http://dx.doi.org/10.15576/GLL/2023.4.259

GLL

Geomatics, Landmanagement and Landscape No. 4 • 2023, 259–273

3D MODELLING OF HISTORIC BUILDINGS BASED ON INTEGRATED DATA FROM AIRBORNE AND TERRESTRIAL LASER SCANNING

Bogusława Kwoczyńska, Kinga Nowak, Krzysztof Woźniak

Summary

Currently, the modelling of historic buildings is most often performed on the basis of data obtained by terrestrial laser scanning. It ensures both the speed of information acquisition and the high accuracy of the final elaboration. However, there are situations in which the terrain layout or the structure of the building limits the possibility of obtaining full information on its shape. In such situations, the solution is to integrate data from various measurement devices. In the case of creating a full 3D model of large buildings, one of the ways to supplement the data, especially the roof of the building, is to use data from airborne laser scanning. The research used the integration of airborne laser scanning data with data recorded with the Leica ScanStation P40 terrestrial laser scanner. Combined point clouds were used for 3D modelling of two different historic buildings in Krakow. Modelling was performed with the Bentley CAD software and in Leica Cyclon 3DR and 3DReshaper. The accuracy of data integration was determined and the advantages and disadvantages of using the above-mentioned software for 3D modelling of architectural objects were shown. The result of the study is a 3D model of St. Florian's Gate and the Palace of Art in Krakow.

Keywords

terrestrial laser scanning • airborne laser scanning • data integration • 3D modelling

1. Introduction

In recent years the use of three-dimensional technology to visualize architectural objects in various types of architectural and planning studies has been noticeable. This applies to both small and large architecture objects that are cultural monuments, as well as newly constructed buildings that are part of actual cities and also presented in the form of 3D models. *The 3D model of the object makes it possible to reproduce the properties as well as features of the examined object. Presenting the object in the third dimension allows architects to draw up a full inventory of complex architectural objects, including those with limited accessibility*. [Kwoczyńska 2019, p. 155].

The use of various methods and the latest technologies in geodesy depends on the needs, the scale of the examined object (or area), or the purpose of the final product. For example, if one wants to develop a detailed façade intended for technical drafting, the best way is to use a relatively new technology, such as laser scanning. This method allows to collect information about the shape and dimensions in the form of a point cloud in a very short time, with remarkable accuracy, where the error often does not exceed tenths of a millimetre. [Kwoczyńska and Małysa 2022, p. 311].

However, often the location, shape or size of an object creates a situation, where it is impossible to obtain full information about its structure. In such situations, the best solution is to integrate data from various measurement devices. *For example, to create a full 3D model of an architectural object, it is best to complete data with an unmanned aerial platform, because the resolution of images made on a low altitude is good enough to deliver a satisfactory effect in the form of a point cloud* [Kwoczyńska and Małysa 2022, p. 311]. Nonetheless, even such measures are not always possible. The solution then is to integrate data from airborne and terrestrial laser scanning. The cloud of points from airborne laser scanning provides information about the upper parts of the object (e.g. its roof) that are inaccessible from the ground level and unreachable by terrestrial laser scanning.

1.1. Aim of the article

The aim of the article is to demonstrate the possibility of using data integration of modern measurement techniques, such as airborne and terrestrial laser scanning, to create 3D models of historic buildings. On the basis of selected examples of Krakow's monuments, the concept of integrating data obtained from various altitudes, which ultimately enabled a full and accurate 3D model of the object, was presented.

Relevant literature on the subject of laser scanning and its application in various fields of economy was also studied. The text is complemented by a presentation of created 3D models of selected objects with the use of various tools and computer programs.

1.2. Range

The scope of work includes the creation of 3D models of two selected monuments in Krakow, namely St. Florian's Gate and the Palace of Art. These are two completely different architectural objects that are both equally significant symbols of the city. St. Florian's Gate is a medieval gate with a tower, which is a fragment of the remains of the defensive walls of the Old Town and one of the eight entrance gates. The Palace of Art is the seat of the Society of Friends of Fine Arts in Krakow and serves as an art gallery. Construction of the building began in 1898 to a design by architect Michał Mączyński. The building was erected and decorated in Art Nouveau, Modernist and Symbolic styles. It is a synthesis various art disciplines, such as architecture, sculpture and ornamentation.

1.3. Review of the literature

The continuous technological progress has led to the replacement of old and still inconvenient methods of collecting geospatial information with modern technology, which has completely revolutionized the work of engineers. Information about places and objects registered using geospatial data can be obtained in various ways, including cartographic materials [Klapa et al. 2022], point clouds from the air [Kwoczyńska et al. 2018], mobile [Kukko et al. 2012] and terrestrial laser scanning [Gawronek and Mitka 2015], as well as aerial and close-range photogrammetry [Boroń et al. 2007]. Spatial data has a wide range of applications - from visualization and presentation of places and objects [Kocur-Bera and Dawidowicz 2019] to the construction of their 3D models [Skrzypczak et al. 2022] and various types of spatial analysis [Kudas et al. 2022, Janus and Ostrogórski 2022].

The various forms of currently used laser scanning (terrestrial, airborne, satellite scanning) have become a new tool that has expanded the existing measurement capabilities, as well as found application beyond the geodetic industry, for example in archaeology, conservation of monuments and medicine. One of the geodetic tasks that has benefited greatly from scanning technologies is architectural inventory. *Due to scanning, we receive coordinates for almost every point on the scanned surface. This allows us to determine the dimensions of a room in any location, even after the measurement is completed and the facility is left. Thus, we receive full and detailed information about the dimensions of the facility and its inner infrastructure, which can sometimes be difficult to access or complex. In addition, the use of point cloud, created by the measurement, increases versatility compared to the traditional inventory, giving us the opportunity to make not only horizontal projections and vertical sections, but also a 3D model or a visualization of the facade* [Kwoczyńska et al. 2016, p. 263].

Currently, terrestrial and airborne laser scanning are the most modern and convenient forms of data collection. They became popular mainly thanks to their efficiency and high accuracy of processing compared to previously used measurement methods. Progress in geoinformation technology, associated with both hardware and software development for data processing, has led to the continuous improvement of modern methods of data acquisition, as exemplified by the studies [Buckley et al. 2006, Figiel 2015, Mitka et al. 2023]. Laser scanning technology is becoming more and more available, and thus more frequently used and improved. The continuous technical advancement of scanning enables significant automation of data acquisition and processing.

Research on the use of laser scanning for registration and inventory of architectural objects has been conducted for many years around the world, as evidenced by the studies [Cantoni and Vassena 2002, Boehler and Marbs 2004, Mitka and Szelest 2013, Bernat et al. 2014, Bęcek et al. 2015]. The use of terrestrial and airborne laser scanning in many scientific and research works made it possible to identify the advantages and disadvantages of each of the mentioned techniques [Guarnieri et al. 2006, Kwoczyńska et al. 2016, Klapa et al. 2017]. The data obtained in this way and their accuracy made it possible to run a number of analyses presented, among others, in the studies [Buckley et al. 2006, Pyka and Rzońca 2006, Lichti and Gordon 2007, Uchański and Soerensen 2010].

2. Laser scanning technique

Laser scanning is based on a very quick determination of the XYZ coordinates of a huge number of points by laser measurement. The 'point cloud' created as a part of the scan is processed, and then used for the generation of a three-dimensional model of the scanned object. Laser scanning technology has been adopted in cartography, architectural inventory, measurements of deformation of engineering structures, environmental studies, archaeology, etc. The information contained in the point cloud is not only XYZ coordinates, but also the reflection intensity parameter or the RGB attribute associated with colour of the object, as well as many others used depending on the needs. Laser scanners can be placed on various platforms, such as aeroplanes or helicopters, hence the name airborne laser scanning (ALS). Laser scanning can also be performed using static measurement (TLS – Terrestrial Laser Scanning). *Terrestrial laser scanners are actually electronic total stations that perform a reflectorless distance measurement. A basic model of a terrestrial laser scanner consists of a transmitter, rotating mirrors, an optical telescope, a detector and a recorder. The transmitter produces a laser beam that reaches a system of rotating mirrors* [Quintero et al. 2008]. This precisely distributes the beam over the surface of the object with an appropriate resolution, resulting in the acquisition of a point cloud.

Terrestrial laser scanning is widely used in inventory measurements of architectural objects due to the ability to record actual state and shape of an object. Effects of inventory can therefore be applied in all conservation works, where, based on the scanning data, any imperfections or defects in the object can be detected. The inventory of architectural objects is a quite demanding process. It is important to ensure that inventory documentation is detailed and accurate, so that the 3D model of an object is in a form that fully meets technical requirements. With the obtained data, it is possible at a later stage to prepare vector documentation of the object – all sections, projections or vector drawings. At present, however, 2D drawings are being replaced by 3D models, which also accurately reflect the geometry of the object. The range of laser scanner applications in architecture does not end only with their use for renovation purposes. Very popular are also virtual tours of selected facilities. In this way, using the Internet, one can get acquainted with the objects of interest, even in the most distant parts of the world, without leaving home [Pilecki 2012].

3. Measurement works

Measurements of architectural objects are a subject to a wide range of tasks, methods and solutions. Traditional measurement methods are time consuming and laborious, even though they provide a high level of accuracy. Hence, the demand for and use of terrestrial and airborne laser scanning has increased significantly, wherever a compromise between the quality and the speed of obtaining information is required and possible [Kwoczyńska 2019].

When we deal with historic objects and monuments that are symbols of cultural identity and constitute the most important part of the cultural heritage, we treat them with particular reverence. *Most historic buildings are very complex masonry structures. Depending on the period in which they were built, they may differ in terms of geometric typology, structure and construction system, size of elements and type of building material used* [Vatanet et al. 2009, p. 659]. This is the case in our research.

3.1. Characteristics of the research object

One of the objects selected for the study was the St. Florian's Gate located in the vicinity of Planty Park, which is part of the medieval defensive walls of the city. St. Florian's Gate is 34.5 meters high. The façade of the Gate is decorated with two bas-reliefs. On the side facing Floriańska Street there is a bas-relief of St. Florian from the 18th century, while on the side facing the Barbican there is a bas-relief of the Piast eagle made by Zygmunt Langman, which replaced the earlier one in 1882. Inside the main passage there is an altar with a late Baroque copy of the image of Our Lady of Sand. The altar dates from the beginning of the 19th century.

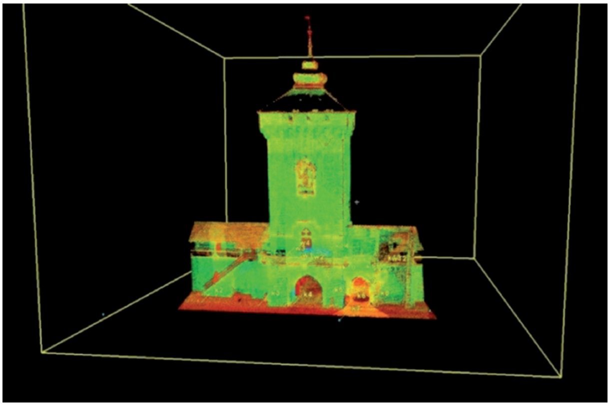
The second research object was the Palace of Art. The building was erected in the years 1898–1901. *The Art Nouveau building was designed by architect Franciszek Mączyński, based on the famous Secession exhibition pavilion in Vienna. The most outstanding Krakow artists took part in decorating the Palace of Art. The impressive frieze, showing the volatility of the artist's fate, was designed by Jacek Malczewski. Antoni Madeyski, Konstanty Laszczka and Teodor Rygier made busts of especially distinguished masters of Polish art. The façade of the palace is decorated with a columned portico crowned with a figure of Apollo in a sunny halo. The roof of the building is made of sheet metal and partly glazed. From Szczepański Square there is a bust of Jan Matejko by Antoni Madeyski, and from the Planty side there is a bust of Stanisław Wyspiański by Anna Reynoch. The walls are decorated with pilasters, flattened window arches and, above all, the entrance portico with two columns* (https://www.palac-sztuki.krakow.pl).

3.2. Field and office works

Terrestrial laser scanning in both cases was carried out using the Leica ScanStation P40 scanner, following the planning of measurement stations and placement of reference spheres and targets for point cloud orientation. Due to the nature of the objects, a scanning resolution of 0.002 m was adopted for St. Florian's Gate and 0.005 m for the Palace of Art.

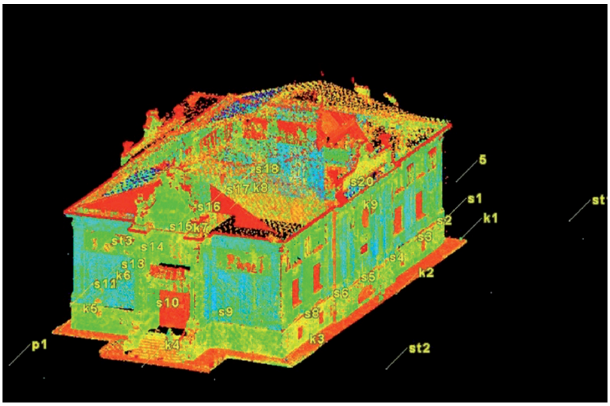
St. Florian's Gate was scanned locally from 10 stations, while for the Palace of Art 9 measurement stations were planned for the scanner, and additionally the control points were measured using the Trimble R8-3 GNSS receiver. The measurement was carried out using the RTK method, the stream of corrections of the ASG-EUPOS system used was VRS_CMR. For both objects, photos were taken simultaneously with the scanning, and used for texturing the model. In the case of St. Florian's Gate, additional photos were taken using the Canon EOS 400D camera.

Data from terrestrial scanning was processed in the Leica Cyclon software, which has all the necessary functions to carry out work with the point cloud. The point cloud orientation was performed with an average error of 0.002 m (for St. Florian's Gate) and 0.006 m (for the Palace of Art). The next phase of the work was to clean the combined point cloud by removing measurement noise, i.e. all fragments of the cloud outside the measured object of the study, such as people, trees and buildings located in the vicinity of the object. The effect of the noise-free point cloud is visible in Figures 1 and 2.



Source: Nowak [2022]

Fig. 1. St. Florian's Gate – cleared point cloud



Source: Woźniak [2019]

Fig. 2. Palace of Art – cleared point cloud

Point clouds from airborne laser scanning were obtained from the Head Office of Geodesy and Cartography in the 1992 coordinate system. The point cloud density was 12 points/m^2.

Integration of the ALS and TLS point clouds was easier in the case of the Palace of Art due to the fact that both point clouds were in the same coordinate system (the measured grid for terrestrial scanning was also embedded in the 1992 coordinate system). Therefore, the next step was to upload the point cloud from ALS in the Leica Cyclon and check the alignment of both clouds. The accuracy of data integration on cross-sections and longitudinal sections as well as the measured distances between points were assessed. The analysis indicated a height discrepancy of 5.58 cm and a site discrepancy of 3.4 cm on the roof sections of the building, and a site discrepancy of 3.99 cm on the walls of the building. The average accuracy of data integration was 4.32 cm. Information about the roof of the facility was obtained from the ALS cloud, which would be impossible to measure from the ground position.

In the case of St. Florian's Gate, information was obtained from the ALS cloud for roof elements and cloisters, which were impossible to reach for the TLS from the level of Floriańska Street. Integration of ALS and TLS point clouds for this object was performed with the CloudCompare, because the object was scanned in the local system. It was necessary to transform the ALS cloud by identifying four pairs of the same points on both clouds. The accuracy of matching the clouds was 0.08 m. The point cloud after integrating the ALS and TLS data is shown in Figure 3.

Source: Nowak [2022]

Fig. 3. St. Florian's Gate – integrated ALS and TLS data

4. 3D modelling of objects based on the integrated data

The process of 3D modelling comes down to creating a three-dimensional object with the use of specialized computer software, which usually provides ready-made tools, e.g. in the form of basic geometric figures.

Numerical modelling of an actual geometric shape of a historical building is a difficult task. *Architects are used to drawing all documentation based on photos and manual measurements. In the traditional method of numerical modelling of existing buildings, all structural elements must be modelled manually in several versions. It is a time-consuming and laborious process. First, it is necessary to prepare a projection of the building, and then, if possible, with help of additional 2D drawings (sections, elevations), generate the model. In general, photos are used to create 3D models and their inaccuracy can lead to errors in the documentation of elevations and sections. It is difficult to verify whether the model created in this way is accurate or not* [Vatan et al. 2009, p. 662].

Point cloud modelling follows a completely different procedure. The *processing phase of data obtained by laser scanning is as follows: filtering the point cloud to eliminate noise, removing redundant points, generating a mesh model and supplementing discontinuities in the model using a filling algorithm that tracks surface curves* [Schueremans and Van Genechten 2009].

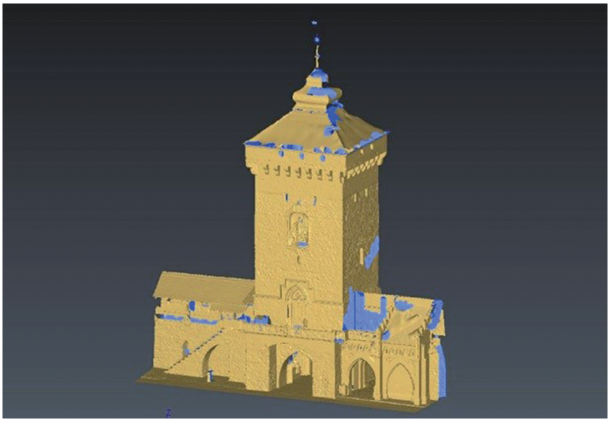
Modelling of historic buildings, which often have irregular shape, is a long-term process. Masonry historical buildings are very complex structures and preparing an accurate and comprehensive model of a historical building is a very difficult task. Therefore, choosing the right software for this stage of work is extremely important.

St. Florian's Gate was modelled in two different ways, using Leica Cyclon 3DR and Microstation software.

4.1. Modelling in Leica Cyclone 3DR

Making a 3D model in Leica Cyclone 3DR is a type of polygonal modelling, which consists of modelling an object using a mesh, i.e. a mesh of triangles. A great advantage of the program is that it generates a model that is very similar to the real object, creating a rough surface of a shape and modelling the smallest fragment of bas-reliefs or other decorations. The 3D model of the object was created using the regular sampling method with an average distance between points of 0.002 m. The process of generating the model itself took several minutes, but later it required filling the gaps in the model caused by too low density of points. The model had large gaps (Fig. 4) in places where the measurement was difficult and as a result of obtaining part of the model from airborne laser scanning, where point density was too low. Fragments of the model in the roof section and in the recesses of the building were deformed, so these fragments were removed and remodeled, maintaining a similar effect to the real object [Nowak 2022].

The final result, after eliminating most of the gaps, was the obtained 3D model of St. Florian's Gate, ready for further development. The next step was to apply the textures. Photos taken with the Canon EOS 400D camera were used as the texture in order to obtain a photorealistic 3D model of the study object. 55 photos were imported and superimposed for texturing the St. Florian's Gate, so that the offend product reflected the real object. Figures 5a and 5b show the finished model of the study object after texturing in Leica Cyclone 3DR.



Source: Nowak [2022]

Fig. 4. St. Florian's Gate – the generated mesh model

a

b

Source: Nowak [2022]

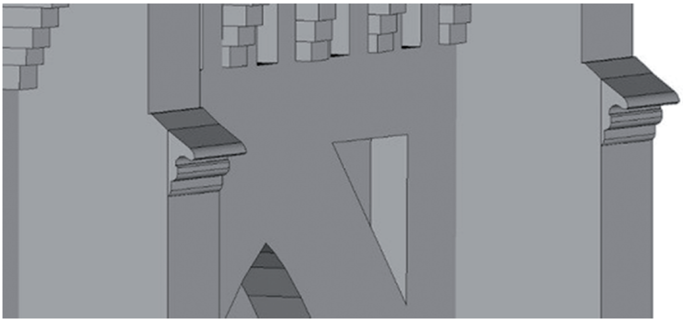
Fig. 5. 3D model after texturing in the Leica Cyclone 3DR software: a. view from the Barbican, b. view from Florianska Street

4.2. Modelling in MicroStation

Making a 3D model in the MicroStation is modelling with shapes and surfaces based on the obtained cloud of points. The big disadvantage of modelling in this program is the separate process of creating a model compared to Leica Cyclone 3DR where the model was generated by selecting one of the options. Creating a model in MicroStation is very time consuming. Another disadvantage is the inability to represent the real surface of the object and bas-reliefs. The creation of the object model consisted of several phases.

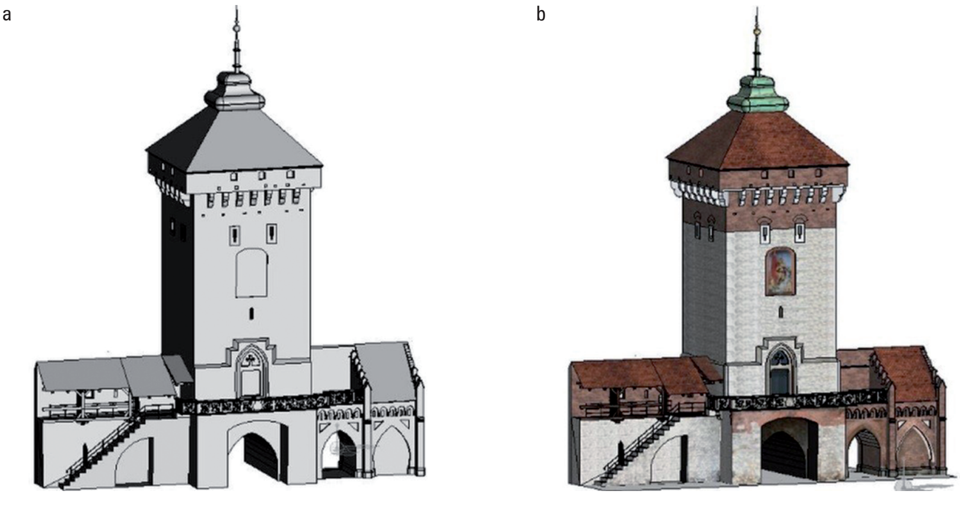
Source: Nowak [2022]

Fig. 6. Modeled railing in MicroStation software



Source: Nowak [2022]

Fig. 7. Modeled cornices in MicroStation software



Source: Nowak [2022]

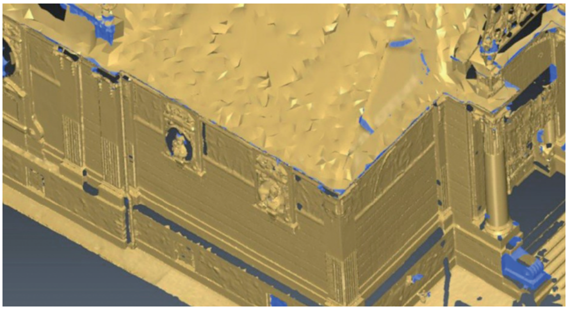
Fig. 8. 3D model of the St. Florian's Gate: a. made in MicroStation software, b. after texturing in MicroStation software

The main phase was to model the main shape, and then, using the appropriate program functions, to create the subsequent elements of the object. Modelling of balustrades, cornices and decorations around the balustrades are presented in Figures 6 and 7.

The advantage of modelling with this software is that the low density of the point cloud is not an obstacle in the modelling process [Nowak 2022]. The effect of modelling St. Florian's Gate in MicroStation can be seen in Figure 8a. Texturing of the model was made on the basis of photos, and the final effect is shown in Figure 8b.

4.3. Modelling in 3D Reshaper

Due to the numerous sculptures, bas-reliefs, columns and other decorations, it was decided to make the 3D model of the Palace of Art, as a vector mesh model. This allowed to the model of the object to be as close to reality as possible. Based on the data from terrestrial scanning, a model was created using the regular sampling method with an average distance between points of 0.006 m.



Source: Woźniak [2019]

Fig. 9. Defects in the modeling of the walls of the Palace of Art in 3DReshaper software

Source: Woźniak [2019]

Fig. 10. 3D model of the Palace of Art made with 3DReshaper software.

The model created in result of generating the mesh for both the roof and side walls had gaps in places where point density was lower than the set parameters for the model creation (Fig. 9). The gaps were filled automatically using the edge-joining method [Woźniak 2019]. In order to preserve the real image of the model, it was decided to apply a texture from photos, thanks to which a photorealistic 3D model of the Palace of Art in Krakow was created (Fig. 10).

5. Summary

Photogrammetric methods or techniques has been used to document historical buildings for many years. Laser scanning technology, which enables effective, accurate and quick collection of information about the actual state of the building, has found particular application. This technology combines and integrates various data and various software modules that facilitate digital reconstruction and creation of accurate models. Often, integration of data from various measurements is the only way that allows a complete representation of the object. Although these data may differ in density, in the end they allow for an accurate reconstruction of the modelled buildings. It is important to choose the right method, as well as modelling software, to ensure the accuracy of the mapping details.

The authors, inspired by the possibilities of laser scanning technology, analysed several scientific studies from Polish and foreign research centres dealing with the use of this technique in the measurement of architectural objects. They also familiarized themselves with the market of software that supports processing and analysis of point clouds, and presented some of the possibilities in this study.

Using two different methods and tools for modelling of St. Florian's Gate made it possible to compare the obtained models, as well as to demonstrate the possible advantages or disadvantages of the software used. The 3D models created in Leica Cyclone 3DR and MicroStation differ not only in their execution method, but also in their level of detail.

The Leica Cyclone 3DR is a software that automatically generates a mesh model composed of triangles. The process of creating a model takes only a few minutes. The software has many advantages, but also disadvantages. One great advantage is that the generated model closely resembles the real object, preserving high detail of the surface of the object and decorative elements, i.e. cornices and bas-reliefs. Another advantage is the photorealistic appearance of the model after applying the texture from photos. The main disadvantages of modelling in the Leica Cyclone 3DR software include the occurrence of large gaps in the model, caused by the low density of the point cloud, which require a time-consuming process to remove. The software also has a difficulty with modelling small or elongated elements such as balustrades and fragments of grating. Another disadvantage is the software's texturing procedure, which consists of only a few functions. the software also lacks the ability to texture by duplicating the image.

The MicroStation is a software that creates a model as a result of independent modelling of shapes and surfaces based on a point cloud. For this reason, the creation of the model is very time-consuming. The software is mainly designed for modelling objects of regular shapes. The application of a texture to an object can be replicated by uploading a fragment of the image or by fitting the photo to the entire surface. Too low point cloud density is not an obstacle in the modelling process. The software also has several other disadvantages besides the lengthy modelling process. The software is not designed for modelling irregular surfaces, which makes it impossible to create an object with a realistic, rough surface. Modelling bas-reliefs is very difficult.

The Palace of Art was modelled with the 3DReshaper software, which is used in a wide range of industries including surveying, building information modelling (BIM), civil engineering, cultural heritage, mining and more. Due to its many features, 3DReshaper is used for data cleaning, segmentation and filtering, as well as for 2D and 3D modelling. Modelling in this software is similar to that of Leica Cyclone 3DR, so its capabilities have already been demonstrated earlier.

To sum up, modelling objects based on point clouds is a difficult process that requires both the right instrument for data acquisition and software for data processing. However, if the objective of modelling is to achieve the highest geometric accuracy, metricity and detail, this method is essential. The development of a 3D model of historic buildings requires extensive work both in the field and in the office. An important element of the measurement is its planning, which guarantees that the facility can be fully developed. Data integration is a useful tool to supplement the measurement data with additional information that was not obtainable in direct measurement. Integrated TLS and ALS data ensure creation of a full 3D model of an object that is large in size and not all of its elements are accessible.

Financed by a subsidy from the Ministry of Education and Science for the University of Agriculture in Krakow for 2023.

References

Bernat M., Janowski A., Rzepa S. 2014. Studies on the use of terrestrial laser scanning in the maintenance of buildings belonging to the cultural heritage. 14th SGEM GeoConference on Informatics, Geoinformatics and Remote Sensing. Albena, Bulgaria, vol. 3, 307–318. https://doi.org/10.5593/SGEM2014/B23/S10.039.

Bęcek K., Gawronek P., Klapa P., Kwoczyńska B., Matuła P., Michałowska K., Mikrut S., Mitka B., Piech I., Makuch M. 2015. Modelowanie i wizualizacja danych 3D na podstawie pomiarów fotogrametrycznych i skaningu laserowego. WSIE, Rzeszów.

Boehler W., Marbs A. 2004. 3D Scanning and Photogrammetry for Heritage Recording: a Comparision. 12th International Conference of Geoinformatics, Gavle, Sweden, 291–298.

Boroń A., Rzońca A., Wróbel A. 2007. The digital photogrammetry and laser scanning methods used for heritage documentation. Roczniki Geomatyki, 5, 129–140.

Buckley S.J., Howell J.A., Enge H.D., Leren B.L.S., Kurz T.H. 2006. Integration of Terrestrial Laser Scanning, Digital Photogrammetry and Geostatical Methods for High-Resolution Modelling of Geological Outcrops. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Dresden, Germany, XXXVI, Part B.

Cantoni R., Vassena G., Lanzi C. 2002. Laser Scanning and Traditional Survey Integration to Build a Complete 3D Digital Model of Sagrestia dell'Archivo di Stato a Mantova. CIPA-ISPRS Workshop on Scanning for Cultural Heritage Recording, Korfu, Greece, 105–114.

Figiel M. 2015. Skanowanie laserowe, modelowanie i inwentaryzacja 3D w przemyśle i budownictwie. Nowoczesne Technologie w Przemyśle, 1/3a (52), 56–64.

Gawronek P., Mitka B. 2015. The use of terrestrial laser scanning in monitoring of the residential barracks at the site of the former concentration camp Auschwitz II-Birkenau. Geomatics, Landmanagement and Landscape, 3, 53–60. http://dx.doi.org/10.15576/GLL/2015.3.53

Guarnieri A., Remondino F., Vettore A. 2006. Digital Photogrammetry and TLS Data Fusion Applied to Cultural Heritage 3D Modelling. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Dresden, Germany, XXXVI, Part B.

Janus J., Ostrogórski P. 2022. Underground Mine Tunnel Modelling Using Laser Scan Data in Relation to Manual Geometry Measurements. Energies, 15(7), 2537, http://dx.doi.org/10.3390/en15072537

Klapa P., Mitka B., Zygmunt M. 2017. Application of Integrated Photogrammetric and Terrestrial Laser Scanning Data to Cultural Heritage Surveying. IOP Conference Series: Earth and Environmental Science, 95, 032007. http://dx.doi.org/10.1088/1755-1315/95/3/032007

Klapa P., Mitka B., Zygmunt M. 2022. Integration of TLS and UAV data for the generation of a three-dimensional. Advances in Geodesy and Geoinformation, 71, 2, article e27

Kocur-Bera K., Dawidowicz A. 2019. Land Use versus Land Cover: Geo-Analysis of National Roads and Synchronisation Algorithms. Remote Sensing, 11(24), 3053, https://doi.org/10.3390/rs11243053

Kudas D., Wnęk A., Tátošová L. 2022. Land Use Mix in Functional Urban Areas of Selected Central European Countries from 2006 to 2012. International Journal of Environmental Research and Public Health, 19(22), 15233. https://doi.org/10.3390/ijerph192215233

Kukko A., Kaartinen H., Hyyppä J., Chen Y. 2012. Multiplatform Mobile Laser Scanning: Usability and Performance. Sensors, 12, 11712–11733.

Kwoczyńska B. 2019. Modelling of a heritage property using a variety of photogrammetric methods. Geomatics, Landmanagement and Landscape, 4, 155–169. http://dx.doi.org/10.15576/GLL/2019.4.155

Kwoczyńska B., Litwin U., Piech I., Obirek P., Śledź J. 2016. The Use of Terrestrial Laser Scanning in Surveying Historic Buildings. IEEE Xplore, *263–268.* https://doi.org/*10.1109/BGC.Geomatics.2016.54*

Kwoczyńska B., Małysa B. 2022. Integration of data obtained from laser scanning and UAV used to develop a 3D model of the building object. Archives of Civil Engineering, LXVIII, 4, 311–33. https://doi.org/10.24425/ace.2022.143040

Kwoczyńska B., Piech I., Góra K., Polewany P. 2018. Modeling of Sacral Objects Made on the Basis of Aerial and Terrestrial Laser Scanning. IEEE Xplore, 275–282. https://doi.org/10.1109/BGC-Geomatics.2018.00059

Lichti D.D., Gordon S.J. 2007. Modeling Terrestrial Laser Scanner Data for Precise Structural Deformation Measurement. Journal of Surveying Engineering, 133, 272–280.

Mitka B., Klapa P., Pióro P. 2023. Acquisition and Processing Data from UAVs in the Process of Generating 3D Models for Solar Potential Analysis. Remote Sensing, 15, 1498, https://doi.org/10.3390/rs15061498

Mitka B., Szelest P. 2013. The problem of acquisition and processing of photogrammetric data and data from terrestrial laser for the creation of educational portals and virtual museums on example of the Wawel Cathedral. Archives of Photogrammetry, Cartography and Remote Sensing, 25, 107–115.

Nowak K. 2022. Wykorzystanie skaningu naziemnego do modelowania 3D obiektu architektonicznego na przykładzie Bramy Floriańskiej w Krakowie. Praca dyplomowa wykonana pod kierunkiem dr inż. Bogusławy Kwoczyńskiej. UR Kraków.

Pilecki R. 2012. Zastosowanie naziemnego skanera laserowego. Czasopismo Techniczne. Wydawnictwo Politechniki Krakowskiej, 9-M/2008, Kraków, 223–233.

Pyka K., Rzońca A. 2006. Badanie jakości radiometrycznej ortofotogramów sporządzonych na drodze integracji fotogrametrii biskiego zasięgu i skaningu. Archiwum Fotogrametrii, Kartografii i Teledetekcji, Olsztyn, Polska, 16, 512–526.

Quintero M.S., Garcia J.L.L., Genechten B.V. 2008. 3D Risk Mapping Theory and Practice on Terrestrial Laser Scanning. Training Material Based on Practical Applications, Universidad Politecnica de Valencia, Valencia, Spain.

Schueremans L., Van Genechten B. 2009. The Use of 3D Laser Scanning in Assessing the Safety of Masonry Vaults. A Case Study on the Church of Saint Jacobs. Optics and Lasers in Engineering (Journal of Elsevier), 47, 329–335.

Skrzypczak I., Oleniacz G., Leśniak A., Zima K., Mrówczyńska M., Kazak J.K. 2022. Scan-to-BIM method in construction: Assessment of the 3D buildings model accuracy in terms inventory measurements. Building Research & Information, 50, 859–880. https://doi.org/10.1080/09613218.2021.2011703

Uchański Ł., Soerensen L. 2010. Technologia naziemnego skaningu laserowego w zagadnieniach inżynierii odwrotnej oraz analiz procesów dynamicznych. Archiwum Fotogrametrii, Kartografii i Teledetekcji, 21, 415–421.

Vatan M., Oğuz Selbesoğlu M., Bayram B. 2009. The use of 3D laser scanning technology in preservation of historical structures. Conservation News, 26, 659–669.

Woźniak K. 2019. Opracowanie modelu 3D obiektu na podstawie zintegrowanych danych z lotniczego i naziemnego skaningu laserowego. Praca dyplomowa wykonana pod kierunkiem dr inż. Bogusławy Kwoczyńskiej. UR Kraków.

https://www.palac-sztuki.krakow.pl [accessed: 2.03.2023].

Dr. Eng. Bogusława Kwoczyńska
University of Agriculture in Krakow
Department of Agricultural Land Surveying,
Cadastre and Photogrammetry
30-198 Kraków, ul. Balicka 253a
e-mail: boguslawa.kwoczynska@urk.edu.pl
ORCID: 0000-0001-7230-5397

mgr inż. Kinga Nowak
Krakowska Firma Geodezyjna
os. Złota Jesień 6, Kraków
e-mail: kinga_nowak16@interia.pl

mgr inż. Krzysztof Woźniak
GeoWay Marek Zapała, Krzysztof Woźniak s.c.
Zachybie 16, 26-080 Mniów
e-mail: krzysiek106l12@wp.pl