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RESEARCH ARTICLE

PHOTOGRAMMETRIC INVENTORY OF MONUMENTS IN THE ASPECT OF LASER SCANNING

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KEY WORDS: inventory of monuments, photogrammetric inventory, laser scanning of monuments, orthoimage, point cloud, LiDAR.

ABSTRACT: The purpose of this article is to present the architectural documentation of the Bishops' Palace in Kielce. This palace, built between 1637 and 1641, is a historical object part of the National Museum in Kielce. Photogrammetric documentation was presented in the form of orthoimages with hybrid vector supplementation, along with a comparison of the results obtained from terrestrial laser scanning of the historical object. The article discusses the advantages and limitations of the traditional photogrammetric method in the inventory of historical objects, as well as the possibilities of using terrestrial laser scanning for the inventory of monuments. Emphasis is placed on the importance of using high-quality equipment to combine laser scanning results and photogrammetric images to achieve a final result of good quality both visually and geometrically.

1. INTRODUCTION

Inventorying historical objects is essential for the preservation of cultural heritage. It is a crucial task for every generation, aiming to protect what we have received from our ancestors against destruction and oblivion. The documentation should reflect the actual state of the object as faithfully as technology allows. Monument inventory defines the studied architectural object's type, shape, spatial location, and dimensions. Previous work (Apollo *et al.*, 2023) demonstrates that most research projects require spatial alignment. The same applies to inventorying activities.

The concept of inventorying can be understood in various ways, such as:

1. collecting geometric information using measurement technologies as presented in works (Gawronek *et al.*, 2017; Bieda *et al.*, 2020; Trybała *et al.*, 2023; Rzonca, Pargieła, 2018),

2. acquiring multi-source data and their integration as shown in (Rzonca, 2018; Liu *et al*., 2023a; Bocheńska *et al*., 2019; Klapa *et al*., 2017; Markiewicz & Robak, 2022).

Integration can occur at the product level or the level of source data. Inventorying products can range from flat hand-drawn or CAD drawings to 3D models or BIM/HBIM models (Colosi *et al*., 2022; Liu *et al*., 2023b).

The final output can serve designers for further project work (Markiewicz-Zahorski, P., 2018), archival/preservation of the current condition of the building (Zapłata, 2016; Zapłata, 2015; Pastucha *et al*., 2018), or as a means to showcase historical objects to a wider audience or support the promotion of a region or country, especially in tourism (Gorgoglione *et al*., 2023, Quattrini *et al*., 2016; Bieda *et al*., 2021).

Each of these applications has a specific purpose, allowing the proper selection of both measurement technologies and parameters describing source or final products from an engineering perspective (Warchoł, 2019; Warchoł & Lęcznar, 2022). If we focus on acquiring data for flat products such as vector drawings or orthoimages, orthomosaics, the most intuitive solutions are terrestrial photogrammetry or terrestrial laser scanning.

Currently, two methods are commonly used in the inventory of architectural objects: laser scanning and photogrammetric methods. Both methods are continuously improved and provide increasingly better results. The decision to use one or the other method, or both together, should be preceded by considering the ultimate goal of the final product. Firstly, the type of object in question – for flat objects like paintings, frescoes, or flat facades of historic buildings, the use of photogrammetry seems obvious. A simple single-image method to generate an orthophoto provides quick and good results both geometrically and in terms of maintaining realistic values. This results in a faithful copy – a digital orthoimage that looks like a photo but has cartometric qualities.

In the case of spatial objects, which are prevalent in most inventorying works of cultural monuments, as even a simple building facade has non-flat ornaments, recesses, etc., the choice of processing method is crucial.

Laser scanning is favored due to its high spatial accuracy and less time-consuming fieldwork. In a short time, a massive point cloud can be obtained as data for developing a 3D model (Guarnieri *et al*., 2006). For the documentation of historical objects, the ability to add color information to the reflected laser impulse, derived from photos taken during scanning, is crucial for obtaining the most faithful representation of reality. This is evident in 3D models of architectural objects viewable in various projects [http://lanmarservices.com]. Most importantly for architects and engineers, a point cloud can be measured and dimensioned, creating surface geometry. Measuring buildings and historic facades becomes easy. The ability to view and measure the object directly from a computer reduces the need for additional on-site visits, which can be an advantage in such projects (Kucak *et al*., 2016). Due to the parameters of the sensors used, standard laser scanning does not provide the same image quality as photogrammetric processing. To obtain image data with similar parameters, the scanning density would need to be increased to a level close to the ground sampling distance (GSD) of a pixel, which is practically challenging and time-consuming. For reflective objects with a porous texture, it is better to use photogrammetry. For objects with more complex shapes, it is more advantageous to utilize scanning, as it requires less effort and is less labor-intensive to process. However the best results are achieved through the integration of these two technologies.

Photogrammetry is a better tool if documentation, especially for smaller spaces, is needed with less geometric accuracy but a more realistic representation of reality. However, it depends on the texture and contrast of the surface. If it is weak and lacks contrast, the accuracy of the reproduction will be lower, leading to less precise automatic image matching. Laser scanning, on the other hand, is more advantageous when high geometric accuracy is needed for large spatially complex objects.

Photogrammetry allows the acquisition of information in a non-contact and non-invasive way. It is often the best method for measuring inaccessible elements and objects with irregular shapes and places emphasis on preserving data about the structure and texture of the studied surfaces. All activities, except for placing GCPs on the building, are performed in a non-contact manner. Photogrammetric inventory enables renovation, historical research, or the reconstruction of an architectural object subject to damage over the years, natural disasters, etc. The accuracy of photogrammetric processing based on the obtained spatial elevation model allows the repair or reconstruction of damaged parts of a monument. After additional vectorization, the final product is an orthomosaic with a hybrid vector overlay, supporting the process of restoration and reconstruction of objects (Bar *et al*., 2010).

2. RESEARCH OBJECT AND DATA ACQUISITION

The objective of this project was to perform photogrammetric documentation of the Bishops' Palace in Kielce and to compare the results with the outcomes of laser scanning of the building. The Bishops' Palace in Kielce, constructed between 1637 and 1641, is part of the National Museum in Kielce. This Baroque edifice - see Fig. 1 was commissioned by the Krakow bishop Jakub Zadzik. The main corpus in the early Baroque style was erected first, accompanied by hexagonal towers in the corners. The workshop of Tomasz Dolabelli was responsible for the decorative painting. In the 20th century, the palace served as the headquarters of Marshal Józef Piłsudski's legion. Three coats of arms capture attention above the main entrance: Zadzik's "Korab," the Krakow Chapter's "Tree Crowns "and the "Eagle from the Vasa era".

Fig. 1. Photo of the Palace of Kraków Bishops in Kielce

The documentation of the Bishops' Palace shows the main part facing the courtyard between the towers with the main entrance. Additionally, documentation of the architectural details of the historic building has been conducted, including, among others, the large window above the main entrance of the Bishops' Palace, the window on the 1st floor, the "Eagle from the Vasa" era emblem above the main entrance, and the door at the right tower of the Bishops' Palace.

2.1 Photogrammetric work in a terrain

The first stage of the work involved obtaining camera calibration parameters in the Dephos software, calculating calibrated values for the camera, such as lens focal length, radial distortion, tangential distortion, and the position of the camera's principal point. The next stage of the work included the measurement of control points, partially signalized in the ground control network consisting of 9 stations - see Fig. 2. The control points were measured and adjusted in the local coordinate system using a Topcon GPT-3100N total station. After the control network computations, photogrammetric work commenced, involving the measurement of 35 GCPs on the building and capturing images with a Canon EOS 6D digital camera. Several photographs were taken, and 10 were selected for further analysis. Based on these 10 images, 8 stereo pairs were created.

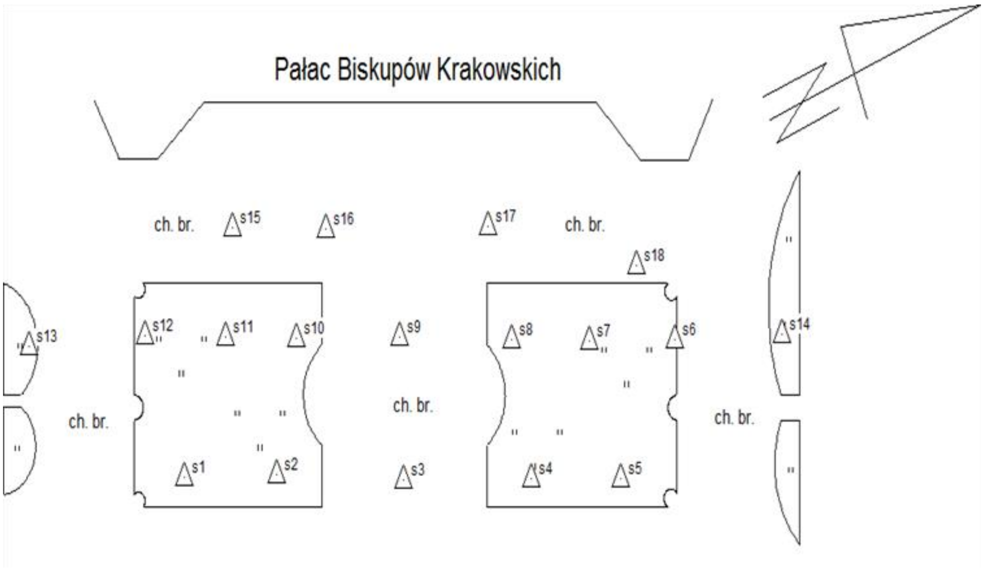

Fig. 2. Sketch of the ground control points network (Brożyna & Kabata, 2016)

The photogrammetric work included measuring 20 feature signalized points on the lower part of the elevation (8x8cm), and points capturing architectural details such as windowsills and cracks, due to restricted access to the upper part of the facade. It was 35 points measured on the building. The distribution of these points is illustrated in Fig. 3.

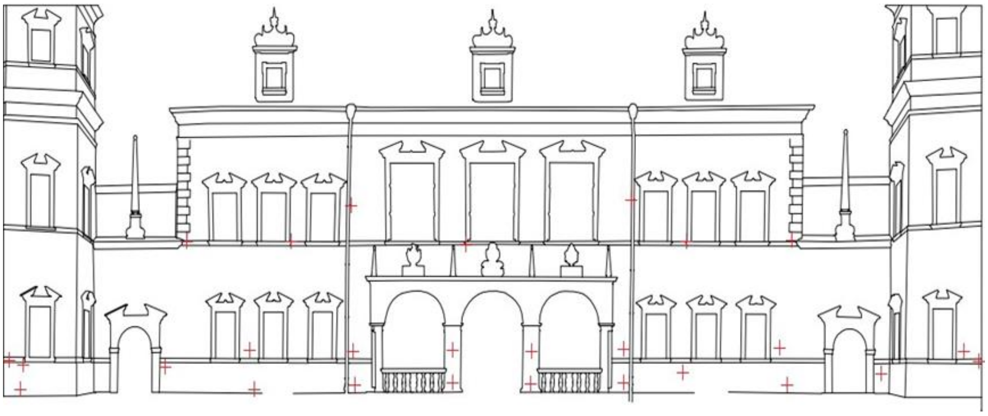

Fig. 3. Sketch of the measured points on the building (Brożyna & Kabata, 2016)

The measurements were conducted from two stations, and the coordinates from each station were aligned and averaged. The calculation of coordinates commenced with the transformation of points from the original coordinate system to a new system adapted to the wall coordinate system. The photogrammetric coordinates of the 35 points were then calculated in the local coordinate system, with a positioning error of +/- 2mm.

2.2 Terrestrial Laser Scanning work in the terrain

In addition to the classical photogrammetric method, a laser scanning inventory of the Bishops' Palace in Kielce was conducted using the Stonex X300 laser scanner. This scanner, capable of measuring up to 40,000 points per second, operated with a laser beam length of 905 nm. The scanner's horizontal plane is fully panoramic, with a vertical range of 90º and angular resolution of 0.0225º. The distance from the measurement point to the object was 30 meters. The average scanning resolution was one point per square centimeter. Equipped with two integrated 5-megapixel cameras, the scanner allows the overlay of RGB information on the LiDAR cloud during the camera processing stage. The sketch of the ground control network for terrestrial laser scanning is shown in Figure 4.

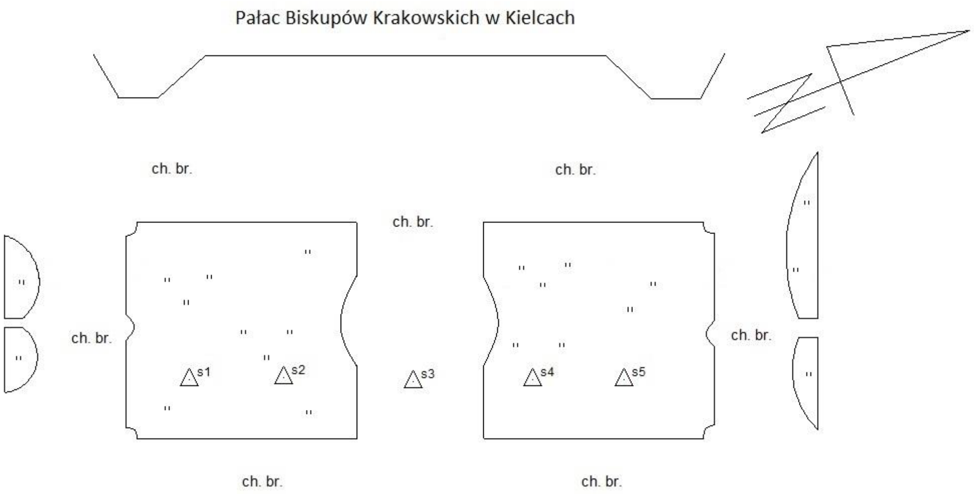

Fig. 4. Sketch of the ground control network for laser scanning (Cygan & Kania, 2017)

3. RESULTS

3.1 Photogrammetric documentation results

Photos were taken with a Canon EOS 6D digital camera equipped with a 50mm lens, featuring a full-frame CMOS sensor with an effective resolution of 20.2 megapixels. The photos were saved in RAW format to ensure better quality, primarily due to the absence of compression, a wide tonal range, and tonal span options (12, 14, 16 bits per pixel). This is beneficial for maintaining a realistic representation of colors and textures (Kwoczyńska, 2012). The photos were taken from five positions, with the camera axes perpendicular to the building's elevation. GSD for building was 6 mm, for details was about 3mm. The photos for photogrammetric documentation of details were taken from about 14 meters and for details from about 7 meters. The along-track coverage was not less than 60%, and the cross-track coverage was not less than 30%. The dimensions of the photos taken were 5472 x 3648 pixels. The exposure time for the photos was set at 1/125s, and the aperture f/20 ensured adequate depth of field. Several photos were taken, of which 10 were selected for further work, and 8 stereo pairs were subsequently created. Photos of details were also taken from four closer positions. Photogrammetric processing was performed using PCI Geomatica software. The digital terrain model of the facade and image orthorectification were computed. Subsequently, orthophotographs of the palace elevation and specific architectural details were generated through mosaicking. These orthophotographs were complemented with hybrid processing, involving the vectorization of architectural details and discontinuity lines. This process resulted in vector maps of the building's elevation and architectural details. The PCI Geomatics software was used for photo orientation. The average error of tie points – the RMS error in the pixel system was X RMS = 6.02 pixels, Y RMS = 4.87 pixels. The error for control points was X RMS = 1.64 pixels, Y RMS = 2.42 pixels. Subsequently, 8 stereo pairs were created. In the next step, a digital object model of the building was generated based on the stereo pairs, used for calculating the architectural details of the building.

In the next step, using the Ortho Generation tool, 10 orthoimages were generated. Subsequently, they underwent radiometric control to ensure quality in terms of the illumination of the photos. Contrast adjustment and brightness standardization were applied to all the photos. The orthoimages were then mosaiced using the PCI Geomatica Mosaic software. The final result was obtained as an orthophoto of the building, visualized in Figure 5, with a detailed view shown in Figure 6.

Fig. 5. Orthomosaic of the Bishops' Palace with GSD 6 mm (Brożyna & Kabata, 2016)

Fig. 6. Fragment of the orthophotomap of the Bishops' Palace wall, with GSD 3mm (Brożyna & Kabata, 2016)

To obtain a hybrid elevation inventory, vectorization of orthoimages was carried out with the aim of creating a vector drawing encompassing surface details of the elevation, window and door openings, as well as ornaments (Prarat, 2015). Typically, vectorized elements include wall edges, window outlines, cornices, and relief outlines. The line drawing significantly facilitates the reconstruction or replication of the elevation in case of damage, helping conservators reflect the dimensions and condition of the historical building's facade. The vector drawing, forming part of the architectural documentation of the Bishops' Palace, is presented in Figure 7, while the hybrid development is depicted in Figure 8.

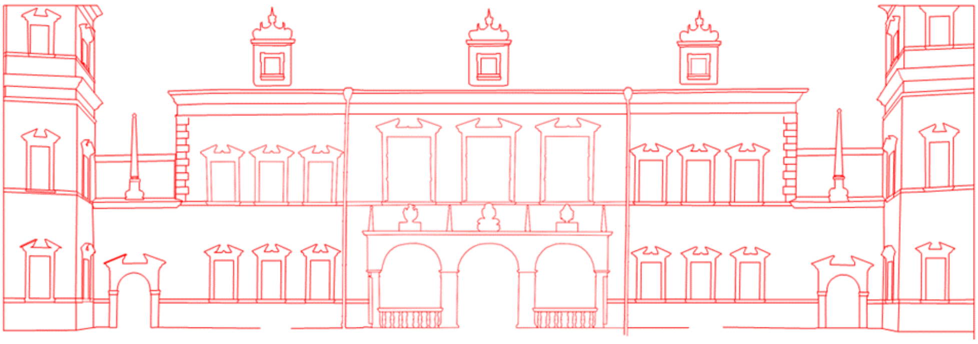

Fig. 7. Vector layer of the Bishops' Palace (Brożyna & Kabata, 2016) generated based on monoplotting on orthoimages in GSD of 6 mm

Fig. 8. Hybrid comparison of the orthophotograph with the vector layer (Brożyna & Kabata, 2016)

Orthophotos were also created, illustrating architectural details such as the outline of a large window above the main entrance (Figure 9), the outline of a gate next to the right tower to scale (Figure 10), or the coat of arms "Eagle from the Vasa era" located above the main entrance (Figure 11). The capabilities of presenting orthoimages in high magnification emphasize the merits of photogrammetry, where every detail of the building is crucial and distinctly visible.

Fig. 9. Orthoimage, vector drawing, and their integration for the window above the main entrance (Brożyna & Kabata, 2016)

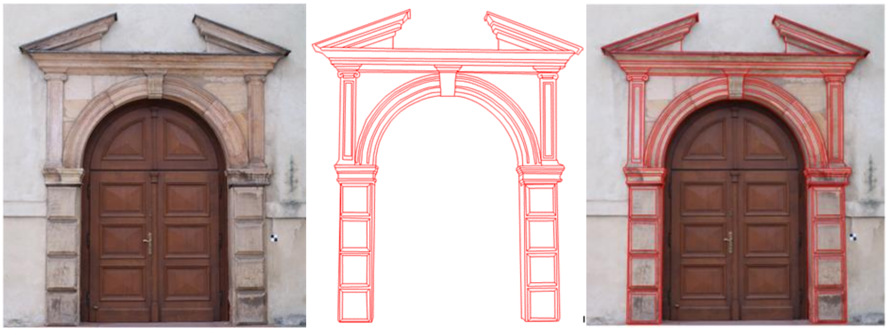

Fig. 10. Orthoimage, vector drawing, and their integration for the gate near the right tower (Brożyna & Kabata, 2016)

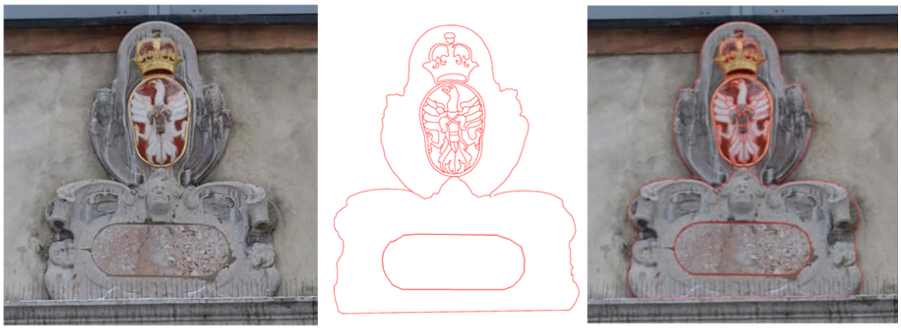

Fig. 11. Orthoimage, vector drawing, and their integration for the "Eagle from the Vasa era" emblem (Brożyna & Kabata, 2016)

3.2 Terrestrial Laser Scanning Results

A total of 47 656 000 points were obtained from all laser scanning point clouds, as shown in Figure 12. Data processing was carried out using the JRC 3D Reconstructor software from Gexcel, designed for processing data from the Stonex X300 scanner. After the automatic registration of the acquired point clouds, followed by manual fine-tuning, distinctive common points were selected and marked, such as the corners of windows on both scans. As a result, the program aligned the scans and calculated an error of 14 mm. The Iterative Closest Point (ICP) algorithm further refined the manually aligned point clouds. ICP is an algorithm that iteratively minimizes the distances between point clouds. According to the report generated by the program, the average error of the iterative closest point was 6 mm.

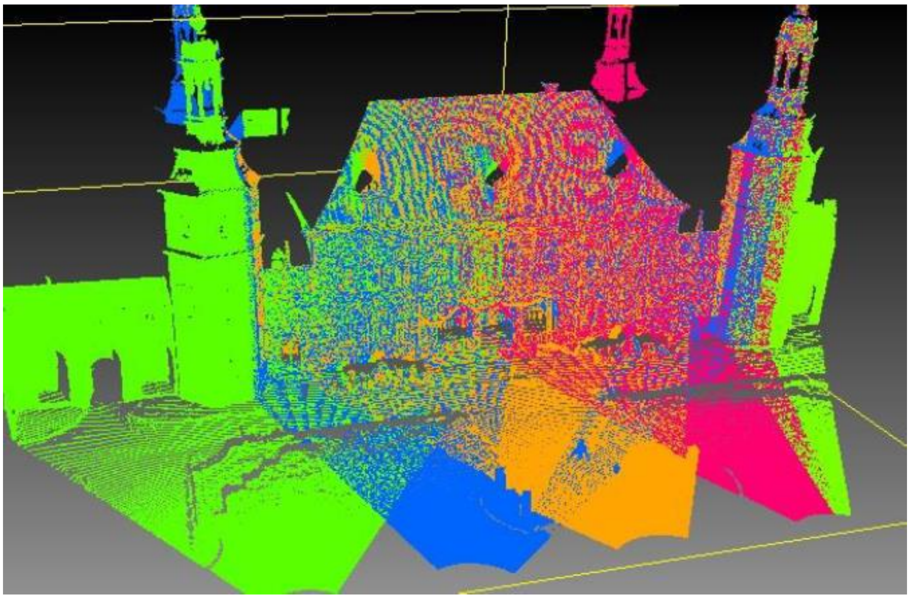

Fig. 12. Laser scanning point cloud set from five measurement stations (Cygan & Kania, 2017)

As a result, a view of the laser scanning point cloud with overlaid information from photos acquired during scanning was obtained, as shown in Figure 13.

Fig. 13. Laser scanning point cloud with overlaid texture from images (Cygan & Kania, 2017)

3.3 A'posteriori Photogrammetric Product Quality and Accuracy Analysis

The photos were taken in favorable atmospheric conditions with no direct sunlight, ensuring the absence of deep shadows that could compromise the quality of the final product. The photo quality allows for a detailed representation of the smallest architectural details of the entire facade. The orthophoto of the entire facade of the Bishops' Palace was created with a ground pixel size of 6 mm at a scale of 1:130, and a ground pixel size of 3 mm for detailed architectural elements at scales ranging from 1:30 for windows and the entrance gate to 1:10 for the detail of the "Eagle from the Vasa era" coat of arms. The ground pixel sizes enable a detailed reflection of the shapes of even the smallest elements on the facade.

To assess accuracy, 20 distances between tie points on the orthophoto of the facade were measured. These distances were then compared with distances calculated from coordinates. This process was repeated for orthomosaics of details. After comparing and averaging all discrepancies, it was established that the accuracy achieved in creating the orthomosaics was ±6 mm. This result is satisfactory for the documentation of such a large architectural object (https://www.gov.pl: Katalog dobrych praktyk i standardów digitalizacji obiektów zabytkowych). The distance measurements include a table 1:

Table 1. Distance measurements from coordinates and ortophotomaps.

Points number	Dist. from coord. [m]	Dist. from orthofoto-map [m]	Differ-ence [m]	Points number	Dist. from coord. [m]	Distance from orthofoto-map [m]	Differ-ence [m]
1-2	1.178	1.172	-0.006	12-14	5.027	5.025	-0.002
2-3	1.239	1.234	-0.005	13-14	1.600	1.592	-0.008
4-5	4.870	4.875	0.005	14-15	3.119	3.121	0.002
5-7	5.466	5.460	-0.005	15-13	2.887	2.882	-0.005
6-8	4.970	4.964	-0.006	16-17	1.721	1.721	0.000
7-9	5.721	5.728	0.007	19-21	1.085	1.090	0.005
8-10	5.679	5.674	-0.005	21-35	1.994	1.994	0.000
9-11	4.247	4.234	-0.012	25-27	5.678	5.680	0.002
10-12	4.303	4.315	0.012	31-33	3.599	3.593	-0.006
11-13	5.146	5.141	-0.005	33-34	5.763	5.773	0.010
						RMSE [m]	0.006

4. SUMMARY

Analyzing the visually obtained results, it can be concluded that in the photogrammetric method, compared to laser scanning, colors are significantly more realistic, accurately reflecting the natural hues of the facade of the Bishops' Palace, with details being more clearly visible. On the other hand, the laser scanning method benefits from more faithful preservation of the geometry of the entire facade and faster data acquisition in the field.

The images below in Fig. 14 provide a comparison of details on the facade captured using both techniques. Images from the laser scanning method are on the right side. It is worth noting that the scanning was performed from approximately 30 meters, while the photos for photogrammetric documentation of details were taken from about 7 meters. This has a significant impact on the scale of accuracy and the quality of the detailed documentation. In the results obtained through the classical photogrammetric method, colors and the full geometry of the details are well visible. For the documentation created with the terrestrial laser scanner, we observe a lower-quality image, mainly due to the use of the camera available in the measuring instrument - the Stonex X300.

Fig. 14. Comparison of a large window above the main entrance. Left – classical photogrammetry, right – laser scanning (Brożyna, Kabata, 2016)

When choosing between different project development methodologies, it is crucial to consider the pros and cons. Certainly, when deciding between laser scanning and photogrammetry, factors such as accuracy, speed of execution, costs, mapping scale, and data utilization should be taken into account. Considering the specificity of historical objects, where geometry is important but realistic representation of the object, especially its details, textures, structures, colors, etc., is paramount, the application of photogrammetry and high-quality photos is essential. For conservation work on small objects, photogrammetric documentation may be more advantageous, while for comprehensive building inventory tasks, a laser scanner is expected to yield better geometric results.

To visually compare laser scanning with photogrammetric processing, achieving a similar Ground Sampling Distance (GSD) in the scanning would be necessary, meaning a dense point cloud at the millimeter level. In practice, this may be challenging to accomplish. When considering laser scanning, using a digital camera is crucial, not necessarily at the 5-megapixel level as in the project, but at least at the 20-megapixel level as in photogrammetric processing in this project. However, the sheer volume of scanning points introduces technical challenges due to the vast amount of data.

Currently, RGB sensors in laser scanners generally do not provide data of higher quality than classical photogrammetric methods. It is important to note that for spatial heritage objects with numerous architectural details, such as the Bishops' Palace, the photogrammetric documentation of an orthomosaics holds significantly greater value than a photoplan. This is because it accounts for radial displacements associated with the non-flatness of details on the building. After generating a digital object elevation model, details are accurately replicated in the final product - orthomosaic. This allows for precisely recognising the color of a specific detail on the facade, facilitating a faithful restoration in case of damage and subsequent conservation work.

In the future, more attention should be focused on more precise elevation model calculations. If laser scanning data is not used for its determination, despite its geometric accuracy, obtaining photogrammetric images with a coverage well beyond 60% (best 80%), ideally using UAVs, would be necessary. The elevation model should not be computed from stereopairs, which often have blind spots and require manual editing, but rather from a dense point cloud obtained from many images with large coverage.

5. CONCLUSIONS

In summary, classical photogrammetry supplemented by a precise digital surface model of the building's facade, enables the creation of a detailed orthomosaic and vector map. These components can be combined to form a hybrid visualization or used independently. Due to the high radiometric quality of the orthomosaic and its consistently accurate results, documenting historical monuments using this method is well-deserving of its application.

In heritage documentation, classical photogrammetry and laser scanning can be employed due to their complementarity in radiometry and geometry. Classical photogrammetry excels in faithfully rendering the content, especially for sections with subtle color textures and intricate structures (decorations, paintings, friezes, sculptures), providing adequate geometric accuracy. On the other hand, terrestrial LiDAR laser scanning significantly better reproduces the geometry of huge objects with complex shapes.

LITERATURE

Apollo M., Jakubiak M., Nistor S., Lewińska P., Krawczyk A., Borowski L., Specht M., Krzykowska-Piotrowska K., Marchel Ł., Pęska-Siwik A., Kardoš M., and Maciuk K., 2023. Geodata in science - a review of selected scientific fields. *Acta Scientiarum Polonorum. Formatio Circumiectus*, 22(2), 17-40. https://doi.org/10.15576/ASP.FC/2023.22.2.02.

Bar E., Fałdrowicz J., 2010. Dokumentowanie zabytków architektury metodami fotogrametrycznymi i skaningu laserowego, *Acta Scientifica Academiae Ostroviensis*, 34, 5-14.

Bieda A., Balawejder M., Warchoł A., Bydłosz J., Kolodiy P., Pukanská K., 2021. Use of 3d technology in underground tourism: Example of Rzeszow (Poland) and Lviv (Ukraine). *Acta Montanistica Slovaca*, 26 (26), 205–21. https://doi.org/10.46544/ams.v26i2.03.

Bieda A., Bydłosz J., Warchoł A., Balawejder M., 2020. Historical Underground Structures as 3D Cadastral Objects. *Remote Sensing*, 12, 1547. https://doi.org/10.3390/rs12101547Acta Slovan.

Bocheńska A., Markiewicz J., Łapiński S., 2019. The combination of the image and range-based 3D acquisition in archeological and architectural research in the royal castle in Warsaw. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 42, 177–184, https://doi.org/10.5194/isprs-archives-XLII-2-W15-177-2019.

Boroń A., Rzonca A., Wróbel A., 2007. Metody fotogrametrii cyfrowej i skanowania laserowego w inwentaryzacji zabytków, *Roczniki Geomatyki*, 5(8).

Brożyna K., Kabata A., 2016. Wykonanie dokumentacji fotogrametrycznej wybranych części Pałacu Biskupów Krakowskich w Kielcach, praca dyplomowa inżynierska, Politechnika Świętokrzyska w Kielcach.

Colosi F., Malinverni E.S., Leon Trujillo F.J., Pierdicca R., Orazi R., Di Stefano F., 2022. Exploiting HBIM for Historical Mud Architecture: The Huaca Arco Iris in Chan Chan (Peru). *Heritage*, 5, 2062-2082.

Cygan K., Kania K., 2017. zastosowanie skaningu laserowego do pomiaru elewacji Pałacu Biskupów Krakowskich w Kielcach, praca dyplomowa inżynierska, Politechnika Świętokrzyska w Kielcach

Gawronek P., Makuch M., Mitka B., Bożek P., Klapa P., 2017. 3D Scanning of the Historical Underground of Benedictine Abbey in Tyniec (Poland). *Proceedings of the International Multidisciplinary Scientific GeoConference: SGEM-Section Geodesy and Mine Surveying*, 17. DOI:10.5593/sgem2017/22.

Gorgoglione L., Malinverni E.S., Smaniotto Costa C., Pierdicca R., Di Stefano F., 2023. Exploiting 2D/3D Geomatics Data for the Management, Promotion, and Valorization of Underground Built Heritage. *Smart Cities*, 6, 243-262. https://doi.org/10.3390/smartcities6010012.

Guarnieri A., Remondino F., Vettore A., 2006. Digital Photogrammetry and TLS Data Fusion Applied to Cultural Heritage 3D Modeling. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *36*, 1-6.

Klapa, P., Mitka, B., & Zygmunt, M. (2017, December). Application of integrated photogrammetric and terrestrial laser scanning data to cultural heritage surveying. In IOP Conference Series: Earth and Environmental Science, 95(3), 032007.

Kwoczyńska B., 2012. Inwentaryzacja i wizualizacja obiektów architektonicznych wykonana na podstawie zdjęć metrycznych i niemetrycznych. *Infrastruktura i ekologia terenów wiejskich*, 1/II, 53–66.

Kucak R., Kilic F., A. Kisa A., 2016. Analysis of terrestrial laser scanning and photogrammetry data fot documentation of historical artifacts, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *42*, 155-158.

Liu J., Willkens D., Gentry R., 2023. Conceptual Framework for Integrating Terrestrial Laser Scanning (TLS) into the Historic American Buildings Survey (HABS). Architecture. 3(3):505-527. https://doi.org/10.3390/architecture3030028.

Liu J., Willkens D., López C., Cortés-Meseguer L., García-Valldecabres J. L., Escudero P. A., Alathamneh S., 2023. Comparative analysis of point clouds acquired from a TLS survey and a 3D virtual tour for HBIM development. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVIII-M-2-2023, 959–968, https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-959-2023.

Markiewicz J., Robak A., 2022. The generation of high-resolution orthoimages based on TLS data and close-range images – the case study. *Journal of Modern Technologies for Cultural Heritage Preservation,* 1(1). https://doi.org/10.33687/jmtchp.001.01.0004.

Markiewicz-Zahorski P., 2018. Pierwszy krok w kierunku „smart project", czyli inwentaryzacja stanu istniejącego budynku w standardzie BIM. *Środowisko Mieszkaniowe,* 2018, 63-71. https://doi.org/10.4467/25438700SM.18.036.9201.

Pastucha E., Rzonca A., Szombara S., 2018. Digital Documentation of Heritage Objects on Non-Developable Surfaces. Baltic Geodetic Congress (BGC Geomatics), Olsztyn, Poland, 2018, pp. 159-163.

Prarat M., 2015. Wykorzystanie tachimetrii i fotogrametrii w dokumentacji zabytków architektury na przykładzie inwentaryzacji pomiarowo-rysunkowej wybranych kamienic toruńskich, *Acta Universitatis Nicolai Copernici, Zabytkoznawstwo i Konserwatorstwo XLVI*, Toruń.

Quattrini R., Pierdicca R., Frontoni E., and Barcaglioni R., 2016. Virtual Reconstruction of Lost Architectures: From the TLS Survey to AR Visualization. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLI-B5, 383–390, https://doi.org/10.5194/isprs-archives-XLI-B5-383-2016.

Rzonca A., 2006. Integracja wyników skanowania laserowego i pomiarów fotogrametrycznych na przykładzie inwentaryzacji nagrobka Anny Jagiellonki w Katedrze Wawelskiej, *Geodezja,* 12 (2/1).

Rzonca A., 2018. Review of methods of combined orientation of photogrammetric and laser scanning data. *Measurement, Automation, Monitoring, 64*(3), 57-62. 10.1127/1432-8364/2012/0136.

Rzonca A., Pargieła K. 2018. Inwentaryzacja obiektu metodą gęstego matchingu. *Nauka, badania i doniesienia naukowe* 2018.

Tokarczyk R., Boroń A., 2000. Badanie cyfrowych aparatów fotograficznych dla zastosowań fotogrametrycznych, *Archiwum Fotogrametrii, Kartografii i Teledetekcji,* Vol. 10.

Trybała P., Kasza D., Wajs J., and Remondino F., 2023. Comparision of low-cost handheld lidar-based SLAM systems for mapping underground tunnels. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*., XLVIII-1/W1-2023, 517–524, https://doi.org/10.5194/isprs-archives-XLVIII-1-W1-2023-517-2023.

Uchański J., 2008. Problematyka standaryzacji w dziedzinie inwentaryzacji obiektów architektonicznych technikami skaningu laserowego naziemnego, *Archiwum Fotogrametrii, Kartografii i Teledetekcji,* Vol 18b, s. 633-641.

Warchoł, A., 2019. The concept of Lidar data quality assessment in the context of BIM modeling. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*., XLII-1/W2, 61–66, https://doi.org/10.5194/isprs-archives-XLII-1-W2-61-2019.

Warchoł A., Łęcznar J., 2022. Gęstość naziemnych chmur punktów LiDAR w kontekście modelowania BIM w Pozyskiwanie danych geodezyjnych dla potrzeb gospodarowania przestrzenią regionu świętokrzyskiego. Red. Wolski B., Cienciała A.

Zapłata R., 2016. Autentyzm zabytkowej architektury i palimpsest w przestrzeni historycznej – nowe media a prezentacja dziedzictwa kulturowego. Architectus 45, 97-114. DOI: 10.5277/arc160109.

Zapłata R., 2015. Measurement, inventory and diagnostics of wooden vernacular architecture - selected issues the use of terrestrial scanning technology. Budownictwo i Architektura. 4/14/2015, pp. 165-181.

FOTOGRAMETRYCZNA INWENTARYZACJA ZABYTKÓW W ASPEKCIE SKANOWANIA LASEROWEGO

SŁOWA KLUCZOWE: inwentaryzacja zabytków, fotogrametryczna inwentaryzacja, skanowanie laserowe zabytków, ortofotoplan, chmura punktów, LiDAR

STRESZCZENIE: Celem niniejszego artykułu jest zaprezentowanie wykonanej dokumentacji architektonicznej Pałacu Biskupów Krakowskich w Kielcach. Pałac ten został wybudowany w latach 1637-1641 i jest on obiektem historycznym, wchodzącym w skład Muzeum Narodowego w Kielcach. Zaprezentowano opracowanie fotogrametryczne w postaci ortoobrazów z uzupełnieniem hybrydowym wektorowym oraz porównanie uzyskanych efektów z możliwościami jakie daje naziemne skanowanie laserowe obiektu zabytkowego. W artykule przedstawiono zalety i ograniczenia tradycyjnej metody fotogrametrycznej w inwentaryzacji obiektu zabytkowego, oraz możliwości wykorzystania naziemnego skanowania laserowego do inwentaryzacji obiektów zabytkowych. Zwrócono też uwagę, jak istotne jest użycie dobrej jakości sprzętu do połączenia wyników skanowania laserowego i zdjęć fotogrametrycznych, aby uzyskać efekt końcowy dobrej jakości zarówno pod względem wizualnym jak i geometrycznym.

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