particularly focus on historic monuments, which are material heritage of human culture. In order to gain comprehensive knowledge of such monuments and ensure their adequate protection, it is indispensable to survey them carefully. This process ought to entail the precise determination of their types, shapes, dimensions, geometry and spatial locations [1]. So as to acquire spatial information on historic monuments, we have for a long time been using geodetic and photogrammetric tools. However, direct methods for site and
elevation measurement, that is tacheometry, are more and more often replaced with measurements performed with terrestrial laser scanners and digital photogrammetry [2].

In their article, Arriaga and Lozano [3] describe the option for using photogrammetric data to build a 3D model of the Cathedral of Santa Maria, Vitoria-Gasteiz. The digitalisation of its respective pictures and their association with the cartographic model has allowed the creation of the System of Geographical Information about the Monument (SIM). The system was based on a range of applications using 3D meshes built with digital imagery. The reconstruction of the structural elements, furnishings, memorials and polychromy enabled the creation of a 3D visualisation of the cathedral. A variety of works and procedures provided the opportunity to build a system of light designs for the historical reconstruction of the cathedral image, its polychromy and other architectural elements.

By using photogrammetric data combined with historical knowledge of any monument, it is possible to reconstruct complex structural elements of places, monuments and small architectural elements, such as sculptures/carvings, memorials and paintings. Through the acquisition of information on items in the form of digital imagery, use of programmes which combine respective pictures, and creation of their three-dimensional image, it is possible to reconstruct the real image. Such a database allows the virtual reconstruction of damaged elements and reproduction of the entirety or part of the examined monument's structure [4], [5], [6].

Terrestrial Laser Scanning (TLS) has been more and more often used for surveying due to its speed, simplicity and precision of acquired geospatial information. A registered image of an examined object in the form of a point cloud is an excellent source of data which enables the development of comprehensive studies and analyses of any fragment of the object. A great amount of data allows the preparation of high-quality architectural documentation including: projections, cross-sections, façade views, 3D models or multimedia visualisations [7], [8]. Thanks to the use of TLS for cultural heritage surveying, complete documentation can be prepared for maintenance and restoration works, aimed at maintaining the current state of monuments and restoring their valuable architectural elements which have been damaged.

Each historic monument has a different specificity and needs a different type of surveying works. Building structures frequently require the examination of their movement and deformation of structural elements in order to monitor structural consistency. Other structures require speed, accuracy and field works due to the risk of their respective component parts collapsing. Buildings characterised by complex geometry, numerous small architectural elements, ornaments and decorations require using the technology for comprehensive data acquisition, namely TLS. Additionally, images of such elements must be transferred with high mapping accuracy to drawings requested by architects and builders. The maintenance of proper technical standards and complementarity of spatial data is possible by using the point cloud in processes aimed at developing numerous graphic studies [9].

Data used for 3D studies may come from many sources; however, in order to increase the accuracy and quality of studies, respective types of information are integrated into a uniform database. The synergy of spatial data enables the modelling and visualisation of even the most geometrically and architecturally complicated historic monuments. One of the most important aspects of the TLS information integration with photogrammetric data is the option for completing missing elements of one data pool with another. By generating a point cloud based on photogrammetric data and combining it at control points with a cloud generated by scanning, we receive control elements that allow the accuracy analysis of the completed integration; we also cross-control the two methods for geospatial data acquisition [10].

TLS data integration with pictures enables the acquisition of real models, which represent the examined object. A point cloud generated by scanning allows the creation of a 3D model, whereas pictures allow the creation of a new thematic layer to represent the texture of the created solids. This texture enables us to produce imagery of complex flat elements, such as polychromy and roof covering, or to graphically represent the material of which respective structural elements are made: brick, stone or
wood. The textured model is used for complementing the primary solid and giving it characteristics of 
the real object. Such studies are employed for the dynamic presentation of historic monuments, 
memorials, buildings, and even whole towns and cities [11], [12].

2. Cultural heritage surveying with photogrammetric and TLS data

The discussed surveying works have been carried out in the south of Poland. This region, taking into 
account the historical areas, over which Polish kings and princes reigned, is an especially important part 
of Poland due to its tradition, culture, religion and history. It is abundant with monuments, which are 
our national cultural heritage. This article describes options available for surveying monuments thanks 
to the integration of data acquired by Terrestrial Laser Scanning with photogrammetric data. 
Opportunities arising from this integration have been presented for two historic monuments: Castle in 
Będzin and town walls in Byczyna.

In both cases, for the purpose of field works, a terrestrial laser scanner was employed, with which a 
cloud of points was acquired, representing the surface of the examined object, as well as 
photogrammetric images, in order to integrate them with TLS data. The data synergy allows us to 
significantly increase the amount of geospatial information on places and objects, as well as it enables 
obtaining more accurate results of surveying works – cartographic studies, architectural and construction 
documentation, 3D models and visualisations.

2.1 Surveying of the Royal Castle in Będzin

According to the website [w1] of the Będzin Zagłębie Museum, which is the immediate supervisor and 
custodian of the Castle in Będzin, the building is an example of defensive construction from the mid-
16th century. The castle is a typical stronghold, a defensive fortification. It consists of an upper castle 
and large castle grounds, which include remnants of a defensive wall and ruins of an entrance gate. The 
upper section of the castle features a courtyard, residential building and fortified round tower. The entire 
complex is surrounded by a moat and outer wall.

The field measurement of the castle and its adjacent areas was performed with the Z+F 5010 
terrestrial laser scanner, with which the entire monument was scanned, together with its courtyard.
Additionally, complete photographic documentation was prepared in order to acquire a greater amount 
of data on the subject of the study. The data pools obtained with the two measurement methods were 
integrated with each other, thus forming one pool. Terrestrial Laser Scanning data serves as the reference 
material, providing information on the geometry of objects, their shapes and dimensions. Measurement 
is supplemented with pictures, increasing the detail level of acquired information.

The point cloud, obtained thanks to the measurement, was used for creating projections and cross-
sections of the respective structural elements of the castle and for its façade drawing (Figure 1). The 
synergy of the pictures with the cloud of points allowed us to supplement the façade drawings with 
architectural detail and information, to be exact the material of which the building and its component 
parts were made (windows, gate, wall, roof covering). Figure 1 illustrates the juxtaposition of views of 
the same part of the castle, visible in the picture, point cloud and façade drawing.
Another part of the works related to processing geospatial data involved generating a 3D model of the monument and supplementing it with architectural detail in the form of a real texture. The point cloud was integrated with the photogrammetric data to achieve the real view of the respective structural elements of the castle. Figure 2 presents only a fragment of the model. It illustrates the residential building, located in the upper section of the stronghold. The model, in the form of solids, was generated on the basis of the point cloud obtained during the measurement in the MicroStation V8i programme. The integration of the pictures – texture mapping of the solid with the pictures taken – was performed with the Descartes V8i programme from Bentley.

2.2 Surveying of the town walls in Byczyna
The defensive walls of Byczyna preserved to date were built in the 15th and 16th centuries. Some of their sections are made of crushed stone bricks, others – of glacial erratics. They consist of one row of walls, two gate towers and fortified tower. Their mean height reaches 6 m and they are 1.5 m thick. [w2]. Byczyna is one of few Polish towns whose outer walls have almost been entirely preserved. They are oval-shaped (Figure 3), and more than 900 m long.
The works were aimed at surveying the state in which the walls have been preserved for the purpose of developing the design for their further preservation. The main effect of the surveying works were high-resolution orthophotoplans – field resolution 2 mm – of the surface of the walls, allowing the evaluation of the condition of the wall face, and surface measurements. However, due to the specificity of the object of examination – dense buildings, frequently adhering to the wall, plants near the walls, oval shape (Figure 3) – the classic photogrammetric measurement would have been very complicated, labour-intensive and cost-consuming. Therefore, we decided to take advantage of the options provided by the integration of the photogrammetric measurement with Terrestrial Laser Scanning.

The obtained cloud of points for the entire wall circumference (outside and inside) allowed us to map the walls on a plane. It was achieved by dividing the walls into straight sections (limited by the blue lines in Figure 3) and – subsequently – by transforming each section onto a shared plane. Additionally, the point cloud served as the georeference for the photogrammetric images and was used for reading coordinates of natural photopoints, based on which the photogrammetric design was calculated. As a result, a geometrically consistent measurement material was obtained. Based on the processed data, orthophotoplans were generated both with point clouds and with photogrammetric data (Figure 4). Due to the conditions under which the measurements were performed and pictures taken, the orthophotoplans based on the point clouds included a fuller scope of the wall surface than those developed with the photogrammetric method, and as the final product we generated orthophotoplans combining both products (Figure 5).

The use of scanning further enabled the acquisition of additional information related to the geometry of the walls being surveyed. Thanks to their cross-sections prepared with the point cloud, it was possible to perform additional measurements, such as of: the height and width of the wall, difference between the internal and external ground levels, and its deviation from the vertical line.

During the works, we used such software as: LeicaCyclone, for processing point clouds, Agisoft PhotoScan Professional, for processing photogrammetric data, and Bentley: Pointools PODcreator, Microstation V8i with the Descartes module, for integrating orthophotoplans and performing measurements on clouds of points.
3. Results and discussions
The integration of photogrammetric data with the point cloud obtained with Terrestrial Laser Scanning has a wide variety of applications, which are more and more frequently used in geodesy, construction, architecture, archaeology and history. Surveying historic monuments with this type of spatial information enables the acquisition of comprehensive information on the actual state of objects and provides a unique opportunity to "save" the image of each object and transfer it to virtual reality.

The geospatial data obtained while surveying the Będzin Castle enabled the creation of a comprehensive cloud of points, containing all visible external structural elements of the stronghold and
its surroundings. The TLS point cloud was basis for projections and cross-sections (longitudinal and transverse) through the respective elements and drawings of the façade of this historic monument and, further, for building its 3D model (Figure 1). The photogrammetric documentation supplemented the information on the object of the study. The integration of this type of data has become very helpful, for instance in surveying the building's architectural detail and visualising its solid. Three-dimensional models textured with pictures give a better idea of the monument building than the point cloud, orthophotoplan or two-dimensional vector documentation alone. Hence combined data allows the presentation of historic monuments in a manner which directly reaches the audience. The integration of TLS data with the photographic documentation yields excellent results of works aimed at building real models of objects.

In the case of surveying the town walls in Byczyna, the integration of both data types enabled us to significantly reduce the number of works, especially field-related ones, necessary for achieving the goal – the orthophotoplans of the wall surface. Simultaneously, thanks to the use of the point cloud as the source of photopoints for the photogrammetric study, data obtained with the two techniques was homogeneous in terms of georeferences. Therefore, it was later possible to integrate the orthophotoplans developed by the two measurement techniques (Figure 5), which considerably contributed to achieving a full-fledged product. Additionally, the acquired point clouds sort of helped "along the way" to obtain information on the geometry of the object being surveyed.

The TLS technology and photogrammetry combined for cultural heritage surveying works yield excellent works results translating into high-quality studies. The simultaneous application of the two measurement methods allows cross-control; during the integration, presented information is compared, as it should form a coherent whole. The synergy of data on objects may be used for surveying historic monuments, and for acquiring information on other types of building or industrial structures [2]. Designs and works results we will find in numerous academic studies, including but not limited to: [11], [12], [13] confirm the validity of the scanning data integration with digital imagery in order to increase the quality and accuracy of developed studies.

4. Conclusions
In the case of cultural heritage surveying, the integration of photogrammetric and TLS data produces very tangible benefits. First of all, it allows the optimisation of the number of works and, therefore, study costs at the stage of both data acquisition and data processing. Additionally, it enhances the quality of developed studies, makes them more attractive and, in many cases, is the only way to achieve the complete study of an object characterised by complicated geometry or located in an area which proves difficult for classic measurements.

Drawing on data obtained by various measurement techniques is especially useful when the need arises to create a detailed and precise 3D model. Such data is later used for analysis of shapes, geometric consistency of the object or for examining the location of respective structural elements in three-dimensional space [10]. The synergy of data allows increasing the amount and quality of geospatial information about the object; furthermore, it provides the opportunity to yield more accurate results of surveying works, cartographic studies, architectural and construction documentation, 3D models and visualisations.

Acknowledgement(s)
The research was performed within the scope of status activities of the Department of Land Surveying, Department of Agricultural Land Surveying, Cadaster and Photogrammetry, Faculty of Environmental Engineering and Land Surveying at the University of Agriculture in Kraków.

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